GridLab

Assessing the Economic Impacts and Supply Chain Development of Offshore Wind in the US

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clarity from complexity

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Executive Summary

Decarbonizing electricity generation is a key step on the path to a net zero carbon economy. Most existing modeled pathways suggest a future decarbonized US grid would rely heavily on solar PV, augmented by some onshore wind and other technologies, but alternative pathways are possible. In this study, we evaluate the macroeconomic implications of pursuing a decarbonized grid which incorporates ambitious volumes of offshore wind capacity, including impacts on the nascent offshore wind industry in the US, and those across US regions and the economy more widely.

The US offshore wind industry is at the early stages of growth and project implementation with the prospects to become a globally significant sector. In the near-term, capacity growth will mainly consist of fixed-bottom projects on the east coast. Over time, more floating turbines will come online and the west coast, Great Lakes, and gulf offshore wind markets are expected to grow. Given the existing and announced projects, the US is on track to meet the Biden administration's target of 30 GW by 2030 and is expected to grow thereafter.

Developing the Supply Chain of an Emerging Industry Opportunity

The US is well-positioned to benefit economically from future domestic investments and deployments of offshore wind. Its distance from European competitors ensures a significant advantage in the installation, operation and maintenance stages, while the large offshore oil and gas industry can deliver many complementary skills, logistics and infrastructure. Having a higher domestic share along the supply chain can deliver greater levels of economic growth and create more jobs, as can be seen in some European countries. However, having the right economic development policies and a leading position in innovations (including a focus on R&D) is necessary to deliver more sizeable impacts on the economy.

The US supply chain has begun to develop to support the emerging industry. A growing number of manufacturing facilities are starting to come online or are under construction, providing US-based components for offshore wind projects. Most current supply chain manufacturing facilities are located on the east coast and were created to support specific wind farm projects. Over time, these facilities may grow to support a larger portion of the US market. Workforce training and development is also an important component of the US supply chain. Several institutions on the east coast are dedicated to preparing the domestic workforce for jobs in offshore wind but meeting the needs of the thousands of workers and job opportunities in offshore wind will require an even larger and sustained effort.

Ports in the US have invested millions of dollars in infrastructure updates to accommodate the needs of the offshore wind industry, primarily on the east coast so far. In some cases, new ports are being constructed with the primary purpose of serving the offshore wind industry. Until these port infrastructure improvement projects are completed, port capabilities represent a choke point (or at least inefficiency) for offshore wind progress in the US. Currently, only one US port is fully equipped to accommodate full-size wind turbine installation vessels.

Offshore Wind as a US Economic Opportunity

Offshore wind represents a significant and largely untapped opportunity for the US to generate renewable energy and create jobs. The industry has just started to take off in recent years and is expected to grow rapidly over the coming years and decades. As the US supply chain develops, offshore wind farms will rely less on components imported from Europe and Asia. Training and preparing the US workforce for jobs in offshore wind will ensure the US enjoys employment benefits from this growing industry.

The modeling exercise assessed the macroeconomic impacts of two scenarios. However, they also share some similar assumptions. The most important of these is that the US offshore wind industry is expanded to the same extent, reaching 750 GW of capacity by 2050. The results are compared to a business-as-usual (BAU or baseline), which includes some decarbonization compared to today, but does not reach net zero[1]. The decarbonization in the BAU is purely a result of market forces (such as the relative costs of different technologies), rather than through any policy constraint on emissions levels. In contrast, the two alternative scenarios have a 95 percent decarbonized power sector by the middle of the century.

The economic analysis, carried out using Cambridge Econometrics' global E3ME model, focuses on a scenario in which 750GW of offshore wind capacity is installed across the US by 2050. The E3ME model assesses the economic impact of these deployments at the national level – downscaling techniques are then applied to estimate regional impacts.

Deployments are initially of fixed turbines, concentrated on the East Coast, although in later years as floating technologies mature they are deployed in large volumes, particularly in the Gulf, the Great Lakes and on the west coast.

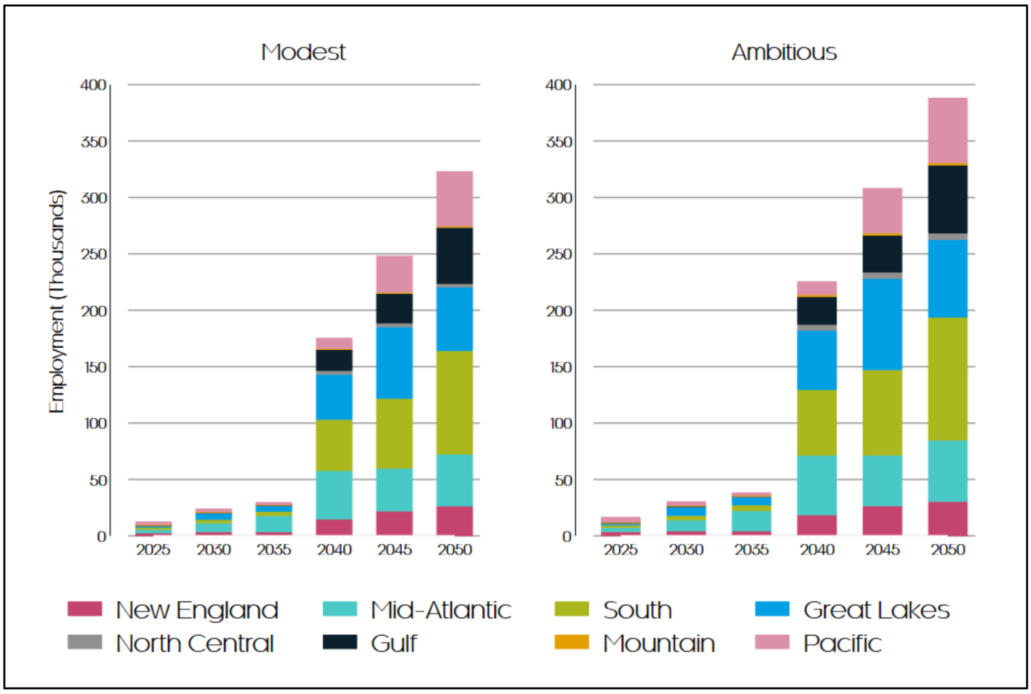
Initial impacts at the national economy-wide level are principally linked to the scale of investment in offshore wind; GDP peaks at 0.4 percentage points above baseline as a result of the additional manufacturing and construction activity during this phase of the project. However, as new installations taper off towards 2050, the economic impacts on the economy as a whole represent a balance between this ongoing investment stimulus (which increases GDP) and the higher electricity costs faced by consumers and businesses (which put downward pressure on GDP). A key determinant of the long-term impact on the US economy is the extent to which the value in the offshore wind sector and associated supply chains can be captured domestically (rather than being serviced by imports). In a scenario where US domestic content shares remain modest, GDP in 2050 is similar to the baseline (i.e. there is no major impact either positive or negative), while if economic policy is leveraged to deliver a supportive environment for domestic industry, and more of the value can be

[1] Note that the baseline in this economic analysis is *not* the same as the baseline used in the main 2035 Report 3.0 report. The baseline in the main report assumes that the power sector will be 95 percent decarbonized by 2050, while our baseline has much higher emissions in 2050, as a result of the lack of an explicit decarbonization target.

captured within the US, the economy could be 0.1 to 0.2 percent bigger in the same year than the 'business as usual' baseline.

When looking at the offshore wind industry (including supply chains), rather than the economy wide impacts outlined above, the industry could support employment for almost 400,000 people by 2050. Around half of these are in the operation and maintenance of the turbines themselves, or the electricity grid required to utilize the electricity that is generated, with the majority of the rest employed in the manufacture of turbines and their installation. When applying downscaling to the national modeled results to estimate regional impacts, employment is closely correlated with the sites of installed capacity: most installation and operations & maintenance jobs are assumed to be fulfilled by workers local to the farms, and while manufacturing supply chains are expected to spread across state lines, most of these activities will remain in similar parts of the country due to the costs associated with moving components long distances across the country (see Figure 1).

Figure 1 Offshore wind employment impacts by region and domestic content assumption



Source: Cambridge Econometrics E3ME modeling

This analysis highlights one of the key challenges for policymakers – how to ensure that the US is well-placed to maximize the economic benefits from offshore wind deployment, and deliver more employment opportunities. There are a number of different aspects to this: substantial investment in manufacturing sites and installation facilities (including deep-water ports) will be required; workers will require training (or retraining) to ensure that they have the required skills to meet the labor demand that such activity will generate; and firms which currently focus on the fossil fuel industry will need to shift their attention, identifying parts of the offshore wind value chain that they can fill, and working with local, state and federal authorities to ensure that there is a sufficient business case (through direct fiscal incentives and/or a clear future pipeline of demand) for them to invest in capital and labor facilities.

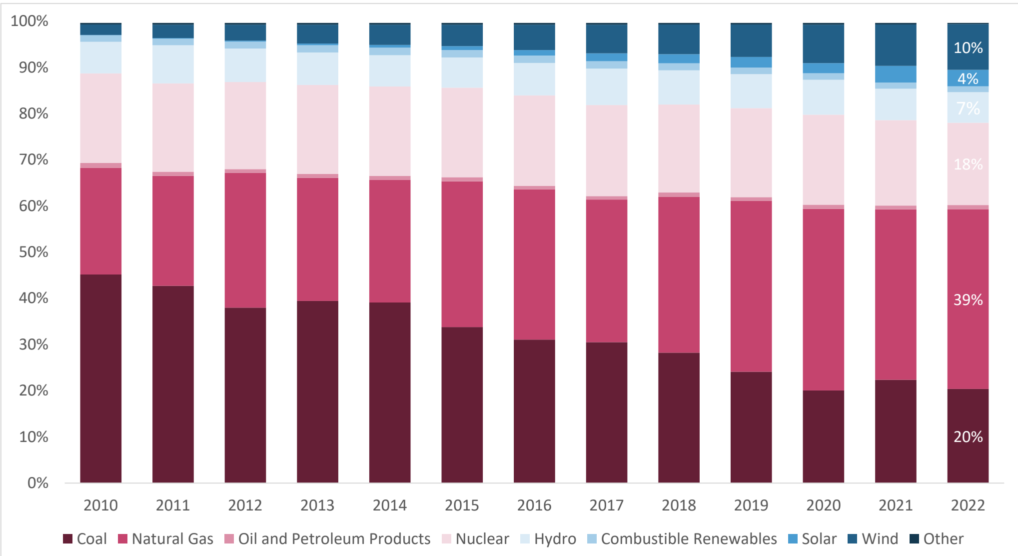
1 Introduction

Climate change poses a major challenge to the future of the human race. As global emissions continue to accumulate in the Earth's atmosphere, average temperatures will continue to increase compared to pre-industrial times, bringing both increased damages from gradual risks, and increasing the risks associated with extreme weather events. The US is actively seeking to address this through, firstly, rapidly reducing emissions from US households and businesses. A first step on this road is to decarbonize electricity generation. Most techno-economic models suggest a decarbonized US grid would rely heavily on a large rollout of solar PV panels – but alternatives exist to diversify future decarbonized electricity generation. In this study, we evaluate the macroeconomic implications of pursuing a decarbonized grid which incorporates ambitious volumes of offshore wind capacity, including impacts on the nascent offshore wind industry in the US, and those across the economy more widely.

The current US electricity mix

The electricity generation mix of the United States consists of a wide range of resources, both fossil- and non-fossil-based. Even though coal was responsible for the greatest share of power generation historically (in 2010, it was 45 percent), its role has steadily been decreasing for more than a decade, down to 20 percent in the first 10 months of 2022. This reduction has been compensated by the increased use of natural gas (growing from 23 percent in 2010 to 39 percent between January and October 2022) and by the growing roll-out of renewable energy sources (see Figure 2). Onshore wind and solar PV are the principal renewables technologies, representing 10 and 4 percent of electricity produced in 2022 (up from 2 and 0 percent in 2010, respectively). Other sources, including nuclear (18-19 percent of total generation), hydro (7-8 percent) and combustible renewables (biomass, 1-2 percent), had a relatively fixed share of generation over the last 12 years. Over the same

Figure 2 Electricity generation mix in the United States, 2010 to 2022 (Jan-Oct)



Source: IEA, 2023

period, total electricity supply has remained broadly constant, at around 4-4.2 million GWh per year. (IEA, 2023)

The share of renewable energy sources has been increasing slowly but steadily over the last 12 years. However, the Biden administration has devoted substantial effort to accelerating the green transition. The most substantive legislation on this topic so far is the 2022 Inflation Reduction Act (IRA). This law channels $370 billion of funding into tackling the climate change. This is expected to accelerate emissions reductions in the US, increasing the previous 24-35% emissions reduction target to 31-44% by 2030, compared to 2005 levels. Amongst other areas, a significant share of spending supports zero and low-carbon energy generation, such as solar and wind energy and hydrogen production, via tax credits and rebates. There is also a focus on increasing the domestic content of renewable energy production, such as solar, battery storage, wind turbine and offshore wind components, through the development of green supply chains. (Bipartisan Policy Center, 2022)

In this report, the potential macroeconomic effects of expanding the US offshore wind industry are analyzed in depth. The structure of the report is as follows: Chapter 2 incorporates a global outlook of different offshore wind markets; in Chapter 3, the US market conditions and economic opportunities for deploying offshore wind investment is examined. Chapters 4 and 5 assess the quantitative impacts that result from economic modelling at the US level, across industry sectors and at the regional level. Chapter 6 concludes with the key findings of the study.

2 The role of offshore wind in global electricity generation

2.1 The role of offshore wind in the supply of electricity

The first offshore wind farm was developed in the 1990s in Denmark. The deployment of offshore wind gained momentum in the 2010s primarily in Europe, but since 2018 deployment has rapidly accelerated in China as well. Due to the significant technological advances in recent years, the levelized cost of generating electricity via offshore wind farms has fallen dramatically. As a result, offshore wind is likely to play a major role in the decarbonization of global energy systems, alongside other forms of renewable generation and measures to improve the resilience and flexibility of the electricity grid.

Up to 2010, the offshore wind industry was responsible for a very small share of power generation, with less than 5 GW of global capacity. Moreover, this capacity was concentrated in a few northern European countries, such as Denmark and Belgium, where geographical conditions (e.g. shallow seabeds and high, sustained wind speeds) were favorable. Since 2010, capacity has experienced exponential growth, exceeding 50 GW total capacity in 2021, and adding almost 18 GW in that year alone (US DoE, 2022). The accelerating roll-out is the result of rapid innovation in the technology. Deployment to date has occurred mainly in regions where wind conditions are considered excellent, (referring to relatively high-speed and sustained wind) and the seabed is shallow (which enabled the ready installation of foundations) such as countries around the North Sea in Europe.

Offshore wind turbines fall into two main categories: fixed and floating. The first refers to turbines which are attached to the seabed by fixed foundations – these are typically deployed in waters not deeper than 50-60 meters and within 60 kilometers of the shore. Floating offshore wind turbines, as their name suggests, float on the surface of the water, and as a consequence, installation can occur in much deeper waters. Fixed is the much more mature of these two technologies; almost all of the offshore wind deployed today globally is fixed to the seabed.

The two technologies together offer the opportunity to generate huge amounts of electricity across the globe. The International Energy Agency (IEA) estimated in 2019 that the technical potential of fixed offshore wind amounted to generation of 36,000 TWh a year – significantly higher than total global electricity demand, which was 28,000 TWh in 2021 (IRENA, 2022). As floating technology is rapidly evolving, it is difficult to precisely estimate future technical potential in the same way, but innovations in floating wind farms are likely to allow it to meet world electricity demand 11 times by 2040 (IEA, 2019) if required. As such, offshore wind will have a crucial role in meeting steadily rising electricity demand, in particular from emerging markets – it is estimated that there is 3.1 TW of technical potential across eight rapidly developing countries (Brazil, India, Morocco, Philippines, South Africa, Sri Lanka, Turkey, and Vietnam) (ESMAP, 2019).

2.2 The advantages of offshore wind

Offshore wind technologies have a number of advantages compared to their onshore counterparts and solar photovoltaic (PV) technologies. In general, offshore wind has higher load factors[2] than solar PV and onshore wind. European wind turbines installed in 2021 were estimated to have load factors in the range of 40-50%, as a consequence of technological advances that unlocked installation in areas with more stable and higher average windspeeds, usually further from the shore and in deeper waters. Compared to solar PV, offshore wind offers lower hourly volatility of power generation (20% compared to 40%). Furthermore, the availability of offshore wind generation at both the hourly and seasonal level differ from that of solar energy, since offshore wind produces electricity (1) during the night, (2) in wintertime in countries with moderate climates and (3) in monsoon season in countries with tropical climates (IEA, 2019).

Due principally to its siting, offshore wind has proven more socially acceptable and has been able to minimize the so-called 'not in my backyard' (or NIMBY) effect, referring to the social phenomenon whereby people often want to keep developments (including onshore wind turbines and solar farms) from encroaching in the immediate vicinity of where they live. If greater offshore wind deployment can reduce the need for more onshore generation resources, it can also reduce the challenges around permitting and delivering such onshore low-carbon resources – although there are currently lengthy permitting processes for offshore wind projects which will need to be undertaken instead.

From an economic perspective, the lifetime cost of offshore wind has been consistently falling for more than a decade. Globally, the levelized cost of electricity has sunk to $0.075 per kWh, down from $0.188 per kWh in 2010 (all values in 2021 US Dollars) (IRENA, 2022). Installation costs have also rapidly decreased, from $4,876 per kWh in 2010 to $2,858 per kWh in 2021 (ibid), however, upfront costs can be significantly higher compared to onshore wind and solar energy (IEA, 2019). The rate of cost reductions has slowed in recent years, due to global supply chain disruptions and the inflationary economic environment (Vestas, 2022).

Synergies between the offshore wind and the offshore oil and gas industries are estimated to be at least 40% of full lifetime costs, particularly in the design, installation and operation & maintenance stages (IRENA, 2019). This opens up the potential for many workers to transfer their expertise to similar roles in the offshore wind industry. For example, the experience and knowledge of installing and maintaining assets far from shore and under harsh weather conditions will be valued in the offshore wind industry in the same way as it has been in offshore oil and gas rigs. The two industries also share some resource and infrastructure requirements: for instance, deep water vessels for installation, offering further synergies and opportunities for movement between the two industries. This also reduces the risk of creating 'stranded' industrial and infrastructure assets. For oil and gas industry workers, the offshore wind industry offers an alternative source of employment and economic opportunity,

[2] Load factors are the proportion of the technical maximum generation that can actually be achieved.

as demand for fossil fuels decreases in the transition to a zero-carbon economy.

2.3 The stages of development of an offshore wind farm

From the initial design and planning through to decommissioning, there are six main stages of an offshore wind farm (The Crown Estate and ORE, 2019). These can be further categorized into 29 substages, which can be decomposed to further components (in the case of manufacturing substages) or processes (in the case of services). Below, the most important stages are introduced to illustrate where different supply chain participants play a role.[3] There are some stages related to manufacturing activities (manufacturing of wind turbines and balance of plant) and others related to services and logistics (development and project management, installation, operation & maintenance, decommissioning).

1. Development and project management

The first stage includes all activities up to the agreement of the funding scheme and commissioning the construction of a wind farm. This covers:

- *development and consenting services*
- *environmental surveys* which assess the impacts on maritime ecosystems, but also on the onshore environment (e.g. due to the cable-laying) and impacts on humans, particularly those who are living in the affected onshore area
- *resource and metocean assessment activities* which involve collecting and analyzing data in order to contribute to the engineering design of the windfarm, and reveal the future operating conditions
- *geological and hydrographical surveys* which help to understand the impacts on local sedimentation and erosion, and also the state of the seabed, where cables will be laid
- the *final design* of the wind farm is fixed, and the plan for construction and contracting is developed.

2. Manufacture of wind turbine components

The second stage is the manufacturing of various parts of the wind turbine. The turbines are responsible for generating electricity from the kinetic energy of the wind. It consists of three main parts: the nacelle, rotor and tower.

- *Nacelles* incorporate several parts, for instance, the generator which converts the rotational energy to altering current (AC) electrical energy. The components are usually provided by a range of external suppliers.
- The *rotor* converts the kinetic energy to rotational energy, through capture by the *blades*.
- The *tower* stabilizes and supports the nacelle.

