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Key Drivers for Offshore Wind Deployment in the Western United States

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ABSTRACT

The western coast of the United States has abundant natural resources, including wind, sun, and water. Despite strong ocean winds, offshore wind energy (OSW) in the Western United States is in the early stages of technology development due largely to the deep water off the coast, which requires floating platforms rather than fixed-bottom turbines. Floating OSW increases the technical difficulty of installation and thus the cost relative to both fixed-bottom OSW and land-based turbines. OSW is a potential generation option to help meet increasing demand on the west coast of the United States because it likely has fewer land-use conflicts than other technologies and complements sources in the existing electricity supply by providing energy during times of high system stress. This paper examines the possible drivers and barriers to OSW deployment on the West Coast using the National Laboratory of the Rockies' state-of-the-art capacity expansion model and the Regional Energy Deployment System (ReEDS) model. We use ReEDS to explore a multitude of future scenarios looking at key drivers for OSW deployment, including variations on the cost of OSW, electricity demand growth, and the availability of competing technologies to examine the factors that may play a role in OSW growth. Assuming coastal state policies such as renewable portfolio and clean energy standards remain in place, we find that OSW can play a role in meeting electricity demand and provide energy during stressful grid conditions and find that deployment from the least-cost investment model ranges from 7.6 to 38 GW by 2045.

1 | Introduction

The western coast of the United States has abundant natural resources, including wind, sun, geothermal, and water [1–4]. Despite strong ocean winds, offshore wind energy (OSW) in the Western United States is in the early stages of technology development. The deep water off the western coast requires floating turbines, which impose additional costs and challenges relative to fixed-bottom turbines [5, 6]. Among the technological challenges of floating OSW are sophisticated mooring configurations to ensure turbines are secure, dynamic transmission cables, and substation design required for deep water [7–10]. Another key limitation is the size and availability of port infrastructure required for construction and assembly of OSW generation platforms [11, 12]. Manufacturing, operations, and maintenance represent the largest share of total capital cost components, while installation activities account for roughly 15% of that total [13, 14]. Furthermore, there are limited onshore interconnection points where offshore generation could connect to the wider network, due in part to challenging terrain for transmission expansion and dispersed load pockets along the western coast [15]. Some possible benefits, such as resilience and coastal network reinforcement, may be difficult to quantify and thus can also be a barrier to deployment if the corresponding value is not reflected in cost–benefit analysis [15].

Despite these difficulties, OSW has many possible benefits, including increasing local jobs, keeping up with load growth, using domestic resources, and avoiding potentially problematic electricity sector infrastructure onshore [2, 16–18]. Previous analysis in the Western United States has found that production cost benefits of OSW development outweigh the costs of both offshore transmission development and necessary costs for onshore system reinforcements [5]. In addition, other studies have shown that the relatively high capacity factor and seasonal availability of OSW may provide a complement to other resources on the grid [19, 20].

Globally, offshore wind installed capacity increased from 7.9 gigawatts (GW) in 2014 to 67 GW in 2023, with 47% of this capacity located in China. The next four top countries in terms of installed capacity are the United Kingdom (22%), Germany (12%), the Netherlands (8%), and Denmark (3%; [21]). However, of the 67 GW of installed capacity around the world, only 240 megawatts (MW) comes from floating projects as of 2023 [22]. This is due mainly to the technical difficulty and the elevated cost of floating OSW, which can be up to twice the cost of fixed-bottom OSW [23]. Floating OSW is not expected to be at the commercialized stage until at least 2030, with possible reductions in cost through 2050 if early-adoption projects serve to de-risk larger development [22, 24–26]. Methods to scale up global floating offshore wind farm installations are currently being investigated and remain uncertain [14, 27].

In the United States, OSW resources are mainly found off the East and West Coasts, and technical pathways for OSW have been examined in previous work [28, 29]. The East Coast has a mix of fixed and floating potential, but the West Coast resources are mainly floating (Figure 1). As such, there has been limited proposed development of OSW in the West [30]. However, the three states along the West Coast (California, Oregon, and Washington) have renewable energy targets and

FIGURE 1 | Offshore wind speeds in the US waters, split by technology type.

emissions reductions goals that could drive OSW deployment. The California Energy Commission has established a strategic plan of reaching 5 GW of offshore wind by 2030 and 25 GW by 2045 [31]. Although Oregon and Washington do not have explicit OSW deployment plans, both states have substantial emissions reduction goals, each aiming to reach net-zero emissions by 2040 and 2050, respectively [32, 33].

This study aims to extend previous work by analyzing the key drivers influencing the possible deployment of OSW along the US West Coast, using a state-of-the-art capacity expansion model [5]. In addition, we employ updated technology cost and performance metrics and include extensive model updates to expand the scope of the previous effort [24, 34]. The goal of the previous report was to comprehensively evaluate *one* future optimistic scenario for OSW buildout in the West, which totaled 33 GW by 2050. By comparison, our approach for this analysis leverages the capacity expansion model's flexible ability to simulate a *range* of dynamic scenarios—including load growth, OSW technology cost evolution, and the availability of competing technologies to explore the complex interactions shaping OSW viability. This comprehensive framework allows us to assess the interplay between these factors individually and in combination, offering a nuanced understanding of the conditions under which OSW might integrate within a diversified energy system.