[3] Even though the referenced study built on British experience, there are no large differences in the lifetime stages of an offshore wind farm, regardless of its location.

In recent years, several innovations have materialized in wind turbine technologies which all contributed to more reliable and increased power generation. As a result, the height of the hub has risen to an average of 108 meters above the sea in 2021 in Europe, up from 83 meter in 2010. Blades can have a diameter of 170-200 meters (and weigh 150 tons), while the capacity of turbines has also increased (they are currently heading towards 15 MW).

3. Manufacture of the balance of plant

The third stage is the manufacture of the balance of plant. It incorporates the remainder of the plant (i.e. everything except the turbine), which is responsible for stabilizing the turbines and transmitting the electricity that has been produced. Specifically, this refers to the following:

- *cables* which deliver the electricity from the offshore wind farm to the onshore grid
- the *foundation* of the wind turbine, consisting of two main parts:
    - the *monopiles* or *jackets* are the two most commonly used foundations which connect the tower to the sea floor; monopiles represent the 80% of the foundations, but *jackets* can also anchor the turbines (they are used in deeper waters, but can be used for fixed and floating turbines)
    - the *transitional piece* creates the connection between the monopiles or jackets and the tower, usually 20 meters above the sea level
- the *offshore substation* aims to reduce losses in transmission to the onshore substation; this is usually achieved by increasing the voltage or, potentially, by converting altering current (AC) to direct current (DC)
- the *onshore substation* is responsible for converting the electricity to the same voltage as that used on the grid
- the *operations base* can be located onshore or offshore and it supports the operations & maintenance and other services (e.g. logistics, surveillance, crew accommodation).

4. Installation and commissioning

This stage covers both on- and offshore activities, with the duration of this stage being highly dependent on the weather and the distance from the shore and the ports. Nonetheless, average installation times have been significantly decreasing, from more than two years between 2010-2015 to less than 18 months in 2020 (IRENA, 2022). This is a consequence of technological advances and more experienced staff, among other factors. The main stages, in order, are the installation of:

- *Onshore substation and onshore export cables*
- *Foundations*
- *Offshore substations*

- *Array cables*
- *Offshore export cables* (laid by *cable-laying vessels*)
- *Turbines*

After installation and a full testing process, the wind farm is commissioned.

5. *Operation and maintenance*

Operations and maintenance starts on the day of commissioning and continues until decommissioning. The main purpose is to maximize the financial profitability of the site by balancing operational expenditures and turbine yield. In practice, it means that more substantive maintenance works are scheduled for summertime and other less windy periods, while during winter – when, for example, solar energy is less available and therefore the price paid for generated electricity is higher – offshore wind farms aim to be operating as much as possible. This stage is mainly divided into two main periods:

1. Warranty time - in the first five to ten years maintenance works and responses to faults are dealt with by the turbine supplier.
2. Thereafter, these tasks are done by an in-house team linked to the operating company, by a contracted third party or by those technicians who worked on the wind farm in the warranty period, and are transferred to the operating company.

6. *Decommissioning*

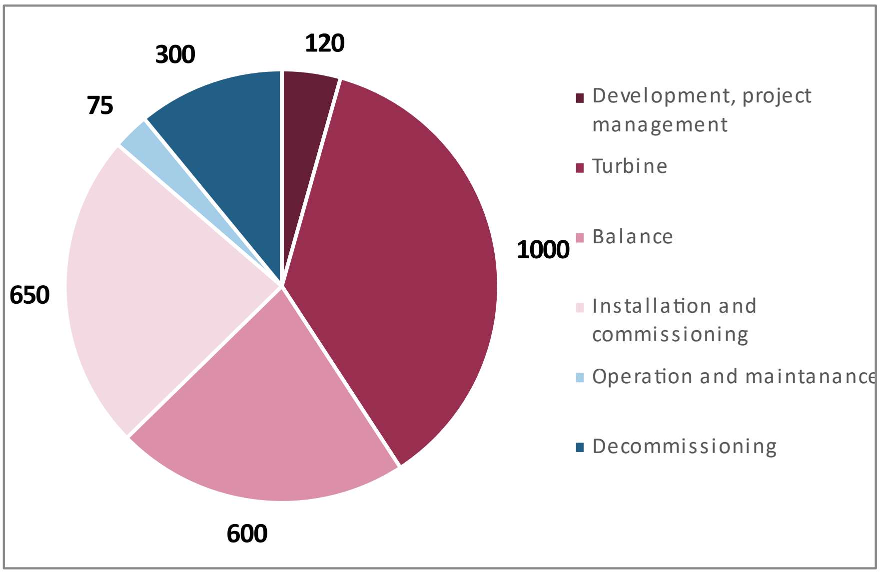
At the end of the original operating life, there are three options for operators:

1. Extending the operating lifetime;
2. Decommissioning the turbines, foundations and array cables and installing new (and larger) turbines while continuing to use the rest of the infrastructure (e.g. the transmission system); or
3. Total decommissioning: this option requires the removal of the entire turbine. Nacelles and towers can in theory be recycled. However, as offshore wind farm decommissioning has not happened at scale yet, further innovations in recycling technologies are required to make this a reality.

The cost of installation

Much of the cost data is confidential, as well as being project-specific, and thus difficult to compare across projects. Costs also vary over time (given learning-by-doing effects) and depend on the country context and exact location of installation. Generally, the turbines are the largest expense in an offshore wind farm, while the balance of the plant has a smaller share (IRENA, 2022; The Crown Estate and ORE, 2019). To illustrate the share of all stages, a 2019 UK-specific estimate of costs has been visualized on Figure 3 (The Crown Estate and ORE, 2019). Another cost share comparison is incorporated in the appendix (see Figure 25) which does not include O&M and decommissioning costs.

Figure 3 The estimated costs of different substages during the whole lifecycle of an offshore wind farm (in million GBP)



Source: The Crown Estate and ORE (2019)
Note: based on the installation of 1 GW offshore wind farm in the UK; assuming turbine size of 10 MW.

2.4 Lessons for the US from existing deployments

Major trends in Europe and in China

In recent years, China has scaled up investment into offshore wind energy to meet its rapidly increasing electricity demand. At the same time, the United Kingdom and European countries, particularly Denmark, Germany, the Netherlands and Belgium, remain among the largest markets in the world, with a total operating capacity similar to China in 2022 (RCG, 2023). Currently, China, the UK and Europe represent the vast majority of the global market for offshore wind.

China's recent experience has shown that further technological advances continue to be unlocked:

- The hub height and rotor diameter of Chinese installs have followed European trends, with an average height of 102 meters and length of 163 meter in 2021 in China, while the equivalent figures in Europe are 108 and 159 meters respectively.
- The capacity of turbines has also been increasing, reaching an average of 6.7 and 8.6 MW in China and Europe in 2021, up from 2.8 and 3.1 MW respectively in 2010.
- Blades have become more efficient and durable over time.
- Enhanced digitalization has resulted in constant monitoring and processing of huge amount of data available from offshore wind farms. This knowledge makes it easier to plan new wind farms, to improve the design

of elements, and to intervene in the right time to improve the load factor of the wind farm. (IRENA, 2022)

However, there is some uncertainty about the long-term trajectory of costs. The strong cost reduction has been seen in Europe is partly the result of economies of scale and more experienced businesses and workforce. For instance, the cost of installation, operation and maintenance of an offshore wind farm has been cut as more ports have been transformed to meet the specific requirements of the offshore wind industry, and businesses operate vessels exclusively to support offshore wind farms. Moreover, even though costs can be kept lower in China by the fact that they can build their offshore wind farms closer to the shore (as the best locations are not yet occupied), the average capacity of a newly commissioned offshore wind farm (i.e., the project size of an average farm) is generally behind their European counterparts (245 MW compared to 591 MW in 2021, respectively) (IRENA, 2022). Generally speaking, installing turbines further from the shore increases availability (as wind blows more frequently) and the power generated (due to higher wind speeds), although it can increase costs through higher logistical, installation and foundation costs.

Operators or countries that are slow in building up their offshore wind operations often find themselves in a position where it is difficult to establish market share, as has happened in the UK. According to a 2018 analysis, British businesses had advantage in substages focused on services (such as design, development, blade design, operation and maintenance, but also in array cabling), while many (mainly manufacturing) subsectors were delivered by overseas suppliers, such as towers, foundations, nacelles, export cables and sub-station topsides. Increasing the domestic shares in these parts of the value chain requires coordinated and ambitious strategy, and any change is not likely to be achieved rapidly (Catapult and Offshore Wind Industry Council, 2018). On the other hand, those countries and businesses who have invested in R&D, or made greater efforts to transform their economy (even their oil and gas industry) towards green industries, have become the global leaders of key substages along the supply chain. For instance, if the Chinese domestic market is excluded, the largest wind turbine companies can be found in countries like Denmark (Vestas) and Germany (see Nordex SE or a Spanish-German company as SGRE) (Vestas, 2022; Wind Europe, 2020).

Box 1 Case study of the port of Esbjerg, Denmark

Case study – Port Esbjerg, Denmark

Esbjerg is a city on the western coast of Denmark. Its port was originally established for fishing activities in the 19th century, but later, it became the center of the Danish oil and gas sector. In 2001 the first large-scale offshore wind farm in the world (Horns Rev 1) was installed from this port. As a result, the offshore wind industry gained traction, and ultimately this transformed the harbor into one of the largest offshore wind hubs globally – 80% of offshore wind capacities in Europe has been shipped out from here. (Port Esbjerg, 2022; QBIS, 2022)

There are several reasons for this success story. Denmark was the first adopter of large-scale offshore wind farms, and Esbjerg was able to claim first-mover advantage in installing turbines. The harbor also served to channel investments into the city as more than 250 companies are operating there, uniquely representing the whole supply chain for offshore wind in a single location. As a result, the port is able to directly connect manufactures with offshore wind sites across the North Sea. Both the port and the city have shifted away from oil into the renewables sector, diversifying as a reaction of oil crisis in 2014. (State of Green, 2022; QBIS, 2020) The state of research and development is also boosted by a local science center (State of Green, 2014).

However, the transition is not finished yet since Esbjerg wants to be a leader in other green sectors. As such, Europe's largest Power-to-X facility will be built in Esbjerg by the mid-2020s, producing green ammonia via 1 GW of electrolysis capacity, powered by offshore wind farms. This will be used in agriculture for fossil-free fertilizers and in the maritime industry to provide carbon-neutral fuels for vessels. (State of Green, 2021)

Economic and employment effects of offshore wind industry

Denmark was the first country in the world to commission an offshore wind farm. However, good geographical features as shallow seawater and windy environment are only one factor of the success. Denmark has channeled significant amounts of investment into the wind industry, across the value chain, since the 1970s. It was initially a response to the oil crisis which shocked the Nordic country at a time when it was extremely reliant on fossil fuel imports (Owens, 2019).

Through their leading role in the offshore wind industry, Danish companies are heavily involved in most newly launched European projects, which has had a positive impact on the national economy.

As Table 1 shows, Danish companies are so heavily involved in European projects that the direct labor impacts of manufacturing, operating and maintaining 1 MW offshore wind capacity outside of Denmark (but within the European Union) creates almost two thirds as much employment as projects that happen within the country. Even though the labor intensity has more than halved in a decade (from 19 full time equivalent workers per MW in 2010 to 7.5 in 2020), the industry is expanding so quickly that total employment in the sector is still increasing.

Table 1 Labor impacts per MW (in full time equivalents, FTE)

	In Denmark	In EU other than Denmark
Direct	4.9	3.1
Indirect	9.7	3.2
Induced		2.8
Total	14.6	9.1

Source: QBIS, 2020

The workforce can be categorized into six main groups: operators, ship crews, workers & technicians, engineers, outdoor and indoor experts. Different groups are involved in different stages of the lifecycle. For instance, workers are mainly needed in the manufacturing process of the turbine and balance of plant, while operators and ship crews are responsible for installation, operations & maintenance and for decommissioning. For more details, see Table 8 in Appendix C.

There are also benefits to GDP from the offshore wind industry, particularly when looking across the whole supply chain. In Denmark, an additional 1 GW of capacity contributes 5 million Euros through direct impacts, while the operation and maintenance adds 0.5 million Euros a year for the whole lifetime of the windfarm (typically 25 years). These figures are multiplied if local suppliers (indirect impacts) are also considered. (QBIS, 2020)

The synergies of the offshore wind industry with other sectors are also a major feature, as expertise in these direct sectors can boost competitiveness in other related sectors, reducing cost and mitigating transitional risk from a fossil-fuel based to a sustainable economy. As mentioned above, the (offshore) oil and gas industry has substantial synergies with offshore wind farms. This comes from the fact that these workers have expertise working in harsh environments, which is vital during operation and maintenance, but also during installation and decommissioning. Material use, manufacturing processes and the use of robotics are also areas with substantial overlap. In addition, aerospace, automotive, space and nuclear all also have shared aspects with the offshore wind industry. For instance, metocean (a combination of meterology and oceanography) assessment and analysis is also important in the space and aerospace industry, while similar reliability issues and solutions appear in the aerospace and automotive sector. For more details, see Table 2.

Table 2 Synergies of offshore wind industry with others

	Aerospace	Automotive	Oil and gas industry	Space	Nuclear
Materials	Blue	Blue	Blue	Grey	Blue
Manufacturing	Blue	Blue	Blue	Grey	Grey
Robotics	Grey	Blue	Blue	Blue	Blue
Health and safety	Blue	Blue	Blue	Grey	Blue
Reliability	Blue	Blue	Grey	Grey	Grey
Asset management	Blue	Grey	Blue	Blue	Blue
Harsh environments	Grey	Grey	Grey	Grey	Grey
Metocean	Blue	Grey	Grey	Grey	Grey

Note: synergies are indicated by blue
Source: Catapult and Offshore Wind Industry Council, 2018, p. 16

2.5 Key takeaways

The offshore wind sector has been experiencing exponential growth due to rapid technological changes and cost reductions, after a record year of commissioning, reaching nearly 56 GW cumulated installed capacity in 2021 (IEA, 2022) and over 60 GW in 2022 (RCG, 2023). This increase mainly comes from two regions of the world: Europe (including the UK) and China. The industry is expected to have a significant role in reducing emissions associated with electricity generation, as the load factor for offshore wind is relatively high compared to onshore wind and solar photovoltaic (PV) technologies, and power generation is uncorrelated with solar, with higher load factors during winter. In addition, cost reductions will soon enable the production of green hydrogen at large scale and low price, providing a further source of demand for intermittent electricity generation.

Having a central role in the installation of large-scale offshore wind farms is crucial to build out a domestic supply chain. Those countries which started to invest heavily into fixed offshore wind first still have a leading position on the European market. This is particularly true for some manufacturing activities. For instance, the UK, which can be considered as a relative laggard, is still working to bolster its domestic content share in some substages, particularly in manufacturing (e.g. towers, foundations, nacelles), while it has a higher domestic content share in services. In contrast, Denmark supplies almost all projects around the Nordic Sea at least to some extent.

The US is well-positioned to benefit economically from future domestic deployments of offshore wind. Its distance from the European competitors ensures a significant advantage in the installation, operation and maintenance stages, while the large offshore oil and gas industry can deliver many synergies. Having a higher domestic share along the supply chain can deliver economic growth and create jobs, as can be seen in case of some European countries. However, having the right policy environment and a leading position in innovations (including a focus on R&D) is necessary to deliver more sizeable impacts on the economy.

3 Offshore wind market in the US

3.1 Introduction and purpose

After years of preparation, the offshore wind industry is on the verge of rapid growth in the US. Currently, two small pilot projects with the combined power generation of 42 megawatts (MW) make up the entire US offshore wind capacity. However, dozens of offshore wind projects are planned or under construction and investment in the industry has risen steeply in recent years. In March 2021, the Biden administration set the national offshore wind target at 30 gigawatts (GW) by 2030. Some states have set their own offshore wind targets as well.

To support the emerging industry, the US market is ramping up efforts to provide domestic supply chain manufacturing and logistics support. A broad array of workforce training facilities and economic development leaders around the country are also working to prepare construction workers and operations and maintenance teams for new jobs in offshore wind. US ports are investing, adapting and growing to accommodate the large turbines, shipping vessel and industry needs.

In the context of these ongoing changes and developments, this chapter summarizes the status of offshore wind initiatives in the US and projections for the future. This chapter outlines where capacity growth and supply chain projects are expected to take place and describes the preparedness of US ports to accommodate the needs of the industry. We also identify cities and regions in the US that are positioning themselves as offshore wind industry clusters and describe the ongoing and planned activities at these hubs.

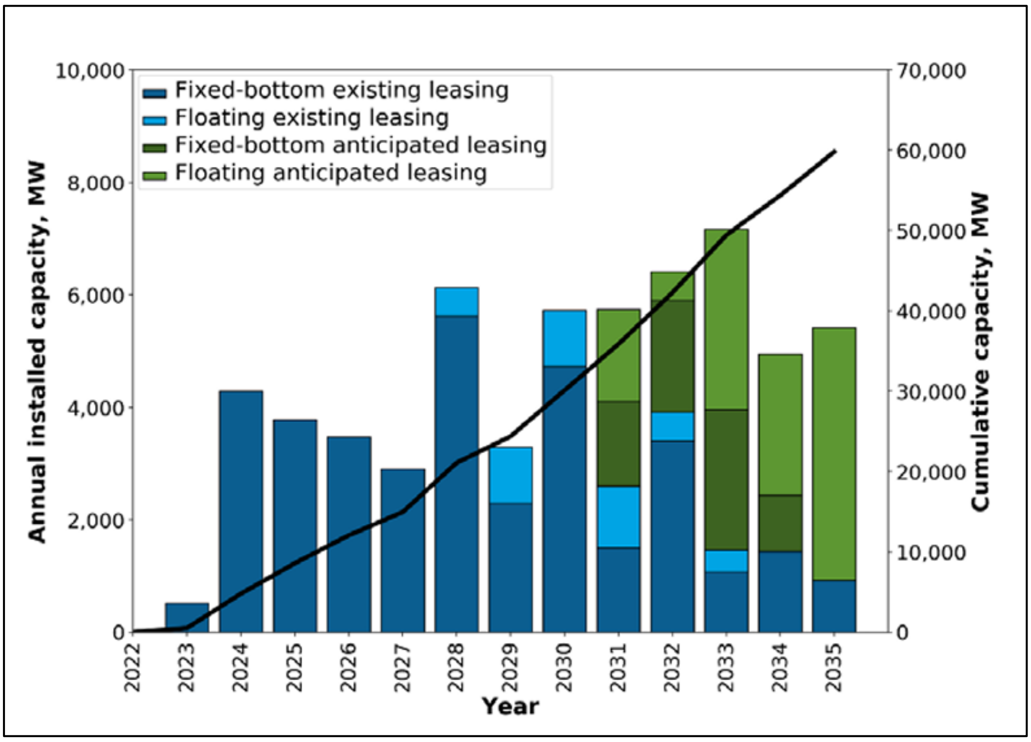
3.2 Capacity growth projections and locations

Offshore wind potential in the US is vast. Some researchers estimate that areas offshore the contiguous US and Hawaii have the technical capacity to generate over 7,000 terawatt hours annually, nearly twice the amount of energy consumed in the US each year.[4] While this estimate does not consider economic feasibility, it demonstrates the immense scale of the untapped market.

In 2022, the total offshore wind capacity in the US was 42 MW. As seen in Figure 4, existing and anticipated lease areas are expected to generate a cumulative capacity of 60 GW by 2035. In March 2021, the Biden administration set the national offshore wind target at 30 GW by 2030. As depicted, the existing and anticipated offshore wind leases have more than sufficient capacity to meet this national goal.

[4] Comay, Laura B. and Clark, Corrie E. December 2021. Offshore wind energy: Federal leasing, Permitting, Deployment, and Revenues. Congressional Research Services. https://sgp.fas.org/crs/misc/R46970.pdf

Figure 4 Annual and Cumulative Installed Capacity for Existing and Anticipated Lease Areas



Source: Shields et al. 2022. *The demand for a Domestic Offshore Wind Energy Supply Chain*. National Renewable Energy Laboratory (NREL).

In the near term, installed capacity will mostly be generated from fixed turbines in the shallow waters of the east coast. The Great Lakes also have substantial offshore wind potential. Initially, offshore wind capacity on the Great Lakes would likely be installed in the shallower waters with fixed foundations (a cause of some controversy as the turbines would be visible from the shore). However, floating platforms would allow turbines to be placed in the deeper waters, opening up substantially more capacity and keeping the structures out of sight from the shoreline.[5] About two-thirds of the offshore wind potential in the US is in deep-water areas, particularly along the west coast and Gulf of Maine.[6] Across the US, after 2030, installation is expected to shift towards floating turbines to capture the vast deep-water energy potential.

Offshore wind projects can be located in state waters, which are generally 3 nautical miles or less offshore, or federal waters, which stretch to about 200 nautical miles away from the coast.[7] Most major offshore wind projects will take place in federal waters, and thus require permitting and approval from the Bureau of Ocean Energy Management (BOEM), the agency responsible for overseeing the development of offshore wind in federal waters. BOEM is also

[5] A 2022 feasibility study for offshore wind in the Great Lakes discusses the potential for floating platforms on the lakes. The report suggests that hybrid substructures, such as TetraSpar or tension-leg platforms are the most feasible options for the Great Lakes, though some adaptations may be necessary. https://www.nyserda.ny.gov/-/media/Project/Nyserda/Files/About/Publications/Energy-Analysis-Technical-Reports-and-Studies/GLWEFS/22-12e-Substructure-recommendations.pdf
[6] White House Statements and Releases, 15 September 2022. Fact Sheet: Biden-Harris Administration Announces New Actions to Expand Offshore Wind Energy. https://www.whitehouse.gov/briefing-room/statements-releases/2022/09/15/fact-sheet-biden-harris-administration-announces-new-actions-to-expand-u-s-offshore-wind-energy/
[7] Government Accountability Office. December 2020. Offshore Wind Energy: Planned Projects May Lead to Construction of New Vessels in the U.S., but Industry Has Made Few Decisions amid Uncertainties. https://www.gao.gov/products/gao-21-153

responsible for issuing offshore wind leases, which typically involves a competitive bidding process.[8]

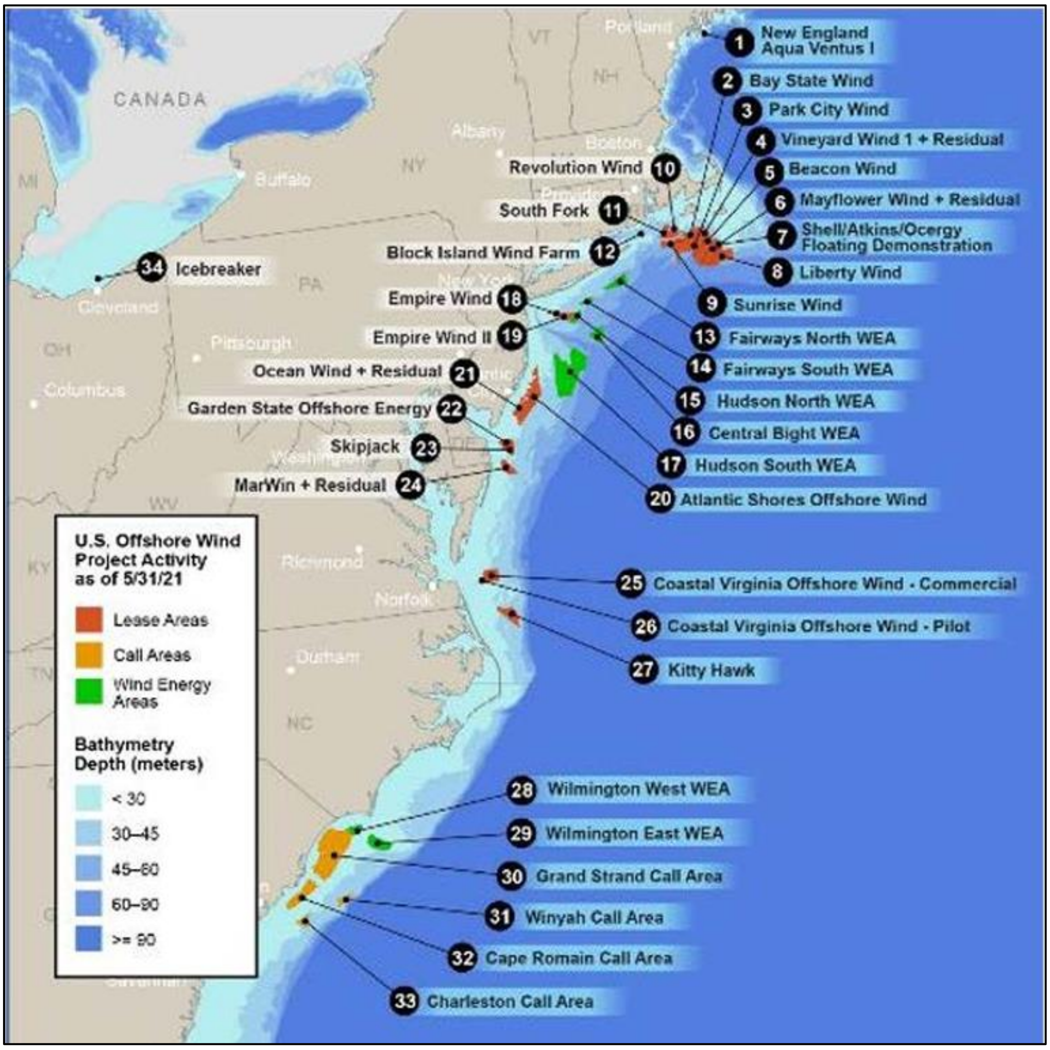
In 2016, Block Island wind farm off the coast of Rhode Island became the first offshore wind project in the US. The 30 MW project operates five turbines in state waters. In 2021, Coastal Virginia Offshore Wind Project became the first operational offshore wind project in federal waters, adding 12 MW to the US's offshore wind capacity.[9] These pilot projects are leading the way for the emerging industry in the US. Dozens of offshore wind projects have since been announced or are under construction.

The 2035 Report 3.0 evaluates varying levels of offshore wind deployment to achieve significant clean energy generation. The High Ambition scenario in the 2035 Report 3.0 evaluates a future in which the US deploys 750 GW of offshore wind, which represents a substantial increase compared to these near-term projections. Scaling up to 750 GW would require investment in wind projects well beyond what has been identified and approved to date and would likely require offshore wind development on all major US coasts as well as the Great Lakes.

In the US, almost all of the existing and anticipated offshore wind projects are located on the east coast. Figure 5 shows the installed projects, projects under construction, projects engaged in permitting, other leased areas, and Wind Energy Areas (WEA) that BOEM has announced will be leased in the near future on the east coast. Projects on the east coast will primarily consist of fixed bottom turbines.

[8] Government Accountability Office. December 2020. Offshore Wind Energy: Planned Projects May Lead to Construction of New Vessels in the U.S., but Industry Has Made Few Decisions amid Uncertainties. https://www.gao.gov/products/gao-21-153
[9] Brown, Tyson M. June 2022. Developers plan to add 6 gigawatts of U.S. offshore wind capacity through 2029. EIA. https://www.eia.gov/todayinenergy/detail.php?id=52940

Figure 5 East Coast Offshore Wind Pipeline and WEAs



Notes: Fairways North and South, Hudson North and South, and Central Bight comprise the New York Bight. Wilmington West, Grand Strand, Winyah, Cape Romain, and Charleston are on hold, subject to executive withdrawal from leasing between 2022 and 2032.

Source: Shields et al. 2022. *The demand for a Domestic Offshore Wind Energy Supply Chain*. National Renewable Energy Laboratory (NREL).

The west coast has fewer offshore wind projects in the pipeline. Figure 6 shows the two offshore wind projects currently planned on the west coast, both off the shores of California. Unlike the east coast, these west coast projects are floating rather than fixed. Offshore wind capacity in the west is expected to grow, especially following the 2022 announcement that the California Energy Commission's offshore wind target increased to 25 GW by 2045.

Figure 6 West Coast Offshore Wind Pipeline and WEAs

Note: The Morro Bay Call Area was converted to a WEA in November 2021

Source: Shields et al. 2022. *The demand for a Domestic Offshore Wind Energy Supply Chain*. National Renewable Energy Laboratory (NREL).

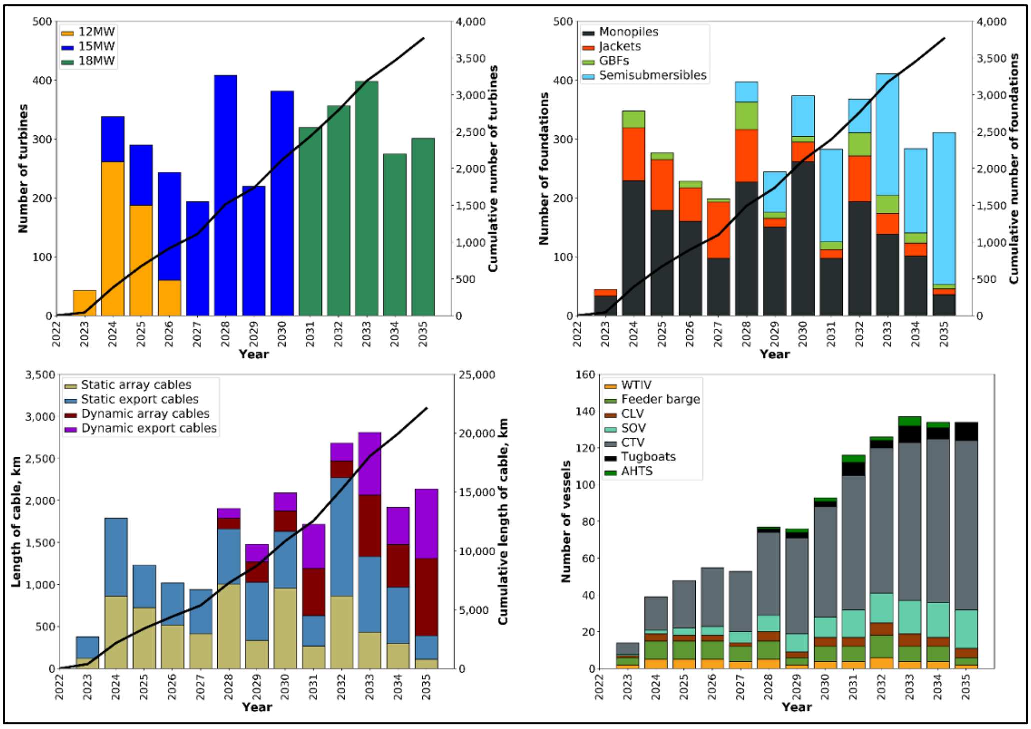
3.3 The US supply chain

The US does not currently have the full-range of manufacturing capabilities or production capacity to support the offshore wind industry and will have to rely on components imported from foreign suppliers in the near term. On the east coast, where the majority of offshore wind projects will initially be built, components will largely be imported from European suppliers. On the west coast, component parts will come from Asian suppliers. However, US-based manufacturing facilities and training centers are currently under construction or in the planning stage, with expectations of localizing the offshore wind supply chain over time. Establishing a domestic supply chain will streamline construction and operation in the US and create jobs.

US Manufacturing Capabilities and Gaps

Each wind turbine consists of three rotor blades, a nacelle, a tower, and a foundation. Cables are also required to carry electricity from turbines to the onshore grid. In addition, installation vessels, feeder barges, crew transfer vessels, and cable lay vessels are required to construct and maintain wind farms. Figure 7 shows the component demand for offshore wind parts. Total demand for each component is closely aligned with the installed capacity forecasts in Figure 4. Over time, turbine demand is expected to shift from 12 MW to 18 MW turbines. At the same time, foundations will shift from mostly monopiles to mostly semisubmersibles by 2035. Demand for static array and export cables will decline over time, replaced by dynamic cables. The number of vessels needed to support the growing industry will increase by around 100 between 2023 and 2035.

Figure 7 Annual and Cumulative Component Demand for Turbines, Foundations, Vessels, and Cables



Notes: Each wind turbines consists of three rotor blades, one nacelle, and one tower. GBF = gravity-based foundation; WTIV = wind turbine installation vessel; CLV = cable lay vessel; SOV = service operation vessel; CTV = crew transfer vessel; AHTS = anchor handling tug supply

Source: Shields et al. 2022. *The demand for a Domestic Offshore Wind Energy Supply Chain*. National Renewable Energy Laboratory (NREL).

Developing a US fleet of vessels to support the offshore wind industry is critical for compliance with the 1920 Jones Act. This act requires cargo ships traveling from one US port to another be US built, owned, and crewed. Without domestic vessels capable of transporting offshore wind turbines, this requirement poses a significant barrier to construction in the near-term.

To develop a domestic offshore wind supply chain, developers and policymakers in the US must be proactive and organized. As outlined in NREL's supply chain roadmap,[10] the focus in the short-term should be

[10] Shields, Matt, Jeremy Stefek, Frank Oteri, Sabina Maniak, Matilda Kreider, Elizabeth Gill, Ross Gould, Courtney Malvik, Sam Tirone, Eric Hines. 2023. A Supply Chain Road Map for Offshore Wind Energy in the United States. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5000-84710. https://www.nrel.gov/docs/fy23osti/84710.pdf.

organization and planning to lay the groundwork for a robust US supply chain. These actions include organizing regional working groups, establishing incentive-based policies to encourage supply chain development, and determining funding streams and curriculum for workforce training. In the medium term (between 2025 and 2030), the focus should shift from planning to implementing as US manufacturers gain critical momentum. This phase includes construction of supply chain facilities, training a sufficient workforce to meet industry needs, and incorporating learning from pilot projects to establish best practices. In the longer term, the focus will have to shift for the US to maintain, upgrade, and expand infrastructure and work to fill in any gaps in the domestic supply chain.

The NREL report also identifies critical barriers to supply chain development. Developers face investment risk due to construction delays, over-budget costs, legal and regulatory complications, and uncertainty about future government support for offshore wind. Manufacturing facilities (for the larger components) require large plots of land and are typically located near service ports. However, the limited availability of port space constrains the opportunity to construct necessary facilities at existing US ports. Furthermore, as turbines continue to grow in capacity (and size), manufacturing facilities and transport vessels may struggle to keep up, becoming outdated before the upfront investment cost is covered. Other potential barriers include insufficient domestic raw materials providers, inadequate port and vessel infrastructure, a workforce that lacks the necessary skills and training in the near term, and insufficient incentives to establish domestic manufacturing facilities and incorporate equity and sustainability into supply chain activities.

Despite these challenges, there is already ample evidence that the US supply chain for offshore wind is emerging, and numerous manufacturing facilities have already been announced. For example, some companies have already communicated plans to provide supply chain support for the offshore wind industry in the US with commitments for offshore wind component manufacturing as shown in Table 3. Apart from the offshore substation manufacturing facility in Texas, all supply chain announcements so far are located on the east coast, where the majority of near-term projects will take place. Generally, these manufacturing facilities are developed to support specific offshore wind projects but hope to expand to support the larger US market over time. In the near-term, the facility in Texas will serve South Fork Wind project powering Long Island, New York.

As seen in Table 3, the first-mover on blade manufacturing is Siemens Gamesa Renewable Energy. The group plans to build the first offshore wind blade manufacturing facility at an 80-acre site leased from the Portsmouth Marine Terminal in Virginia. The $200 million facility will support over 300 jobs, including 50 operations and maintenance jobs.[11] Siemens Gamesa has not announced when the manufacturing facility is expected to come online, but the Coastal Virginia Offshore Wind project it supports is targeted for completion in 2026.

[11] Gurney, Kaile and Veronica Diaz. 2021. Siemens Gamesa Renewable Energy. Global leadership grows: Siemens Gamesa solidifies offshore presence in U.S. with Virginia blade facility. https://www.siemensgamesa.com/en-int/newsroom/2021/10/offshore-blade-facility-virginia-usa

Table 3 Major Supply Chain Project Announcements in the US

Component	Location	Investors	Investment ($ million)	Status
Blades	Portsmouth Marine Terminal (Virginia)	Siemens Gamesa	200	Announced
Nacelles (final assembly only)	New Jersey Wind Port (New Jersey)	Vestas, Atlantic Shores	Not announced	Announced
	New Jersey Wind Port (New Jersey)	GE, Ørsted	Not announced	Announced
Towers	Port of Albany (New York)	Marmen Welcon, Equinor	350	Announced
Monopiles	Paulsboro Marine Terminal (New Jersey)	EEW, Ørsted	250	Under construction
	Sparrows Point (Maryland)	US Wind	150	Announced
Foundation platforms	Port of Providence (Rhode Island)	Eversource, Ørsted	40	Announced
Secondary steel	Port of Coeymans (New York)	Eversource, Ørsted	86	Announced
Transition pieces	Port of Albany (New York)	Marmen Welcon, Smulders	Not announced	Announced
Array and export cables	Nexans high-voltage cable facility (South Carolina)	Nexans	200	Operational
	Kerite (Connecticut)	Kerite, Marmon Group, Vineyard Wind	4	Operational
	Tradepoint Atlantic (Maryland)	Eversource, Ørsted	150	Announced
	Brayton Point (Massachusetts)	Prysmian, Avangrid	200	Announced
Offshore substations	Ingleside (Texas)	Kiewit, Eversource, Ørsted	Not announced	Operational

Source: Shields et al. 2022. *The demand for a Domestic Offshore Wind Energy Supply Chain*. National Renewable Energy Laboratory (NREL).

The nacelles final assembly facility at New Jersey Wind Port will be constructed as part of the port's second phase. During Phase II, which will come online in 2026, 60-70 acres will be added to the built-for-purpose port to accommodate component manufacturing.[12] In addition to the nacelle manufacturing shown in the table above, in 2023 Siemens Gamesa announced a $500 million nacelle factory to be built at the Port of Coeymans in New York.[13] The facility is estimated to create 420 direct jobs.

In 2021 the Port of Albany Offshore Wind Tower Manufacturing project was selected by the New York State Energy Research Development Authority (NYSERDA).[14] The Port of Albany has since received state permits to begin work on the nation's first offshore wind tower manufacturing plant. The project, which is jointly funded by Marmen Welcon and Equinor, will support about 500 jobs during the construction phase.[15] Site construction is in the early stages and a completion date has not yet been announced. The Port of Albany will also host a transition piece manufacturing facility, funded by Marmen Welcon and Smulders.[16] A 2022 ruling by the Maryland Public Service Commission

[12] The New Jersey Wind Port. About the New Jersey Wind Port. State of New Jersey. https://nj.gov/windport/about/index.shtml
[13] Lewis, Michelle. 2023. New York State is Getting a Big Offshore Wind Factory. Electek. https://electrek.co/2023/02/13/new-york-state-offshore-wind-factory/
[14] Port of Albany. Offshore Wind Albany. https://www.portofalbany.us/offshore-wind-albany/
[15] Mahar, Michael. 2022. Port of Albany gets permit for wind manufacturing plant. ABC News 10. https://www.news10.com/news/albany-county/port-of-albany-gets-permit-for-wind-manufacturing-plant/#:~:text=ALBANY%2C%20N.Y.,offshore%20wind%20tower%20manufacturing%20facility.
[16] Marmen Welcon. 2021. Marmen Welcon and Smulders to Produce Offshore Wind Transition Pieces at the Port of Albany, New York. Cision PR Newswire. https://www.prnewswire.com/news-releases/marmen-welcon-and-smulders-to-produce-offshore-wind-transition-pieces-at-the-port-of-albany-new-york-301361910.html

requires that offshore wind developers create a tower manufacturing facility in Maryland, though this project has not yet been announced.[17]

Monopile manufacturing will occur in Paulsboro, New Jersey and Sparrow's Point, Maryland. In New Jersey, the $250 million manufacturing facility has begun operations, with the first component shipments ready for assembly arriving from Europe in January 2023. Despite having started operations, construction at the 70-acre site will continue through 2024, reducing reliance on European suppliers over time.[18] The other US monopile manufacturing facility is farther behind. The $150 million project at Sparrow's Point in Maryland is expected to begin construction in 2024 and come online in 2025.[19]

The 228-foot long foundation platforms manufacturing facility at the Port of Providence, Rhode Island will be used for advanced fabrication and assembly. The platforms will support offshore wind projects in Rhode Island, Connecticut, and New York. The $40 million facility will support approximately 40 union jobs.[20]

The $86 million manufacturing facility in Coeymans, New York is the culmination of a joint venture between Eversource and Orsted. The secondary steel manufacturing facility will support the fabrication of wind tower foundations. The facility will create 230 jobs, including 115 local union positions, and is planned to come online in 2023.

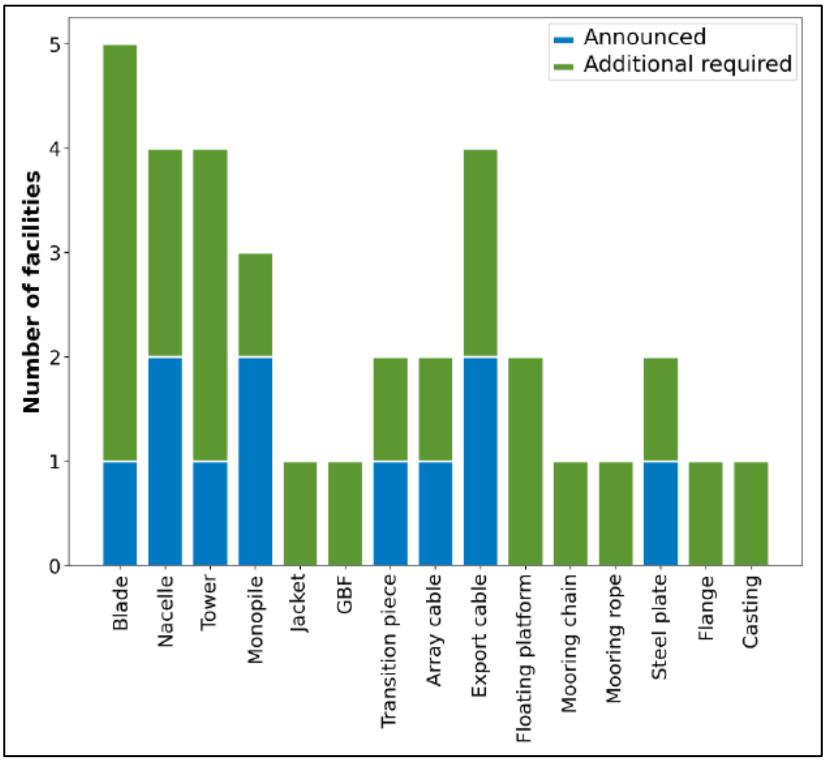
A few cable manufacturing facilities are already operational in the US. The Nexans manufacturing facility in Charleston, South Carolina manufactures subsea high voltage cables to support offshore wind projects. The Kerite power cable facility in Connecticut is also fully operational, though it will likely continue to expand over time. Plans for cable manufacturing facilities in Tradepoint Atlantic, Maryland and Brayton Point, Massachusetts has also been announced. The facility in Maryland would satisfy the 2022 ruling by the Maryland Public Service Commission, which requires that offshore wind developers create array cable manufacturing capabilities in the state. The 47-acre site in Massachusetts will manufacture subsea power cables for projects in Massachusetts and Connecticut.

The first US-manufactured offshore substation was fabricated at the Kiewit facility in Ingleside, Texas in 2023. The 1,500-ton, 60-foot-tall substation will support the South Fork Wind project, serving Long Island, New York. Over 350 workers worked to create the structure. The substation has transported across the Gulf of Mexico and up the east coast for installation, and South Fork is expected to be operational by the end of 2023.[21]

[17] NAIOP. 2022. Ruling sets stage for manufacturing, logistics investment in Maryland. https://www.naiopmd.org/news/ruling-sets-stage-for-manufacturing-logistics-investment-in-maryland/.
[18] Kensinger, Nathan and John Upton. 2023. Giant Offshore Wind Turbines Take Shape as NJ Turns On Major Manufacturing Plant. Gothamist. https://gothamist.com/news/giant-offshore-wind-turbines-take-shape-as-nj-turns-on-major-manufacturing-plant.
[19] Alonso, Johanna. 2022. US Wind Give Update, Timeline to Sparrows Point Steel Project. Maryland The Daily Record. https://thedailyrecord.com/2022/02/10/us-wind-gives-update-timeline-to-sparrows-point-steel-project/#:~:text=Sparrows%20Point%20Steel%2C%20an%20offshore,for%20wind%20turbines%20in%202025.
[20] Skopljak, Nadja. 2021. OffshoreWIND.biz. Ørsted, Eversource Setting Up Foundation Parts Factory in Rhode Island. https://www.offshorewind.biz/2021/04/15/orsted-eversource-setting-up-foundation-parts-factory-in-rhode-island/
[21] Wims, Maeghan and Angela Nemeth. 2021. South Fork Wind to Build the First-Ever American-Made Offshore Wind Substation, Creating Jobs Across Three U.S. States. Business Wire. https://www.businesswire.com/news/home/20210825005627/en/South-Fork-Wind-to-Build-the-First-Ever-American-Made-Offshore-Wind-Substation-Creating-Jobs-Across-Three-U.S.-States

Even with these announced supply chain activities, additional facilities will be necessary to meet expected component demand by 2030. As seen in Figure 8, a total of 34 major manufacturing facilities will be required to support a US-based supply chain in 2030. The 11 announced facilities only account for about a third of this requirement. In total the industry will need to invest an estimated $22.4 billion in manufacturing facilities, ports, and installation vessels.

Figure 8 The number of US Manufacturing Facilities Required to Meet Component Demand in 2030



Notes: GBF = gravity-based foundation
Source: Shields et al. 2023. *A Supply Chain Road Map for Offshore Wind Energy in the United States*. National Renewable Energy Laboratory (NREL).

Workforce Development

In addition to component parts, establishing the US supply chain will require training and skills development of the domestic workforce. The offshore wind industry will require component design and testing engineers and supply chain analysts. Once parts are designed, the next link in the supply chain are plant workers, such as welders, machine operators, and assemblers. Once plants are operational, facilities maintenance and operations workers ensure plants are operating smoothly.[22] These roles, along with the management positions to oversee them, require specific skills and training.

Several institutions have begun preparations to provide training and certifications for the offshore wind industry:

- Bristol Community College in New Bedford, Massachusetts is constructing a National Offshore Wind Institute to provide safety and technical training to prepare workers for jobs in all aspects of the offshore wind industry.

[22] Shields, Matt, Ruth Marsh, Jeremy Stefek, Frank Oteri, Ross Gould, Noé Rouxel, Katherine Diaz, Javier Molinero, Abigayle Moser, Courtney Malvik, and Sam Tirone. 2022. The Demand for a Domestic Offshore Wind Energy Supply Chain. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5000-81602. https://www.nrel.gov/docs/fy22osti/81602.pdf.

- Massachusetts Maritime Academy offers safety training for offshore wind at its Buzzards Bay campus.[23]
- Rowan College of South Jersey will offer a wind turbine technician program in 2023.
- Gloucester County Institute of Technology and Salem County Vocational Technical School in New Jersey are expanding welding and painting programs to support heavy steel manufacturing for the offshore wind industry.
- New York hosts the New York Offshore Wind Training Institute (OWTI), a $20 million investment to train thousands of people in the local workforce to support onshore and offshore wind projects, and the $10 million National Offshore Wind Training Center (NOWTC), which is aimed at training high school and college age New Yorkers for careers in offshore wind.[24]

As seen in Table 4, transitioning to a US-based supply chain to support the offshore wind industry is expected to create thousands of jobs through 2030 (and beyond).[25] Based on a 2022 NREL report, the table considers two scenarios in which 25 and 100 percent of manufacturing occurs domestically. Some component parts are associated with greater job creation than others. For fixed-bottom projects, most potential jobs stems from domestic manufacturing of nacelles, which could generate 4,600-5,300 jobs if 25 percent of the activity is realized domestically, or as many as 18,600-21,200 jobs with all activity taking place domestically. For floating projects, the greatest job potential is in production of floating structures, totaling 2,200-3,600 jobs each year with 25 percent domestic content or 8,700-14,700 jobs with 100 percent domestic content.

[23] Massachusetts Maritime Academy. 2023. US Offshore Wind Training. https://www.maritime.edu/professional-training/offshore-wind-training.
[24] New York State Energy Research and Development Authority. 2022. Offshore Wind Workforce Development. https://www.nyserda.ny.gov/offshorewind-workforce
[25] These estimates through 2030 are based on a 2022 NREL report and are presented here to demonstrate employment potential by component part. Chapter **Error! Reference source not found.** of this report presents total estimated job impacts by sector based on the E3ME model out to 2050.

Table 4 Average and Maximum Number of Direct and Indirect Jobs per Component Part for Different Levels of Domestic Content

Component	Average Number of Jobs Through 2030		Maximum Job Demand Through 2030	
	25% Domestic Content	100% Domestic Content	25% Domestic Content	100% Domestic Content
Fixed-bottom projects				
Nacelle	4,600	18,600	5,300	21,200
Rotor blade	900	3,500	1,100	4,300
Towers	1,200	4,700	1,500	5,900
Monopile	1,300	5,400	1,600	6,600
Transition piece	800	3,100	1,000	3,800
Jacket	500	2,000	700	2,900
Gravity-based foundation	400	1,500	500	2,000
Substation topside	30	100	30	100
Array cable	300	1,100	300	1,300
Export cable	600	2,300	700	2,900
Floating projects				
Nacelle	1,100	4,600	1,900	7,700
Rotor blade	200	800	300	1,300
Towers	300	1,100	400	1,800
Floating (semisubmersible) structure	2,200	8,700	3,600	14,700
Substation topside	3	15	15	60
Dynamic array cable	100	400	200	700
Dynamic export cable	200	800	300	1,400

Source: Shields et al. 2022. *The demand for a Domestic Offshore Wind Energy Supply Chain*. National Renewable Energy Laboratory (NREL).

3.4 Offshore wind service ports

Many US ports have begun preparations to serve offshore wind farms. While few ports currently have all of the necessary capabilities to support the industry, many are actively investing in infrastructure upgrades to accommodate offshore wind vessels and some are already engaged in project support in terms of construction and logistics.

Table 5 shows the readiness of east coast ports to support fixed-bottom offshore wind projects. Only the Portsmouth Marine Terminal in Virginia can currently accommodate both wind turbine installation vessels (WTIVs) and feeder vessels. The New Jersey Wind Port, which will be nation's first port built specifically for offshore wind marshalling, will also accommodate both WTIVs and feeder vessels when it is complete. The first phase of this project includes a 30-acre marshalling port, which began construction in late 2021 with an anticipated completion date in early 2024. The second phase, which is slated to be complete in 2026, will add 35 additional acres for marshalling, as well as 60-70 acres for manufacturing.

The Port of New Bedford in Massachusetts and New London State Pier in Connecticut can accommodate feeder vessels but would need infrastructure updates to support WTIVs. The New London State Pier is already addressing these shortcomings and has begun infrastructure improvement to accommodate WTIVs which are scheduled to be completed in 2023. In New Bedford, offshore wind developer Vineyard Wind took over the lease of the 29-acre marine commerce terminal in January of 2023 to support the Vineyard Wind 1 project. The Massachusetts Clean Energy Center funded the terminal improvements that allow the facility to serve as the primary staging and deployment base for construction and installation of the project. In addition, Crowley Maritime received $75 million of state funding to support offshore wind terminal construction on 42 acres of waterfront property in Salem, Massachusetts.[26] When complete in 2024 or 2025 the site, which was formerly a coal and oil-fired power plant, will provide heavy-lift deployment and logistic services for offshore wind projects in the region. The facility will accommodate wind turbine installment vessels and have space for assembly and storage.[27]

Table 5 East Coast Ports Marshalling Capabilities and Readiness Screening

Port Name	State	Laydown Area (acres)	Quayside Length (meters [m])	Number of Berths	Berth Depth (m)	Channel Depth (m)	Bearing Capacity (tonnes [t]/square meter [m^2])	Air Draft Limit (m)	Readiness Level (WTIV)	Readiness Level (Feeders)
New Bedford	MA	29	366	3	9.1	9.1	20 t/m^2	None	Berth/channel depth, and quayside length	Quayside length
New London State Pier	CT	30	1,244	4	12.2	10	Assume > 15	None	Channel depth	
South Brooklyn Marine Terminal	NY	88	417	2	10.7	12.2	30	60	Berth depth, quayside length, and air draft	Quayside length
New Jersey Wind Port	NJ	70	854	4	11.5	9.88	29.8	None		
Tradepoint Atlantic	MD	3,300	1,021	2	10.97	10.97		None	Berth/channel depth, bearing capacity	Bearing capacity
Portsmouth Marine Terminal	VA	287	1,079	3	13.11	13.11	Assume >15 t/m^2	None		
Other ports (1)	-	-	-	-	-	-	-	-		
Other ports (4)	-	-	-	-	-	-	-	-		
Other ports (9)	-	-	-	-	-	-	-	-		

Note: WTIV = wind turbine installation vessels
Source: Shields et al. 2022. *The demand for a Domestic Offshore Wind Energy Supply Chain*. National Renewable Energy Laboratory (NREL).

[26] Mohl, Bruce. 2022. Santa comes early for offshore wind business. Commonwealth Magazine. https://commonwealthmagazine.org/energy/santa-comes-early-for-offshore-wind-businesses/
[27] Salem Offshore Wind Terminal. 2022. https://salemoffshorewind.com/

West coast ports lag behind the east coast in terms of offshore wind marshalling capabilities. As seen in Table 6, no west coast port has the existing capabilities to support floating wind turbine construction and operations. These ports either do not meet the infrastructure requirements to support the offshore wind construction or are too congested to accommodate the industry. However, several ports, including Coos Bay in Oregon, and Humboldt in California are actively planning upgrades.

Table 6 West Coast Ports Marshalling Capabilities and Readiness Screening

Port Name	State	Laydown Area (acres)	Quayside Length (m)	Number of Berths	Berth Depth (m)	Channel Depth (m)	Bearing Capacity (t/m²)	Air-Draft Limit (m)	Readiness Level (Floating Substructure)
Port of Seattle	WA	1,541.9	2,400	20	23.2	>30		None	High congestion and bearing capacity
Port at Coos Bay	OR	1,335	80	7	11.28	11.28		Select areas limited	Bearing capacity and quayside length
Humboldt Marine Terminal	CA	150	703	2	11.6	10.67	Assume > 15	None	Channel depth
Morro Bay	CA		80	1	5.5	5.5		None	Laydown area, quayside length, berth/channel depth, and bearing capacity
San Francisco	CA		870		15.2	15		67	Laydown area, bearing capacity, and air draft
Oakland	CA	1,300	7,800	185	15	15		67	Bearing capacity and air draft
Hueneme	CA	120	800	5	10.5	11		None	Berth depth
Los Angeles	CA	7,500	3,650	25	12	12		Select areas limited	High congestion
Long Beach	CA	525	4,750	10	25	25		Select areas limited	High congestion
San Diego	CA	96	750	8	12.8	12.8		None	High congestion

Source: Shields et al. 2022. *The demand for a Domestic Offshore Wind Energy Supply Chain*. National Renewable Energy Laboratory (NREL).

3.5 Offshore wind industry clusters

Some areas of the US are positioning themselves as regional hubs to support the offshore wind industry. These areas are often centered around a major port that will service offshore wind farms. But beyond port-related operations, the clusters include a range of activities that are working towards supporting supply chain manufacturing, workforce training and development, and local operations and maintenance. This section outlines a few cities and regions positioning to become major offshore wind clusters as the industry develops in the US.

New Bedford, Massachusetts

The City of New Bedford is engaged in a host of activities to support the offshore wind industry in Massachusetts. The Port of New Bedford will be the service port for the Vineyard Wind 1 and Mayflower Wind projects. Vineyard Wind took over the lease of a marine commerce terminal in the port in January 2023. The terminal, along with a redeveloped Eversource Energy and Sprague site will be used as staging facilities for offshore wind projects. Other sites, including the New Bedford State Pier, are also poised to support activity related to offshore wind.

To support this activity, the city is positioning itself as a hub for training and skills development. Bristol Community College in New Bedford is constructing a National Offshore Wind Institute to provide safety and technical training to prepare workers for jobs in all aspects of the offshore wind industry.

The New Bedford Ocean Cluster (NBOC)[28] is a key advocate for developing offshore wind in New Bedford. The cluster names offshore wind as one of its key pillars and provides marketing and awareness campaigns for the industry. NBOC is also involved in the development of offshore wind supply chain activities in the city, offering support for developers interested in the area.

Southeastern Connecticut

The Southeastern Connecticut Enterprise Region (seCTer)[29] is a federally designated Economic Development Organization that incorporates a wide range of stakeholders, including government organization, business leaders, nonprofits, and academic institutions. The coalition spearheads the region's Offshore Wind Industry Cluster (OWIC) and was a finalist to receive funding from US Economic Development Administration (EDA) Build Back Better Regional Challenge to support these efforts.

The cluster is positioning itself as a regional operational hub for the emerging offshore wind industry. Centered around the Port of New London, the OWIC will follow a hub-and-spoke model that engages the entire southeast region of the state. SeCTer's OWIC will participate in a broad range of activity to support the offshore wind industry, including supply chain development, workforce training, and research. The State Pier in the Port of New London will also host the nation's first Jones Act-compliant offshore wind turbine installation vessel.

Southwestern New Jersey

The New Jersey Wind Port[30] in Salem County will be the first built-for-purpose offshore wind port in the US. The project is divided into two phases. Phase I, which is targeted for completion in 2024, will include a 30-acre marshalling port. Phase II, which will come online in 2026, will add an additional 35 acres of marshalling capacity as well as an additional 60-70 acres for offshore wind component manufacturing. The port is conveniently located with easy access to more than half of the current offshore wind lease areas.

Paired with the activity at the port, New Jersey is also investing in workforce training and development. The state is actively working to develop the New Jersey Wind Institute, following a feasibility study commissions by the New Jersey Economic Development Authority (NJEDA) in 2022. Jointly funded by offshore wind developers and public funding, the institute will pair with local institutions to accelerate workforce development as well as research and innovation. Rowan College of South Jersey will offer a wind turbine technician program in 2023. Gloucester County Institute of Technology and Salem County Vocational Technical School are expanding welding and painting programs to support heavy steel manufacturing for the offshore wind industry.

Hampton Roads, Virginia

The Hampton Roads area, also known as the Virginia Beach-Norfolk-Newport News Metropolitan Statistical Area, is engaged in a host of activities to support offshore wind in the region. Having supported Coastal Virginia Offshore Wind two-turbine pilot project in 2020, the Portsmouth Marine Terminal in Virginia is

[28] https://newbedfordoceancluster.org/

[29] https://www.secter.org/

[30] https://www.nj.gov/windport/

currently the only port in the US that can accommodate wind turbine installation vessels and feeder vessels. The region plans to capitalize on this first-mover advantage and expand its offshore wind capabilities into supply chain manufacturing and workforce training. Siemens Gamesa Renewable Energy plans to build first offshore wind blade manufacturing facility at an 80-acre site leased from the marine terminal. The facility will support over 300 jobs, including about 50 jobs in operations and maintenance.

Although not located in the Hampton Roads region, the New College Institute will host a new program to develop the offshore wind workforce and provide industry-required certifications to support industry growth in Virginia. The program, deemed the Commonwealth of Virginia's Mid-Atlantic Wind Training Alliance, is in partnership with the Mid-Atlantic Maritime Academy and Centura College.

The Offshore Wind Landing,[31] in partnership with the Hampton Roads Alliance and other groups, provides support for the offshore wind cluster. The landing is a collaborative space for companies interested in the growing offshore wind industry in Hampton Roads. The purpose of the group is to connect companies involved in offshore wind in the region to form a coalition for innovation and a hub for supply chain activities.

3.6 Summary of Findings

The US offshore wind industry continues to grow and adapt. In the near-term, capacity growth will mainly consist of fixed-bottom projects on the east coast. Over time, more floating turbines will come online and the west coast, Great Lakes, and Gulf offshore wind markets are expected to grow. Given the existing and announced projects, the US is on track to meet the Biden administration's target of 30 GW by 2030 and will continue to grow thereafter.

The US supply chain has begun to develop to support the emerging industry. A growing number of manufacturing facilities are starting to come online or are under construction, providing US-based components for offshore wind projects. Most current supply chain manufacturing facilities are located on the east coast and were created to support specific wind farms. Over time, these facilities may grow to support a larger portion of the US market. Workforce training and development is also an important component of the US supply chain. Several institutions on the east coast are dedicated to preparing the domestic workforce for jobs in offshore wind but meeting the needs of the thousands of workers and job opportunities in offshore wind will take a substantial and sustained effort.

Ports in the US have invested millions of dollars in infrastructure updates to accommodate the needs of the offshore wind industry, primarily on the east coast so far. In some cases, new ports are being constructed with the primary purpose of serving the offshore wind industry. Until these port infrastructure improvement projects are completed, port capabilities represent a choke point for offshore wind progress in the US. Currently, only one US port is fully equipped to accommodate wind turbine installation vessels.

Multiple cities and metro areas across the country are positioning themselves as industry clusters supporting the emerging offshore wind sector. Across the

[31] https://hamptonroadsalliance.com/offshorewind/vaoswlanding/

east coast, these clusters support a range of offshore wind activity, including component manufacturing, research and innovation, and workforce training. These hubs of offshore wind activity help accelerate the industry and prepare the domestic supply chain and workforce. Additional industry cluster hubs are likely to emerge along the Gulf, west coast and Great Lakes as those offshore wind investment projects advance.

Offshore wind represents a significant and largely untapped opportunity for the US to generate renewable energy and create jobs. The industry has just started to take off in recent years and is expected to grow rapidly over the coming years and decades. As the US supply chain develops, offshore wind farms will rely less on components imported from Europe and Asia. Training and preparing the US workforce for jobs in offshore wind will ensure the US enjoys employment benefits from this growing industry.

4 Assessing the national-level economic impacts

4.1 The economic model

The national-level economic impacts of large-scale offshore wind deployments were estimated using the E3ME model. E3ME is a macro-econometric model designed to assess global policy challenges with approximately 70 country-regions (including the US as a single 'region'). It is an advanced econometric model and is widely used for policy assessment, forecasting and research purposes. It is owned and maintained by Cambridge Econometrics.

E3ME integrates a range of social and environmental processes. The two-way linkages between the economy, the energy system and the environment are a key feature of the model, which also captures 'rebound' effects. The model is designed to address national and global energy-environment-economy policy challenges, but its built-on adaptability allows it to be applied to other policy areas.

In terms of the modeling assumptions, E3ME differs from other, mainstream macro-econometric models as it provides a strong empirical basis for analysis. It is not bounded by unrealistic assumptions, such as optimization behavior, perfect knowledge, market clearing, the lack of involuntary unemployment or full resource utilization which are common to many computable general equilibrium (CGE) models. Instead, the model is based on the system of national accounts (i.e., through accounting identities), and parameters are estimated econometrically based upon up to 50 years of historical data.

More detail on the modelling framework is provided in Appendix A.

4.2 The scenarios that have been modeled

The modeling exercise assessed the macroeconomic impacts of expanding the US offshore industry to 750 GW by 2050, in alignment with the High Ambition scenario detailed in 2035 Report 3.0, under two different assumptions of the domestic content share (i.e. how much of the offshore wind value chain can be captured domestically in the US). The results are compared to the business-as-usual (BAU or baseline), which includes some decarbonization compared to today, but does not reach net zero[32]. The decarbonization in the BAU is purely a result of market forces (such as the relative costs of different technologies), rather than through any policy constraint on emissions levels. In contrast, the two alternative scenarios have a 95 percent decarbonized power sector by the middle of the century.

The domestic content share of the offshore wind industry along the supply chain is a crucial factor in understanding the economic impacts of such a substantial investment. As a result, two different scenarios were considered:

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[32] Note that the baseline in this economic analysis is *not* the same as the baseline used in the main 2035 Report 3.0 report. The baseline in the main report assumes that the power sector will be 95 percent decarbonized by 2050, while our baseline has much higher emissions in 2050, as a result of the lack of an explicit decarbonization target.

1. A scenario with ‘modest’ domestic content shares across most of the offshore wind value chain. Although the proportion of activity captured in the US increases over time, it does so relatively slowly (and from a low base); and
2. An ‘ambitious’ domestic content scenario, where supportive economic policy allows the US to capture more of the supply chain domestically, and therefore domestic content shares increase more rapidly over the period to 2050.

Separate assumptions are made for three different parts of the offshore wind value chain – these reflect key parts of the value chain where there is the greatest uncertainty about how much of the industry could be delivered within the US (and how quickly industrial capacity could scale up) (see Figure 9). They are:

- *Manufacturing*. In both scenarios, the domestic content share is initially assumed to be the same (25 percent). However, the domestic content increases at different rates over time: in the ambitious domestic content scenario, 90 percent of the value is captured domestically by 2050, and the equivalent figure in the modest domestic content scenario is 50 percent by the same year.
- *Construction*. The starting point for domestic content in the two scenarios are different (62 and 50 percent in the ambitious and modest scenarios respectively). The future expansion of domestic content is also projected to grow at different rates, reaching 95 (ambitious) and 66 percent (modest) in 2050.
- *Professional services*. As in the construction sector, the starting points for the higher and lower domestic content share scenarios are different (62 percent in the ambitious scenario, and 43 percent in the modest scenario). By mid-century, domestic content shares in the scenarios reach 95 and 62 percent in the ambitious and modest scenarios respectively.

The different starting points in different scenarios are due to the fact that while supportive policy can play a major role in the longer term, it also has short term impacts. The wave of investment that has occurred at least partly as a result of the Inflation Reduction Act is clear evidence that long-term or long-horizon policy can have an immediate impact on investment decisions.

Figure 9 Domestic content share in the US for key industries

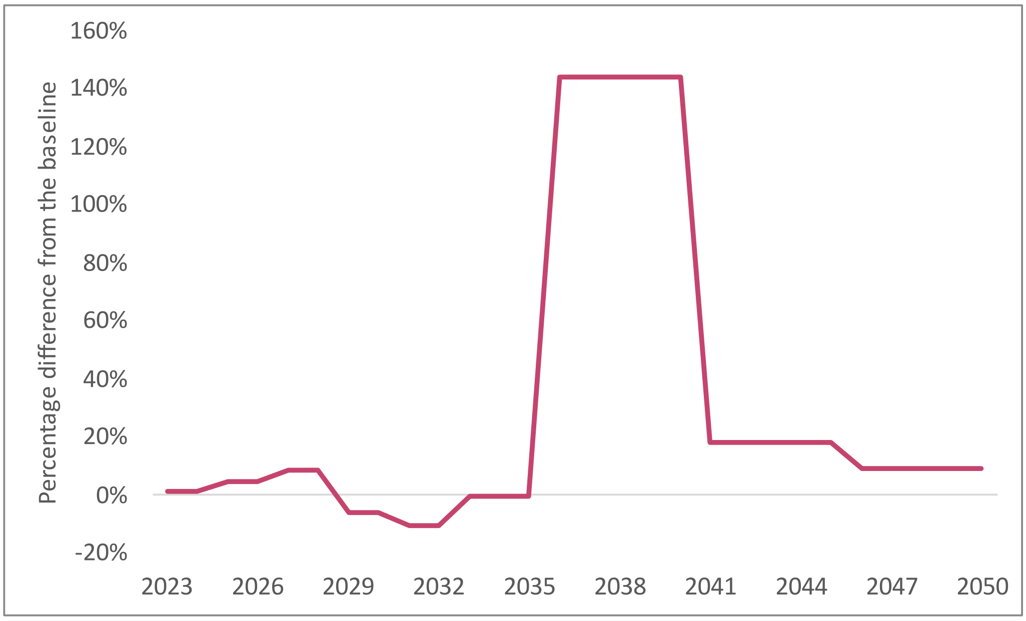
Source: Cambridge Econometrics research and assumptions

Within each of the two scenarios, we consider two different phenomena:

1. The impacts of the outlined scenarios on the US economy as a whole. This includes the substantial investment required, but also the impact that the deployment of large-scale offshore wind has on electricity prices faced by consumers and businesses, and the knock-on effects of this.
2. In the second stage of the analysis of each scenario, we zoom in on the impacts on the offshore wind sector and associated supply chains (as well as follow-on induced effects from higher aggregate wages across these activities). These sector-specific impacts are linked to the scale of investment in offshore wind that is required to build out 750 GW of capacity by 2050.

The level of investment relative to the baseline in both scenarios is visualized in Figure 10.

Figure 10 Power sector investment relative to baseline



Source: ReEDs model outputs from 2035 Report 3.0

In some years, particularly between 2029 and 2032, power sector investment is lower than in the baseline. This is mainly due to increased investment in, and electricity generation from, offshore wind which displaces investment in solar PV. As offshore wind has a higher load factor, less total investment is required in both generation and grid reinforcement (such as improving flexibility by batteries). However, across most of the period, power sector investment significantly exceeds that in the baseline.

In the long run, the expanded offshore wind sector also affects the economy through changing the average electricity price faced by consumers and businesses. However, in the second stage of the analysis, the offshore wind industry is compared to BAU *ceteris paribus*, only assuming increased investments in this industry. In order to estimate the effects of the offshore wind industry only, we exclude any affects of differentiated electricity prices, and focus on the industry, supply chain, and employment contributions of offshore wind investment and deployment in isolation. The scenarios are summarized in Table 1Table 7 below.

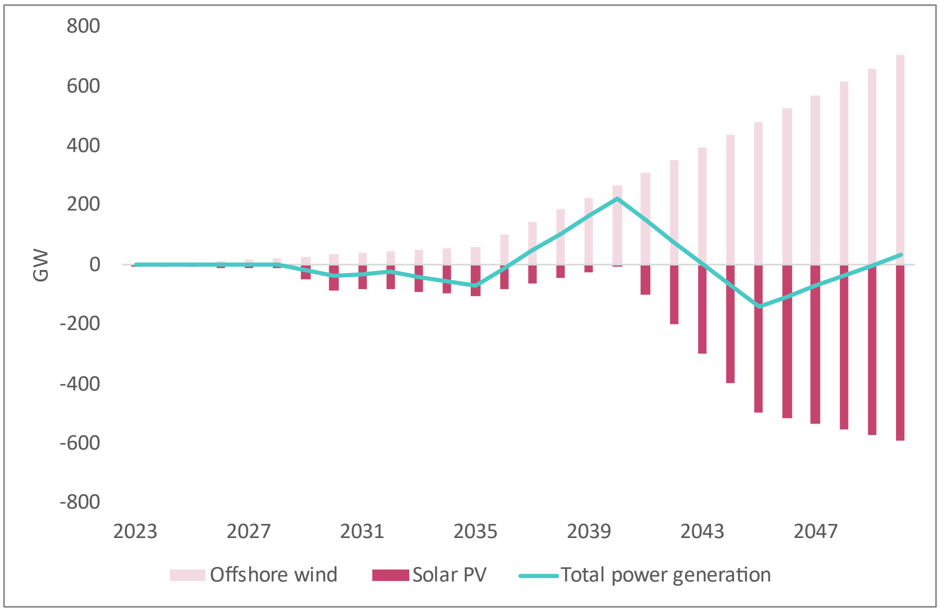
Table 7 Economic Modeling Scenarios of Offshore Wind

Scenario	Baseline	Technology coverage for investment	Rate of development of domestic supply chains	Electricity prices
Economy-wide analysis – lower domestic content share	BAU – limited decarbonization	All energy generation technologies	Modest	750 GW

Offshore wind analysis – lower domestic content		Offshore wind only	Modest	BAU
Economy-wide analysis – higher domestic content share		All energy generation technologies	Ambitious	750 GW
Offshore wind analysis – higher domestic content		Offshore wind only	Ambitious	BAU

Both scenarios have a similar power generation mix, with offshore wind capacity reaching 750 GW in 2050. Substantial deployment of new offshore wind farms starts from 2035 onwards (from when the highest investment occurs in Figure 10) and the total cumulative capacity gradually increases until 2050. However, a higher share of offshore wind has an impact on the overall power generation mix, especially by displacing solar PV capacity (see Figure 11). Other changes in the electricity generation mix are small compared to the changes in offshore wind and solar PV capacity, but they tend to occur in the case of technologies which can act as balancing technologies (such as CCGT and biogas) or are related to the wind industry (onshore wind).

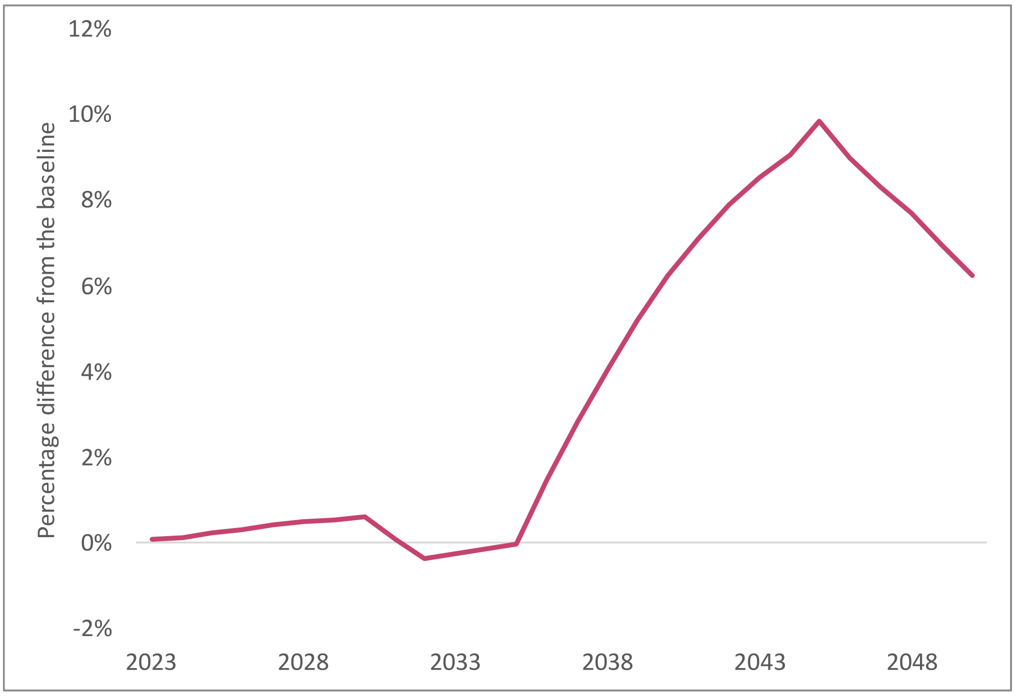
Figure 11 Change in total installed capacity of offshore wind and solar PV technologies, compared to the baseline



Source: ReEDs model outputs from 2035 Report 3.0
Note(s): Total power generation refers to the aggregated change of all technologies, not just that of offshore wind and solar PV.

The additional 750 GW of offshore wind capacity has a sizeable impact on electricity prices in the longer term (see Figure 12). In general, it pushes prices up: in the 2040s, by between 6 and 10 percent compared to a baseline in which the power sector does not decarbonize. This is due to the fact that the offshore wind scenario analyzed has higher levels of renewable resources available (including offshore wind), but at higher levelized costs, which increases electricity prices relative to the baseline which does not deploy nearly as many renewable resources. The rise of electricity prices begins at the end of the 2030s, when the majority of the offshore wind farms are installed, but the effect lasts longer, peaking in 2045.

Figure 12 Electricity price changes in the 750 GW offshore wind scenarios



Source: ReEDs model outputs from 2035 Report 3.0

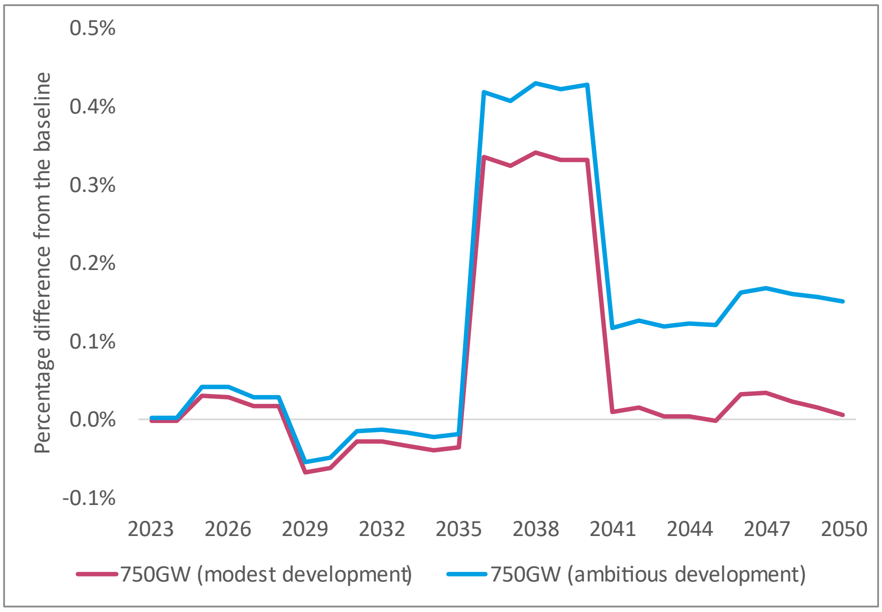
4.3 Quantifying economic impacts

GDP

As a general result, a higher domestic content share has a positive impact on the GDP. As the domestic content share increases over time (particularly from the mid-2030s onwards), the gap between the GDP impact of the modest and the rapid development of the domestic content share widens. As a result, in 2050, the impact of the lower domestic content scenario is virtually zero (0.01 percent) compared to the baseline. Meanwhile, the impact of the higher domestic content scenario is positive (0.15 percent). This is illustrated in Figure 13.

In addition, GDP impacts are strongly correlated with the investment level. When investment is lower than in the baseline (between 2029 and 2035), GDP is also slightly lower than in the baseline (by 0.1-0.0 percent). However, high investment in the offshore wind industry in the second half of the 2030s has a substantial positive impact on the GDP, which is 0.3-0.4 percent higher than in the baseline. This leads to the peak in Figure 13 between 2035 and 2040.

Figure 13 GDP impacts relative to baseline – modest and ambitious scenarios

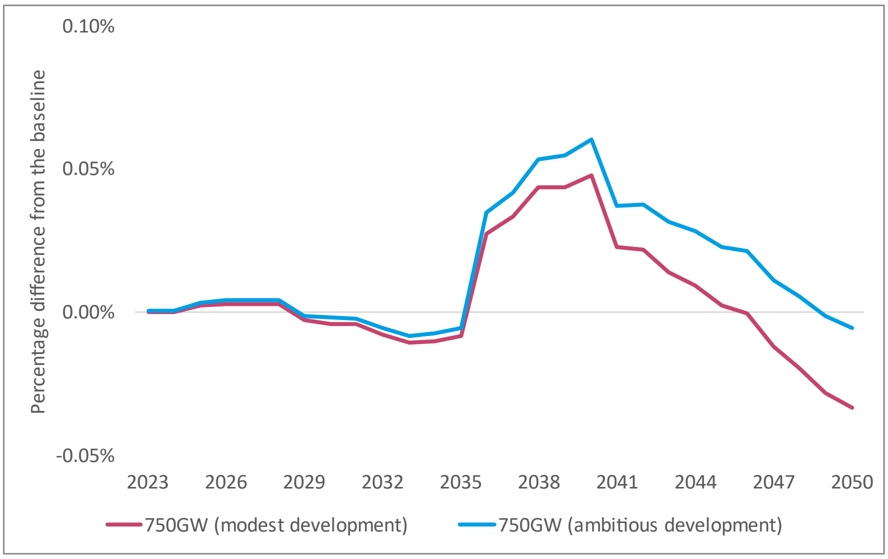


Source: E3ME modeling

Consumer expenditure

The evolution in consumer expenditure is somewhat different (see Figure 14). In the early years of the analysis, consumer expenditure shows a strong correlation with the impact on GDP. On the one hand, similar to the change in GDP, a higher share of domestic content leads to higher consumption expenditure, with the difference between the two scenarios increasing over time. On the other hand, the substantial investment stimulus has a much smaller impact on consumer spending than on GDP (impacts on consumer spending would come primarily through wage effects). Moreover, the impact on consumer spending gradually worsen through the 2040s. This is due to the fact that the benefits of the investment stimulus are offset by higher electricity prices (faced by businesses and consumers). This erodes real consumer spending power.

Figure 14 Consumer expenditure impacts relative to baseline



Source: E3ME modeling

Employment[33]

The overall impact on the US labor market is positive once the major investment stimulus starts from the mid-2030s (this is when the majority of the offshore wind farms are commissioned). As with GDP and consumer expenditure, the figures have a higher positive impact when the domestic content share is higher. This is because some sectors, particularly manufacturing, construction and professional services, capture a higher share of the investment in the offshore wind industry domestically (through a higher share of domestic content), and these additional manufacturing activities and services require a higher level of employment. The higher employment in these sectors has an induced effect through higher wages, which are distributed to other economic sectors. This can both mitigate job losses (e.g. in 2045) and stimulate job creation (e.g. in 2040). In 2050, the state of domestic supply chains (i.e. domestic content shares) is ultimately what determines whether the net impact is positive or negative compared to baseline.

Comparing different economic sectors, some sectors are impacted more than others.

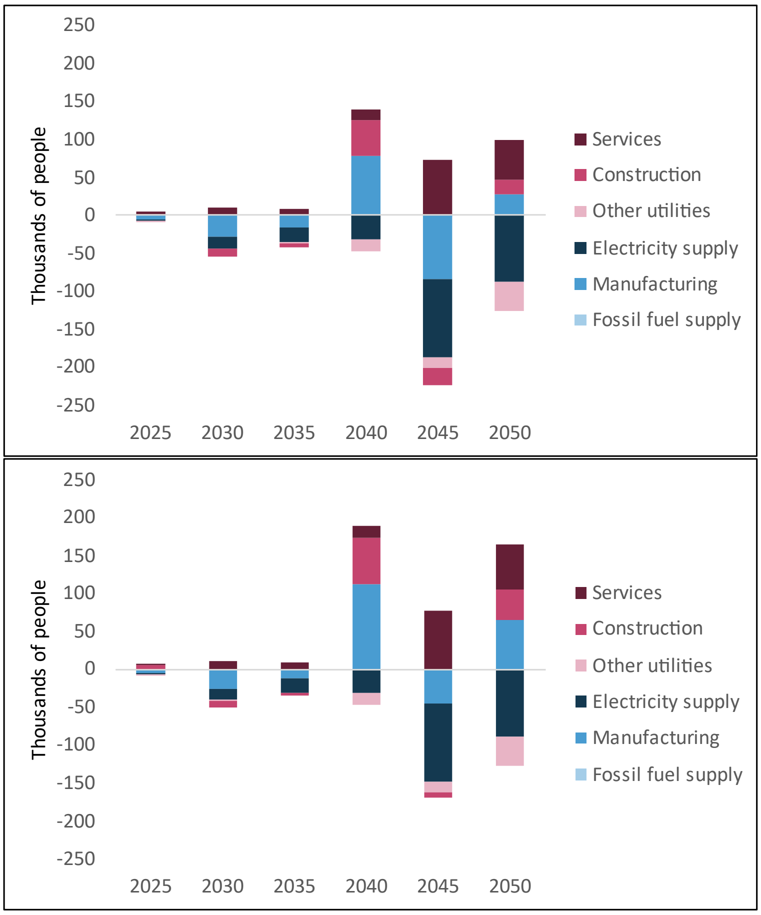
- *Construction*. As the deployment of offshore wind farms requires large-scale investment during the manufacturing and installation process, the construction sector experiences a substantial increase in employment in the second half of the period. It peaks in 2036 with up to 84,000 additional employees (in the high domestic content scenario).
- *Services*. Similarly, the services sector experiences an increase in employment, but slightly delayed into the early 2040s. This is due to (1) the induced effects linked to the spending of higher wages in the economy (largely on consumer services such as retailing and distribution) and (2) professional services linked to the design and operation & maintenance of the offshore wind farms.
- *Electricity*. On the other hand, employment in the electricity sector is much lower as a result of the deployment of offshore wind, with as many as 103,000 fewer employees in 2045 in both scenarios compared to the baseline.[34] This is because less total capacity is needed as offshore wind has a higher load factor compared to the solar PV, which is largely pushing out compared to the baseline. This results in fewer people employed in the operation and maintenance of the capacity, and also fewer opportunities across the electricity supply sector as the grid requires less management.
- *Manufacturing*. In the manufacturing sector, a higher domestic content share has a significant positive impact on employment. As the domestic content share increases, the positive differences also

[33] Employment, as measured in our macroeconomic model E3ME, is based on the International Labour Organization's (ILO) definition of *a person in employment*. This means that our estimates of employment refer to *people*, rather than jobs or full-time equivalents. Under this definition, one person doing two part-time jobs would be counted as a single entity (exactly 1), the same as one person working a full-time job or working a single part-time job.

[34] Since the electricity generation mix is identical in the case of the high and low domestic content share scenarios, the employment impact in the electricity sector are the same.

increase. For instance, in some years (e.g. in 2030, 2035 and 2045), the manufacturing sector in both scenarios suffers job losses

Figure 15 Employment impacts by industry sector for modest and ambitious scenarios



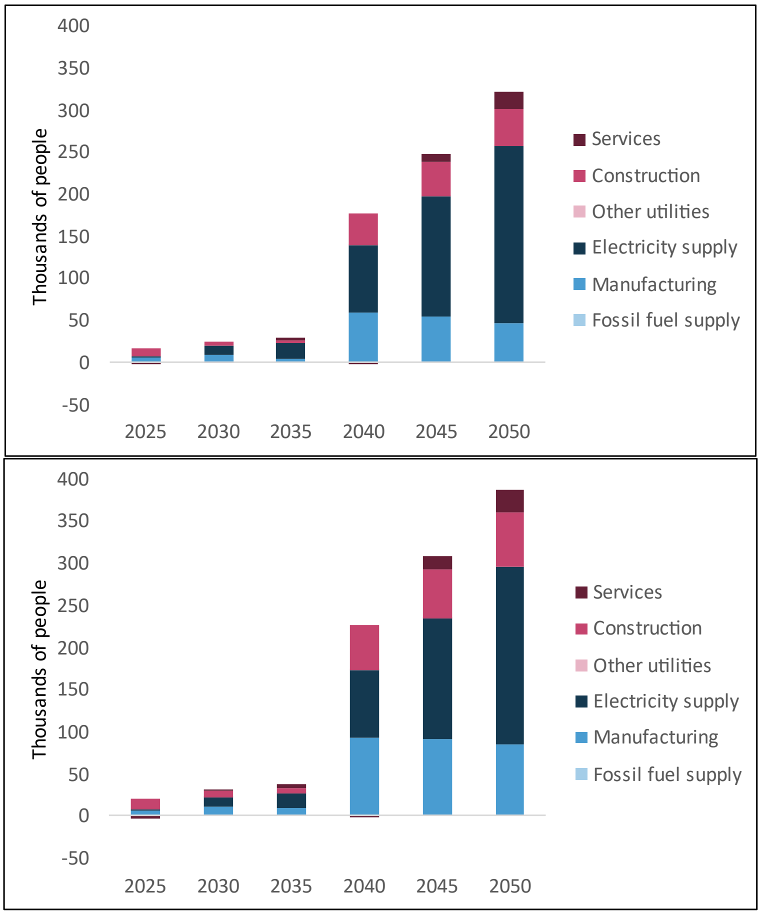
Source: E3ME modeling
Note(s): The upper chart shows the results in the case of modest domestic content shares, the bottom the case of ambitious domestic content shares.

compared to the baseline; however, these job losses are smaller when domestic content share is higher. In some other years (e.g. in 2040 and 2050), there are job gains in the manufacturing sector. This clearly indicates that the US labor market can benefit from policies which will lead to greater domestic content.

However, the figures are different when only the impact of the offshore wind industry and its suppliers is considered (see Figure 16). The cumulative impact on employment is positive and increases over time. For example, in 2050, employment is 388,000 higher in the higher domestic content share scenario, compared to the baseline. The steadily higher employment impact is mainly explained by the need for operation & maintenance services after the deployment of offshore wind farms.

The positive employment impacts in the offshore wind industry and along its supply chain are primarily driven by additional employment in the electricity sector, regardless of the domestic content share (as the same capacity of offshore wind is built). Higher domestic content share has a positive effect in two sectors, namely manufacturing and construction: employment is higher by 38,000 and 21,000 people, respectively, in 2050. This reinforces the earlier finding that the US labor market can profit from policies which incentivize higher domestic content share. Chapter 5 discusses the regional employment impacts of the offshore wind industry in detail.

Figure 16 Employment contributions of the offshore wind industry – modest and ambitious scenarios



Source: E3ME modeling
Note(s): The upper chart shows the results in the case of modest domestic content shares, the bottom the case of ambitious domestic content shares.

4.4 Key takeaways

Two scenarios were examined to assess the national impact of deploying 750 GW offshore wind capacity: a modest low domestic content scenario and an ambitious domestic content scenario. The difference in domestic content share is applied to the manufacturing, construction and professional services sectors. Within each of the scenarios, an economy-wide analysis was conducted, and then the analysis focuses in on the impact on the offshore wind sector and associated supply chains.

- The deployment of 750 GW offshore wind capacity has an impact on (1) the electricity generation mix, with offshore wind mainly replacing solar capacity; (2) the investment profile, which is higher than in the baseline due to the substantial investment needs of the offshore wind industry; and (3) the electricity prices, which are also slightly higher than in the baseline (by 6 percent in 2050).

- Both scenarios have an overall positive impact on the GDP, peaking in the second half of the 2030s with values 0.3-0.4 percent higher than in the baseline. However, GDP gains are higher in the case of the higher domestic content share, and as the domestic content share increases over time, the gap widens. By the late 2040s, the difference is 0.1 percentage point, and the domestic content share determines whether the GDP impact is positive, or zero (i.e. in the modest scenario GDP in 2050 is essentially the same as in the baseline).
- The change in consumer expenditure relative to the baseline is smaller than the change in GDP. Between 2035-2045, it is higher than in the baseline in both cases (although by less than 0.1 percent), but over time the impact erodes due to the higher electricity prices. At the end of the 2040s, a higher domestic content share keeps the change in consumer expenditure close to zero, while it becomes negative in the case of a lower domestic content share compared to the baseline.
- A higher domestic content share leads to more favorable employment outcomes.. In 2050, the ambitious scenario leads to 37,000 more people in work across the economy, while the modest scenario sees 29,000 fewer people employed – so the US' ability to capture activity domestically through a supportive policy environment can make a major difference to how the economic impact of offshore wind is perceived.
- While the overall economy-wide employment impact of deploying 750 GW of offshore wind capacity is mainly positive, there are trade-offs across different economic sectors.
    - On one hand, employment in the electricity sector is lower than in the baseline (103,000 fewer people employed in 2045), which can be explained by the higher load factor of the offshore wind industry compared to solar PV, which is the main displaced technology.
    - On the other hand, higher domestic content has positive effects in the manufacturing and construction sectors, as well as in services due to the induced effects of higher wages in other sectors and the higher domestic content share in professional services.
- Considering the employment impact of the offshore wind industry deployment in isolation (i.e. excluding the induced impact of electricity prices), the employment impact is steadily positive and increases over time, particularly in the electricity sector (the operation and maintenance creates permanent jobs). For example, in 2050, employment is 388,000 higher in the higher domestic content share scenario. Higher domestic content share has a positive impact mainly in the construction and manufacturing sectors (employment is higher by 21,000 and 38,000 people, respectively, in 2050, compared to the lower domestic content share scenario). This indicates that a US and state/local policy that encourages the development of the offshore wind supply chain will result in significantly greater job and economic opportunities.

5 Assessing the regional-level economic impacts

To understand the geographic distribution of economic impacts, we allocate the national-level employment results (from the E3ME model) to regions of the US. This exercise demonstrates where the employment impacts associated with the transition to offshore wind might be expected to take occur.

However, it should be noted that this analysis is indicative of trends that might be expected to occur absent further intervention. The trends highlighted in this chapter reflect the siting of new offshore wind capacity as suggested by the ReEDS model in the 2035 Report 3.0 and some allocation rules (set out in more detail below). Suitable incentives could be utilized to encourage a different allocation of employment opportunities, if that were deemed to be a more desirable outcome.

5.1 The regional distribution methodology

The E3ME model provides results at the national level by industry and year for four scenarios. Building on those results, this chapter allocates national-level estimated employment impacts to regions of the US. In this distributive analysis, we focus on results from the two offshore wind-only scenarios rather than the economy-wide outcomes. As such, this analysis estimates where the offshore wind employment in the US will be located. To demonstrate the net impacts of the transition, we compare the outcomes from the two scenarios to the 'no mandated decarbonization' baseline.

We distribute the net results from the E3ME model to geographic areas based on a few metrics. First, we consider each state's relative share of new and cumulative offshore wind capacity for each year between 2023 and 2050.[35] Estimates of these two capacity factors come from the ReEDS energy system model and were the inputs into the macroeconomic model, E3ME at the national level. For each year, we calculate each state's share of these two indicators (new and cumulative capacity).

We apply these relative shares to the E3ME results by industry sector. Employment in sectors that are directly tied to the offshore wind industry, including construction, manufacturing, and electricity (similar to operations and maintenance), is distributed using the following methodology:

- **Construction:** *New* offshore wind capacity is the key factor driving impacts on the construction sector. Thus, for this sector, we distribute national-level net impacts to states based on each state's relative share of new capacity in each year. For example, if Massachusetts accounted for 10 percent of the country's new capacity in 2025, that state is assumed to have 10 percent of the construction job impacts in that year.
- **Electricity:** Employment in operations and maintenance is closely related to a state's overall (cumulative) capacity in a given year. Therefore, we distribute the net offshore wind employment in the electricity sector based

[35] We do not consider investment, which is another input to the model, because it is closely correlated with capacity and therefore already captured in the selected capacity metrics.

on each state's share of the nation's *total cumulative* offshore wind capacity in each year.

- **Manufacturing:** Unlike the construction and electricity sectors, employment opportunities in manufacturing may not be located in the same state or region as the offshore wind capacity. While proximity to offshore wind projects is a factor in supply chain competitive advantage (as evidenced by the new and announced supply chain manufacturers which are concentrated along the East Coast), the allocation of manufacturing employment also depends on existing manufacturing infrastructure and capabilities. Therefore, the distribution of these activities follows a different methodology than in the above two sectors. First, we calculate the number of people employed in manufacturing linked to demand from each state in each year. This calculation is based on each state's share of the nation's *total* capacity (as is done for electricity jobs). We then complete a second stage distribution, allocating this employment to other states based on each state's:
    - **relative specialization in relevant manufacturing sectors:** we use data from 2021 to calculate each state's share of employment in manufacturing sectors relevant to offshore wind projects[36]
    - **distance from the state where the offshore wind projects are taking place (i.e., the source of demand):** we use the Euclidian distance between the centroids of states to approximate distance

  For example, suppose the offshore wind industry will support 20,000 people employed in manufacturing in 2024 and Virginia accounts for five percent of the total capacity in that year. We estimate that Virginia will support 1,000 people in manufacturing in that year. However, not all those will remain within the state. Other states may have a competitive advantage in manufacturing. Factors contributing to this advantage might include robust freight transportation infrastructure, workforce skills, and natural resources. To account for this variation, our analysis redistributes these 1,000 employed people to states (including Virginia) based on each state's relative specialization in manufacturing and distance from the state with the offshore wind project (in this case Virginia). For more information on the methodology for manufacturing employment, see Appendix A.

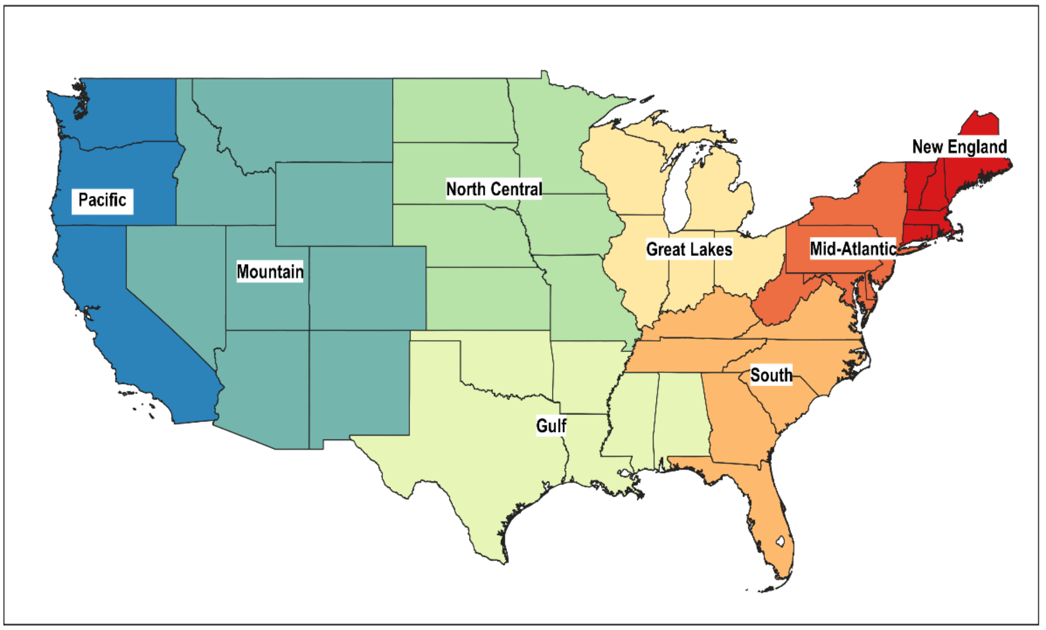
Other sectors, while not directly or indirectly (though supply chain activity) related to offshore wind, will experience induced effects due to re-spending of wages. For these sectors, we assume the impacts will follow the direct and indirect effects from the above three sectors. Therefore, we allocate employment impacts in other sectors to states based on each state's estimated share of the total employment in the construction, electricity, and manufacturing sectors.

These calculations assume that employment opportunities in the construction and electricity sectors will remain entirely within the state with offshore wind capacity. However, this assumption is unlikely to hold in reality, as workers may cross state borders for jobs in nearby states. Regions of the US will likely form clusters of offshore wind capabilities. For example, Massachusetts,

[36] We use 2021 US Census ACS data on employment by industry for the civilian employed population aged 16 and over. Relevant manufacturing sectors include 1) metal and metal products, 2) machinery, and 3) electrical equipment, appliances, and components.

Rhode Island, and Connecticut have offshore wind projects in nearby waters. When Massachusetts builds new capacity, some workers who helped construct the pilot wind turbines in Rhode Island may fill some of the construction jobs. To account for this clustering, as well as general uncertainty in precision, we aggregate results into eight regions of the US, shown in Figure 17.

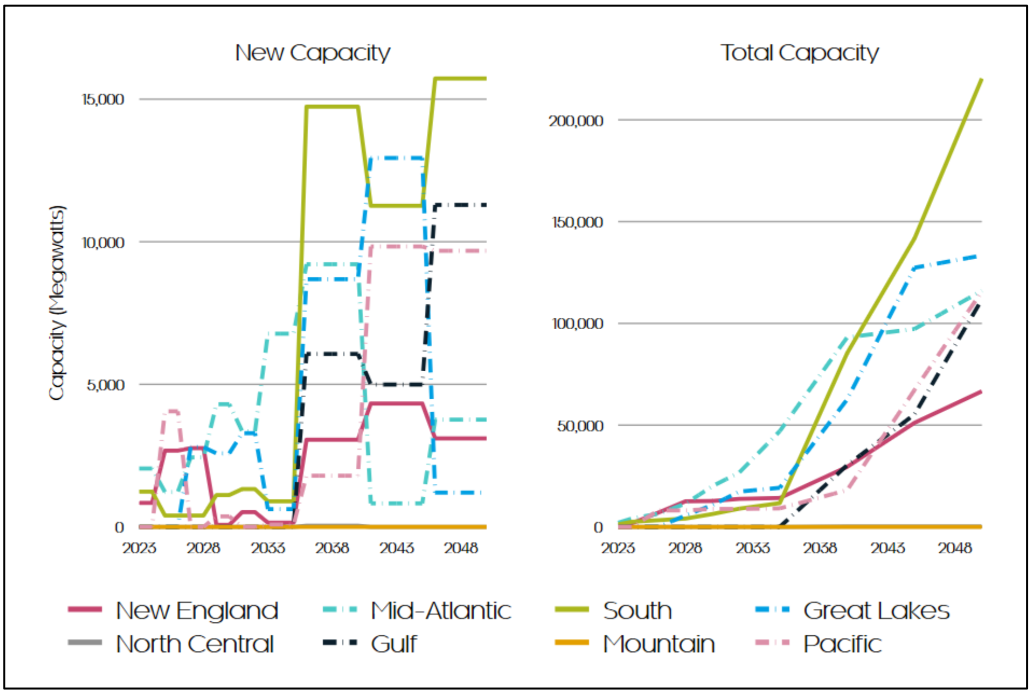
Figure 17 Employment distribution regions



Source: Cambridge Econometrics

Figure 18 shows new and total offshore wind capacity across these regions. As discussed above, employment results are largely allocated based on these two indicators. In the near term, offshore wind projects are concentrated in the

Figure 18 New and total offshore wind capacity by US region



Source: Cambridge Econometrics using state-level ReEDS model outputs.

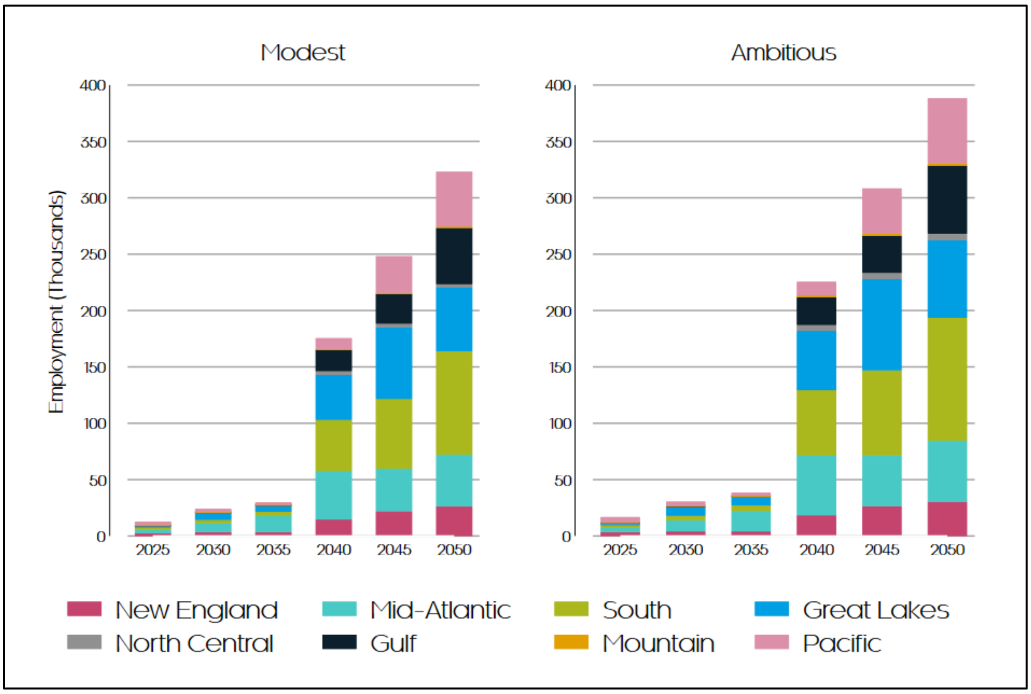
northeast, including the New England and Mid-Atlantic regions. By 2030, these two regions are anticipated to install 33,000 MW of offshore wind capacity. In the longer term, the South will accumulate the most capacity (220,000 MW by 2050), largely due to large capacity investments after 2035. The Great Lakes region also has high offshore wind capacity potential in the longer term (133,000 MW by 2050) with the Pacific and Gulf regions adding capacity in the latter half of this time period.

5.2 Regional employment impacts

Total employment

Following these capacity trends, offshore wind employment will be focused on the East Coast in the near-term and move to other regions over time. In 2025, about 60 percent of employment opportunities created will be concentrated on the East Coast, in the New England, Mid-Atlantic, and South regions. The Great Lakes, Gulf, and Pacific regions are expected to experience job growth in the longer term (as seen in Figure 19). However, the South will remain a dominant player in offshore wind, accounting for 28 percent of employment in 2050. The Mid-Atlantic, Great Lakes, Gulf, and Pacific regions are each anticipated to account for between 14 and 18 percent of total employment in 2050.

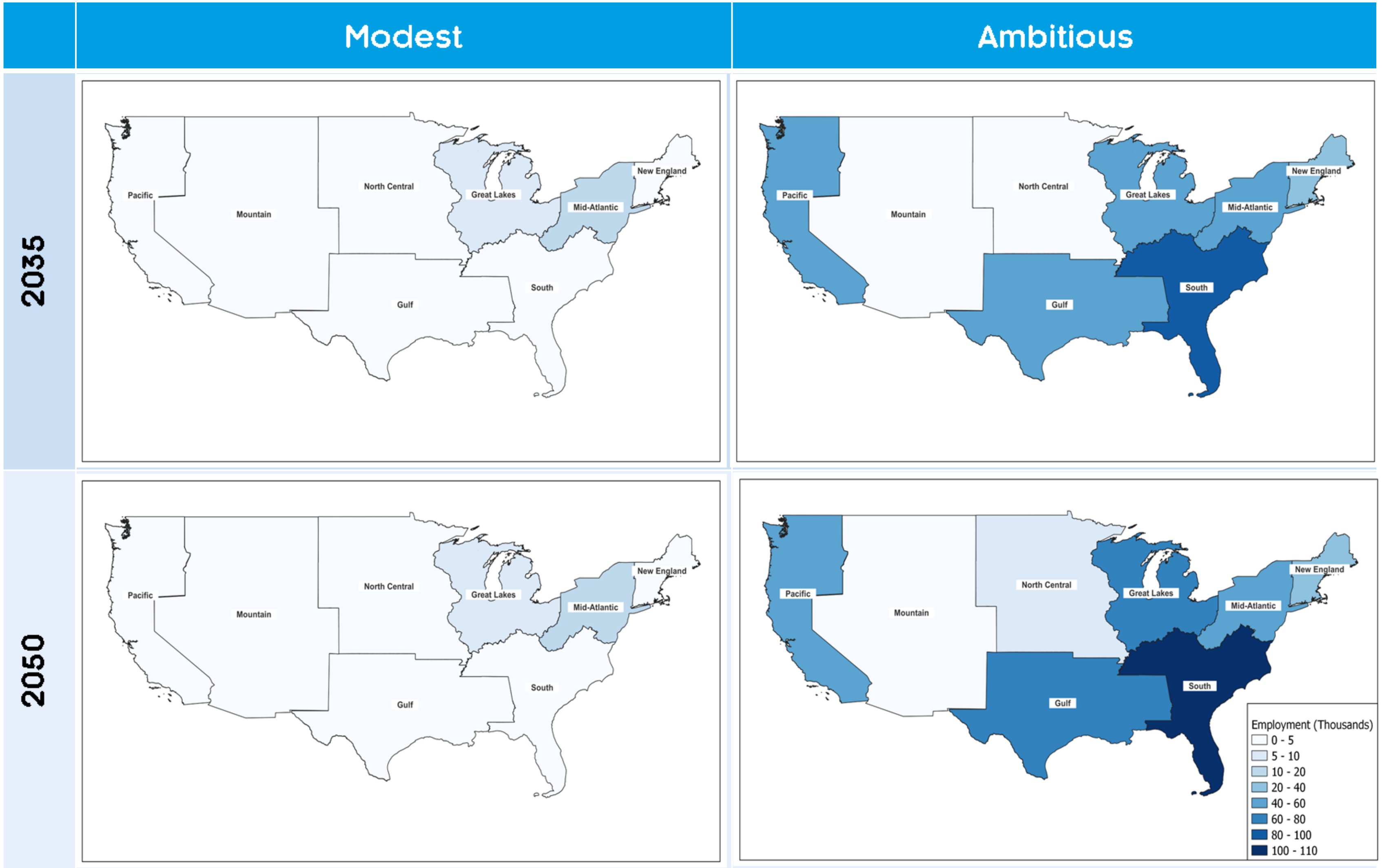
Figure 19 Offshore wind employment impacts by region and domestic content assumption



Source: Cambridge Econometrics

As seen in Figure 20, employment linked to offshore wind will increase substantially between 2035 and 2050. In 2035, most employment will be in the Great Lakes and Mid-Atlantic Regions and domestic content assumptions do not have a substantial impact on employment. By 2050, employment will have spread across the country, with concentrations across all coastal areas and the Great Lakes. In the ambitious domestic content scenario, inland regions will also benefit from offshore wind investment, largely through employment in the manufacturing sector (e.g. 5,700 estimated people employed in the North Central region and 2,100 in the Mountain region, compared to 3,200 and 1,200 in the modest domestic content scenario).

Figure 20 Offshore wind employment for modest and ambitious domestic content assumptions, 2035 and 2050

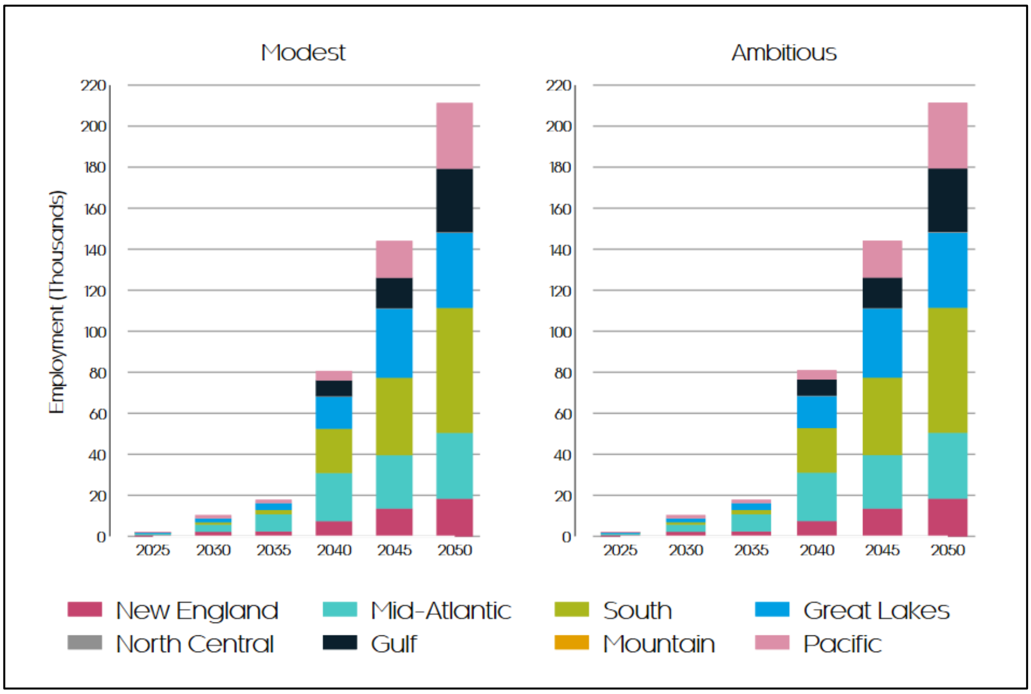


Source: Cambridge Econometrics

Operations and maintenance employment

Operations and maintenance (O&M) activities are required throughout the life of an offshore wind farm, providing long-term employment to local workers. As seen in Figure 21, O&M employment accounts for an increasingly large share of total employment over time, making up 65 percent of employment in the modest scenario and 54 percent in the ambitious scenario in 2050, at around 210,000 people in the same year (up from only 10,000 people in 2030). Unlike other sectors, O&M employment is not sensitive to domestic content assumptions because these jobs are generally assumed to be filled by domestic workers under both scenarios. Following capacity trends, employment in O&M will be concentrated in the northeast in the short term and move to the rest of the country over time. Following the trend in cumulative capacity, O&M employment is expected to grow quickly around 2040, when offshore wind projects in the South, Great Lakes, and Mid-Atlantic regions come online or expand. Additional offshore wind capacity in the Gulf and Pacific will bring O&M employment to these areas between 2040 and 2050.

Figure 21 O&M employment impacts by region and domestic content assumption

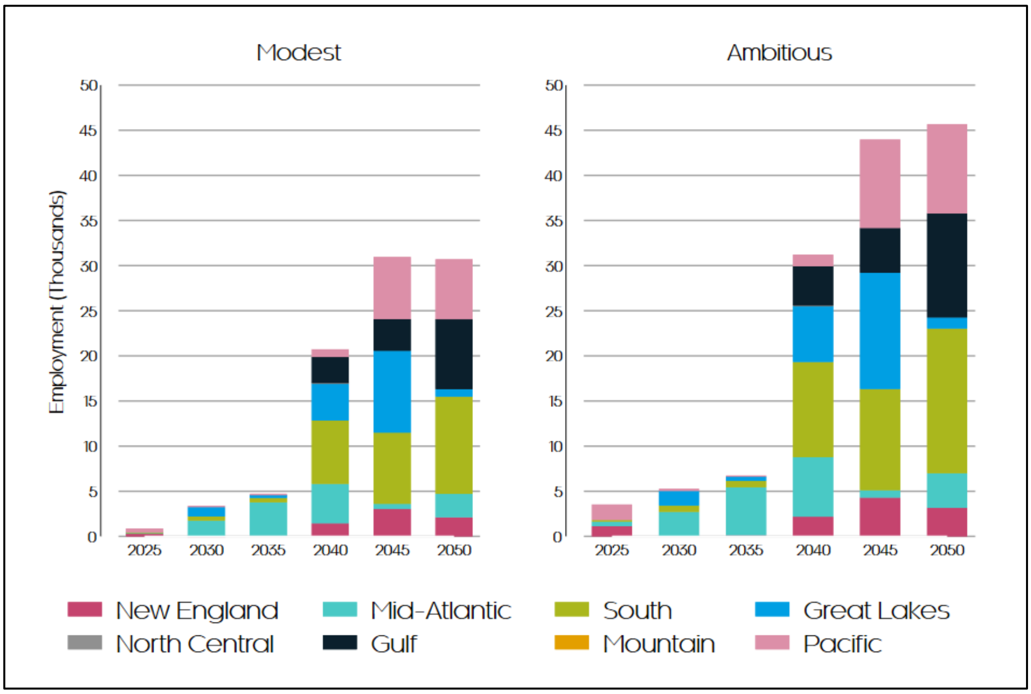


Source: Cambridge Econometrics

Construction employment

Construction jobs are typically relatively short-term, created during the building phase of offshore wind projects. In 2025 through 2035, offshore wind projects will support fewer than 5,000 people employed in construction in the modest domestic content scenario and up to 7,000 people employed in the sector in the ambitious scenario. Each year during that period, between 46 and 81 percent of constructions employment will be in the New England and Mid-Atlantic regions. After 2040, more construction work will also be expected in the rest of the country, particularly the South, which will support between 7,000 and 11,000 people employed in the modest scenario from 2040 to 2050, and between 11,000 and 16,000 people in the ambitious scenario. By 2050, the Gulf will account for a quarter of offshore wind construction employment (about 8,000 people in the modest scenario and 12,000 in the ambitious scenario). The west coast will also see growing demand for construction workers in later years, as the increasing maturity of floating foundations lead to greater capacity installs in this part of the country. In 2045 and 2050, there will be an estimated 7,000 people employed in construction jobs in the Pacific region in the modest domestic content scenario and about 10,000 in the ambitious scenario.

Figure 22 Construction employment impacts by region and domestic content assumption

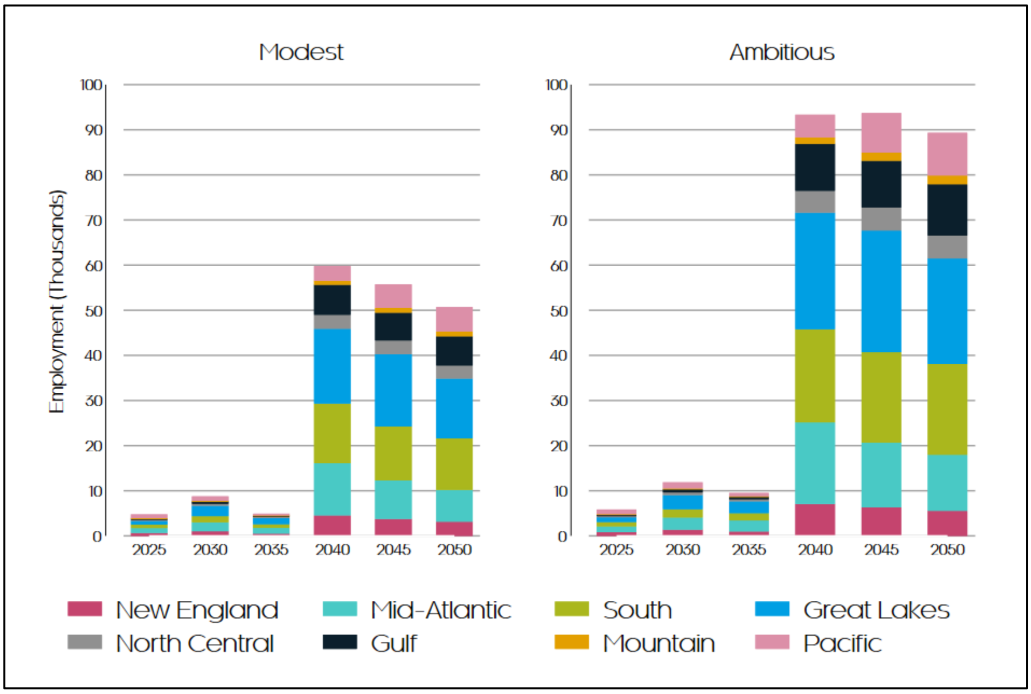


Source: Cambridge Econometrics

Manufacturing employment

Manufacturing employment will also be concentrated around offshore wind projects but are more spread throughout the country than other sectors. As discussed above, we distribute manufacturing employment based on both

Figure 23 Manufacturing employment impacts by region and domestic content assumption



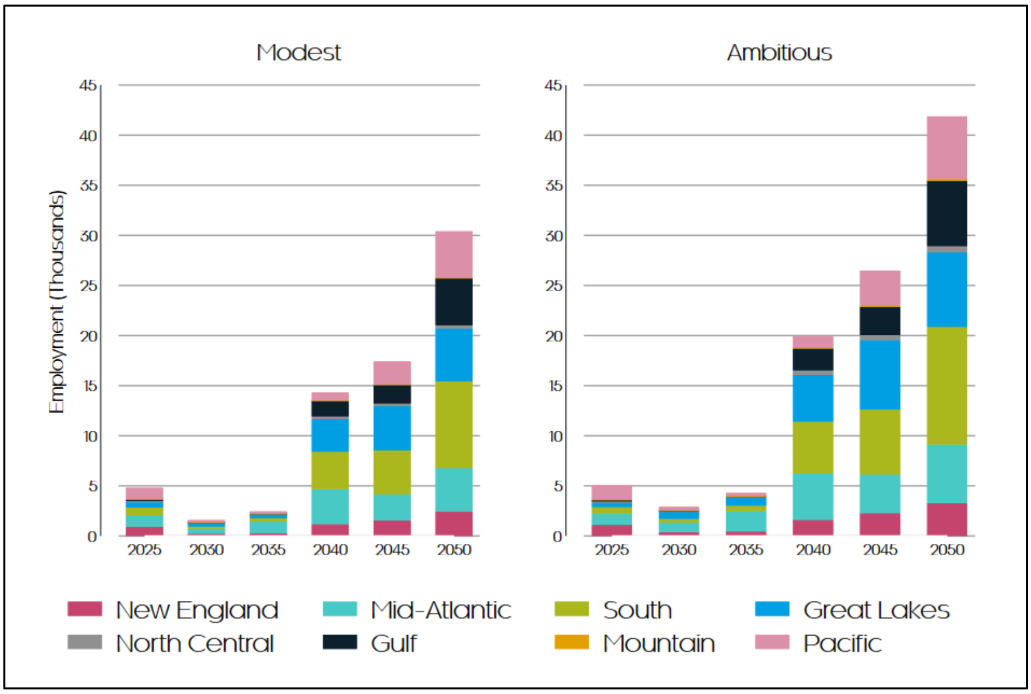
Source: Cambridge Econometrics

proximity to offshore wind projects and specialization in offshore wind related manufacturing industries. Due to its manufacturing specialization and offshore wind capacity potential, the Great Lakes region will have the highest employment in manufacturing, supporting between 23,000 and 27,000 employed people in the ambitious domestic content scenario between 2040 and 2050, and 13,000 to 17,000 in the modest scenario. The next highest regions for manufacturing employment are projected to be the South, Mid-Atlantic and Pacific. The Mountain and North Central regions will also see modest employment in offshore wind related manufacturing (up to 2,000 in the Mountain region and 5,000 in the North Central region, most of which occur after 2035).

Other sectors

Induced impacts in other sectors, such as services, generally arise as a result of increased employment in direct and indirectly impacted sectors, and therefore follow distribution trends in the above three sectors. As seen in Figure 24, the East Coast and Great Lakes will see the greatest additional employment in other sectors in each year. Employment in the Gulf and Pacific will increase over time, accounting for about a third of employment in other sectors in 2050.

Figure 24 Employment impacts in other sectors by region and domestic content assumption



Source: Cambridge Econometrics

5.3 Key takeaways

This regional analysis illustrates the following key findings:

- The northeast regions of the US will see the most offshore wind capacity growth in the near term. In the longer term, the South and Great Lakes regions have the most capacity potential. Over time, as floating turbines become more readily available, offshore wind capacity in the Pacific and Gulf regions will grow.
- Following these capacity trends, offshore wind employment will be concentrated on the East Coast and Great Lakes regions. However, the

Gulf and Pacific will account for an increasing share of overall employment over time (and more than 150,000 people in total by 2050 with ambitious domestic supply chain development).

- The operations and maintenance sector account for the majority of jobs supported by offshore wind capacity (in 2050, this sector makes up 65 percent of total employment in the modest scenario and 54 percent in the ambitious scenario) – around 210,000 people across the US by 2050.
- Despite employment concentrations around coastal regions and the Great Lakes, up to 7,800 people employed in offshore wind manufacturing will also fall in the Mountain (2,100) and North Central (5,700) regions in the longer term.

6 Summary of Findings

This analysis has shown the different implications on the US economy of a major investment and sustained deployment of offshore wind to accelerate the decarbonization of its electricity system.

Deploying 750 GW of offshore wind will require and contribute a substantial investment. In early years, this would be delivering fixed turbines, principally up and down the East Coast. Over time, fixed turbine investment will spread to other areas of the US and as floating turbines achieve maturity and become a more cost-competitive option, this will open up the opportunity to deploy substantial capacity in the Gulf, as well as on the Pacific Coast.

This investment will provide an economic stimulus – creating jobs initially in manufacturing, installation and logistics, and commissioning. Over time, as cumulative capacity builds up, an increasing number of jobs will be dedicated to the operations & maintenance of the turbines, and wider electricity grid operations. By 2050 the offshore wind sector, including supply chains, could employ almost 400,000 people across the US.

Largely in line with where the wind turbines are being deployed and based on existing manufacturing expertise, offshore wind employment will be concentrated on the East Coast and Great Lakes regions. However, the Gulf and Pacific will account for an increasing share of overall employment over time (and more than 150,000 people in total by 2050 with ambitious domestic supply chain development). Despite employment concentrations around coastal regions and the Great Lakes, up to 7,800 people employed in offshore wind manufacturing are projected for the Mountain (2,100) and North Central (5,700) regions in the longer term.

While the investment boom has a positive impact on the GDP figures, in the longer term, the deployment of large-scale offshore wind capacity was estimated to increase electricity prices faced by businesses and consumers (by up to 10%). This will have a dampening effect on consumer spending (less disposable income for other goods and services) compared to the 'business as usual' alternative, and puts downwards pressure on Gross Domestic Product (GDP).

The long-term economy-wide net impact of higher investment and higher electricity prices will largely depend upon the extent to which the US is able to capture value in the offshore wind sector and its associated supply chains. In a case where domestic supply chain development remains *modest*, the net impact on GDP by 2050 is essentially zero, but if supportive policy can drive a more *ambitious* rate of development of these supply chains (with more manufacturing, services and construction supplied domestically) then the US economy could be 0.1 to 0.2 percent bigger by 2050 compared to the 'business as usual' outlook.

This highlights one of the key challenges for policymakers; how to ensure that the US is well-placed to maximize the benefits from offshore wind deployment. There are a number of different aspects to this: substantial investment in manufacturing sites and installation facilities (including deep-water ports) will be required; workers will require training (or retraining) to ensure that they have the required skills to meet the labor demand that offshore wind activity will generate; and firms which currently focus on the fossil fuel industry will need to shift their attention, identifying parts of the offshore wind value chain that they can fill, and working with local and federal authorities to ensure that there is a sufficient business case (through direct fiscal incentives and/or a clear future pipeline of demand) for them to invest in capital and labor facilities.

With the first major offshore wind projects now underway in Massachusetts and more permitted and ready to launch along the East Coast, the US is starting to see a growing number of announcements of manufacturers (OEMs and suppliers) deciding to locate production facilities in the US, along with efforts to train the workforce needed to install, operate and maintain these wind farms. This emerging industry is showing signs of life and how quickly it can grow to support the full range of investment anticipated will determine if the US can meet the more ambitious scenario detailed here.

In this analysis, we've only focused on a single offshore wind deployment scenario, of 750 GW by 2050. This is quite an ambitious figure, and policymakers may decide to help facilitate a role for offshore wind in the US without targeting explicitly as much as 750 GW in total capacity. Scenarios which delivered lower offshore wind volumes would, broadly speaking, be expected to deliver milder versions of the same dynamics that have been outlined in this report: there would be a (smaller) investment stimulus, leading to a short-term boost to GDP, and there would be employment opportunities created across offshore wind value chains that could be maximized through supportive industrial policy which ensures as much as possible of these value chains are captured within the US. At the same time, a smaller role for offshore wind would lead to a smaller increase (or perhaps even no increase or a decrease) in electricity prices faced by consumers and businesses, which would provide a smaller drag on GDP than in the modeling outlined above. As such, the key takeaways from this analysis from a policymaking perspective remain the same, even if the ambition of offshore wind deployment in the US were scaled back from the 750 GW of capacity by 2050 explored here.

7 References

Bipartisan Policy Center (2022): Inflation Reduction Act (IRA) Summary: Energy and Climate Provisions. Available at: Inflation Reduction Act Summary: Energy and Climate Provisions | Bipartisan Policy Center– last accessed on 06/02/2023

Catapult (2018). Offshore wind industry prospectus. Available at: Offshore Wind Industry Prospectus – ORE (catapult.org.uk)

Chinn (2014). The UK Offshore Wind Supply Chain: A Review of Opportunities and Barriers. Available at: Chinn-Review-Supply-Chain.pdf (windenergynetwork.co.uk)

Energy Sector Management Assistance Program (ESMAP) (2019). Going Global: Expanding Offshore Wind To Emerging Markets. Available at: Going Global: Expanding Offshore Wind To Emerging Markets | ESMAP

International Energy Agency (IEA) (2019). Offshore Wind Outlook 2019. Available at: Offshore Wind Outlook 2019 – Analysis - IEA

International Energy Agency (IEA) (2022): World Energy Outlook – 2022. Available: World Energy Outlook 2022 (windows.net)

International Energy Agency (IEA) (2023): Monthly Electricity Statistics. Available at: Monthly Electricity Statistics - Data product - IEA – last accessed on 06/02/2023

IRENA (2022). Renewable Power Generation Costs in 2021. International Renewable Energy Agency, Abu Dhabi

Owens, B. N. (2019). Chapter 11 (pp.159-173). In: *The Wind Power Story: A Century of Innovation that Reshaped the Global Energy Landscape*. John Wiley & Sons.

Port Esbjerg (2022). Wind. Available at: Wind | Port of Esbjerg (portesbjerg.dk)

QBIS (2020). Socioeconomic impacts of offshore wind. Available at: Offshore wind farms | qbis (qbis-consulting.com)

Renewable Consulting Group (RNG) (2023): Global offshore wind soars in face of energy market vulnerability. Available: Global offshore wind soars in face of energy market vulnerability - RCG (thinkrcg.com)

State of Green (2014). Energy Science World. Available at: Energy Science World (stateofgreen.com)

State of Green (2021). Europe's largest PtX facility to be built in Esbjerg, Denmark. Available at: Europe's largest PtX facility to be built in Esbjerg, Denmark (stateofgreen.com)

State of Green (2022). Port of Esbjerg: World's largest base port for offshore wind activities. Available at: Port of Esbjerg: World's largest base port for offshore wind activities (stateofgreen.com)

The Crown Estate and the Offshore Renewable Energy Catapult (ORE) (2019). Guide to an offshore wind farm. Available: Guide to an Offshore Wind Farm – ORE (catapult.org.uk)

Vestas (2022). Fist Quarter 2022 – Vestas Wind Systems A/S. Available at: Vestas – Interim Financial Report, First Quarter 2022

Wind Europe (2020). Offshore Wind in Europe, Key trends and statistics 2019. Available at: WindEurope-Annual-Offshore-Statistics-2019.pdf

Appendices

Appendix A The E3ME model

E3ME is a computer-based model of the world's economic and energy systems, and the environment. It was originally developed through the European Commission's research framework programmes and is now widely used for policy assessment, forecasting and research purposes. E3ME was used to assess the European Commission's 2030 and 2050 emission reduction targets. It was also recently used by the World Bank to model different pathways to carbon neutrality in China.

The full model manual is available at the model website www.e3me.com.

A.1 Main purpose

E3ME has been designed to assess the impacts of climate change mitigation policy on the economy and the labour market. The basic model structure links the economy to the energy system to ensure consistency between economic and physical indicators.

E3ME can provide comprehensive analysis of policies in each of its 71 regions:

- direct impacts, for example reduction in energy demand and emissions, fuel switching and renewable energy
- secondary effects, for example on fuel suppliers, energy prices and competitiveness impacts
- rebound effects of energy and materials consumption from lower prices, spending on energy or other economic activities
- overall macroeconomic impacts; on employment and the economy at a high level of sectoral detail and (where data allow) household income group

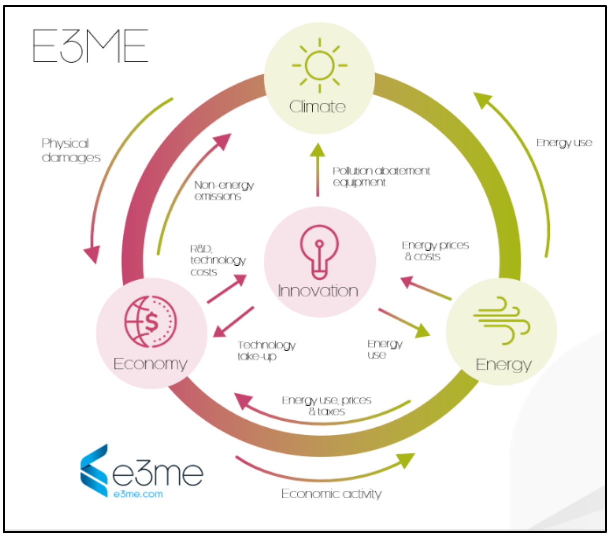
A.2 Theoretical underpinnings

E3ME is designed primarily as an empirical tool. It draws on the Cambridge (UK) tradition of macroeconomics, supplemented by more recent applications of complexity theory to economics. The key properties of the model include recognition of fundamental uncertainty, possible non-rational behaviour and market structures determined by the available data.

The model has been shaped to meet the needs of policy makers, both in terms of the types of scenarios assessed (e.g. a wide range of market-based and regulatory climate policies) and output indicators (e.g. detailed employment, unemployment and measures of inequality).

E3ME incorporates bottom-up technology models of four major energy-using sectors[37] (power, personal transportation, steel and household heating). These models follow the 'S-shaped' diffusion paths of new technologies as they gain market acceptance and incorporate cost reductions through learning rates.

[37] Called the FTT (Future Technology Transformation) models. See e.g. Mercure et al (2014) for details.



E3ME is often compared to Computable General Equilibrium (CGE) models. In many ways the modelling approaches are similar; they are used to answer similar questions and use similar inputs and outputs. However, there are important underlying differences between the modelling approaches.

In a typical CGE framework, optimising behaviour is assumed, output is determined by supply-side constraints and prices adjust fully so that all the available capacity is used. In E3ME the determination of output comes from the demand side of the economy and it is possible to have spare economic capacity. It is not assumed that prices always adjust to market clearing levels.

The differences have important practical implications, because they mean that in E3ME regulation and other policies could potentially lead to increases in output, if they are able to draw upon the available spare economic capacity. The role of the financial sector is key (see the model manual for further details).

The econometric specification of E3ME gives the model a strong empirical grounding. E3ME uses a system of error correction, allowing short-term dynamic (or transition) outcomes, moving towards a long-term trend. The dynamic specification is important when considering short and medium-term analysis (e.g. in Covid-19 recovery).

A.3 Basic structure and data used

The structure of E3ME is based on the system of national accounts, with further linkages to energy demand and environmental emissions. The labour market is also covered in detail, including both voluntary and involuntary unemployment. The other econometrically estimated equations cover the components of GDP (consumption, investment, international trade), prices, energy demand and materials demand. Each equation set is disaggregated by region and by sector.

E3ME's historical database covers the period 1970-2018 and the model projects forward annually to 2050. Apart from the IEA energy balances and prices, the model's data is based entirely on freely available information from international sources and national statistical agencies. Gaps in the data are estimated using customised software algorithms.

A.4 The main dimensions of E3ME are:

- 71 regions – all major world economies, the EU28 and candidate countries plus other countries' economies grouped
- 44 industry sectors, based on standard international classifications
- 28 categories of household expenditure
- 25 different users of 12 different fuel types

- 22 power generation technologies
- 14 types of air-borne emission (where data are available) including the 6 GHG's monitored under the Kyoto Protocol

Appendix B Methodology for regional distribution of manufacturing employment

Unlike the construction and electricity sectors, employment in manufacturing may not be located in the same state or region as the offshore wind capacity. Therefore, the distribution of this employment follows a different methodology than employment in the other two sectors. Manufacturing employment is distributed to states in two stages. In the first stage, we calculate the number of people employed in manufacturing demanded in each state in each year. We do this based on each state's share of the nation's total capacity. In the second stage, we distribute these demanded roles to states based on each state's 1) relative specialization in relevant manufacturing sectors[38] and 2) distance from the state demanding the employment. Manufacturing employment that is demanded in state *i* moves to state *j* in year *t* based on the following calculation:

$$e_{i\to j,t} = m_{i,t} * \frac{\left(\frac{p_j}{d_{ij}}\right)}{\sum_{j=1}^{j=48} \frac{p_j}{d_{ij}}}$$

Where $e_{i\to j}$ is the manufacturing employment supported by offshore wind capacity in state *i* that is filled by employment in state *j*. In other words, it is the employment in state *j* supported by demand for offshore wind supply chain components in state *i* in a given year. m_i is the total manufacturing employment supported by offshore wind projects in state *i*. This measure is calculated by allocating the national manufacturing employment to states based on each state's share of total offshore wind capacity in each year. p_j is state *j*'s percent of the total manufacturing employment in 2021. This variable captures each state's relative specialization in manufacturing.

d_{ij} is the Euclidian distance between the centroids of states *i* and *j*. The distance variable always appears in the denominator of the equation, so that when states *i* and *j* are farther apart, less employment will move from state *i* to *j*. The large size of many offshore wind supply chain components, combined with the existing tendency for manufacturing facilities to be located very nearby the port serving the wind farm (and often right in the port), indicate that distance is an important factor of supply chain location. If *state i* = *state j*, then distance is set to 1, so allocation is based on p_j, the state's relative specialization in manufacturing.

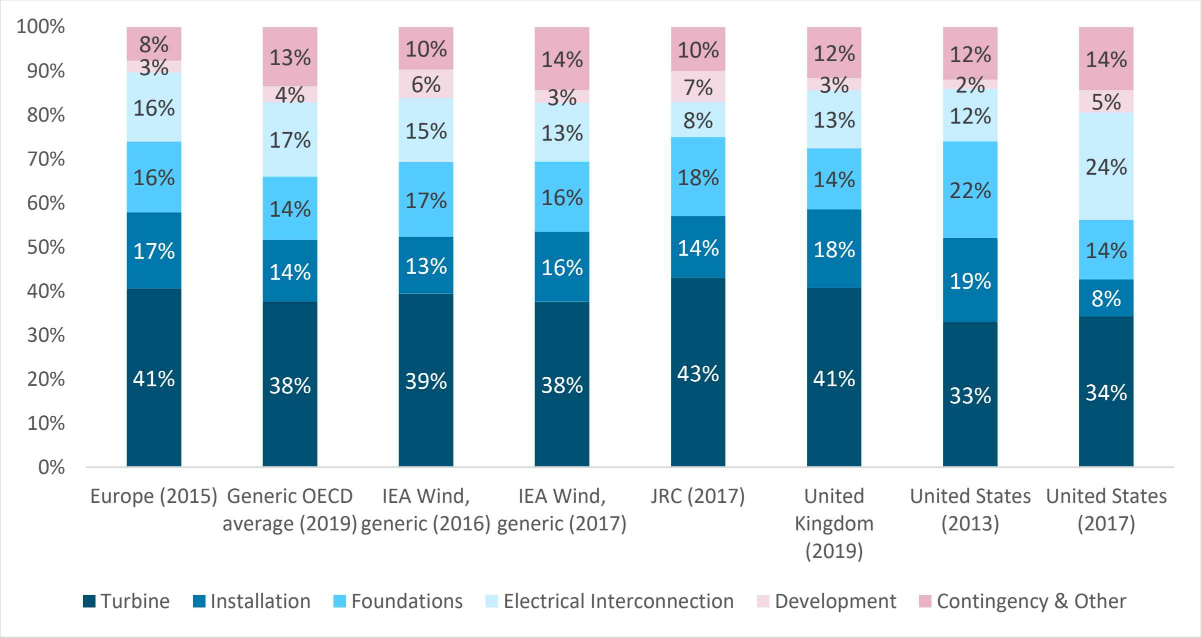
The relative score determined by $\left(\frac{p_j}{d_{ij}}\right)$ is then divided by the sum of all states' relative scores,[39] such that the ratio sums to 100 percent for each *state i* when aggregating across all *state js*. Because distance and manufacturing share (taken from 2021 and assumed to be constant) are not time dependent, this ratio is constant for all years. Thus, the share of the manufacturing employment demanded in *state i* that are filled in *state j* is constant over time.

[38] We use 2021 US Census ACS data on employment by industry for the civilian employed population aged 16 and over. Relevant manufacturing sectors include 1) metal and metal products, 2) machinery, and 3) electrical equipment, appliances, and components.

[39] We sum over the 48 states in the continental US. Alaska and Hawaii are not included.

Appendix C Supplementary third-party data

Figure 25 Total installed cost breakdowns of different offshore wind farm in different countries/regions, in different years



Source: IRENA, 2022 (Figure 4.7.)
Note: As many of the financial data are confidential, the reported values are rather estimates and not fully comparable with each other.

Table 8 Workloads according to professions (in full time equivalents, FTE)

	Development	Turbine	Balance of plant	Installation	O&M	Decom-missioning	Total
Operators	7	0	0	155	177	248	587
Ship crews	82	0	0	726	443	207	1457
Workers and technicians	6	1479	1005	2	885	216	3593
Engineers	76	134	143	37	413	130	934
Outdoor experts	64	402	244	20	333	75	1137
Indoor experts	88	803	427	20	405	0	1743
Total	323	2818	1818	959	2656	876	9451

Source: QBIS, 2020, p. 20