2 | Methodology and Data

To examine the costs and drivers of potential OSW deployment in the West, we rely on Regional Energy Deployment System (ReEDS), a capacity expansion model developed by the National Laboratory of the Rockies (NLR; https://github.com/ReEDS-Model/ReEDS). This section describes the model, underlying data, and OSW-specific resource specifications.

2.1 | Model Description

NLR's capacity expansion model, ReEDS, simulates planning and operational decisions of the electric power system and has been used for several studies exploring future evolution of the grid [35, 36] and for studies of offshore wind resources [5, 37–39]. ReEDS takes in a range of built-in inputs, including load growth forecasts, fuel price trajectories, technology cost and performance projections, transmission cost, and state and federal policies. It then does least-cost optimization for generation, transmission, and storage buildout and operation, subject to a comprehensive set of constraints. The outputs include the optimal, least-cost mix of generation, transmission, and storage resources to meet future demand [40].

In the configuration used for this study, ReEDS simulates capacity expansion and grid service requirements for 35 balancing regions, each of which is an aggregation of counties where demand (load) equals supply, accounting for transfers between regions on available transmission capacity. In this study, we limit ReEDS focus to the area of the Western Interconnection, whose coastal states include California, Oregon, and Washington as shown in Figure A-1 in the Supporting Information Appendix A. These modeled regions respect state boundaries, facilitating the tracking of state energy regulations and incentives.

In ReEDS, renewable energy resources are represented with high temporal and spatial resolution. The raw inputs for renewable sources (utility-scale photovoltaics [PV], distributed photovoltaics [dPV], land-based wind, and OSW) come from the reV Model, which accounts for hourly weather data, resource technical features, and land-use exclusions [9, 41]. reV uses 11.8-kilometer (km) by 11.8-km resolution for land-based wind and solar and 15.8-km by 15.8-km resolution for OSW, providing ReEDS with site-level raw inputs for detailed transmission costs such as interarray, export cable, spur line, substation connection, and reinforcement costs (where applicable). For OSW, reV provides site-varying capital costs that consider difference in water depth, technological requirements, and regional differences [42, 43].

A unique aspect of ReEDS is that it iterates with a resource adequacy model that determines whether a potential system buildout meets certain adequacy criteria in terms of unserved energy by considering "stress periods" [34]. During the days classified as stress periods, which contain the hours with the highest risk of shortfall, dispatch is directly considered to ensure the load (plus some planning reserve margin) can still be met with a reasonable amount of expected unserved energy. ReEDS accounts for multiple weather years by considering the historical years of 2007–2013 as possible stress periods. Any day within these 7 years may be chosen, and the chosen days vary slightly by solve year. The model chooses "seed" stress days on the first iteration, which cover the lowest solar and wind day of the 7 years, as well as peak load day for each region. Many tend to be in late summer when cooling demand is the highest in the Southwest United States given the highest load and thus risk of unserved energy. Some of these stress days also occur in the winter, considering parts of the West also see increased heating load during the colder months. If the resource adequacy target is not reached for a given buildout, the process is repeated with additional stress periods. We use this capability of ReEDS to assess the resource adequacy impacts of various technologies for comparison with OSW.

Despite its detailed representation of the power system, ReEDS models a simplified version of the highly complex grid, leading to several caveats. It adopts a least-cost, systemwide optimization approach that does not necessarily reflect the perspectives and constraints of individual decision makers, such as utilities. Although it offers high spatial resolution, it lacks the detail to model individual power plants, transmission lines, and operational behaviors such as ramp rates. Temporal resolution is limited to, in this case, 40 representative days with 3-h resolution across multiple historic weather years, with 5-year solve steps. Each 5-year step has no foresight, preventing the model from fully accounting for future market or policy changes. ReEDS does not explicitly simulate manufacturing or supply chains, assuming technology availability without fully reflecting all deployment limits or bottlenecks. In addition, ReEDS focuses solely on the power sector within its defined geographic scope, without dynamically representing competing resource uses or broader energy-economy system interactions. Despite these limitations, we consider ReEDS a valuable tool for analyzing long-term capacity expansion decades into the future.

2.2 | Floating Offshore Wind Resource

For consideration of OSW resource, we use the reference access case resource availability [9]. The availability of fixed-bottom OSW locations off the West Coast is limited to less than 1 GW available in ReEDS, whereas for this reference access case, the West has a technical potential of approximately 90 GW of *floating* OSW capacity—which represents 355 terawatt-hours (TWh) of annual energy production for the reference weather year 2012. For comparison, total retail sales of electricity in 2023 for the Western United States were around 690 TWh [44]. The West Coast OSW sites range in capacity factor from 26.5% to 58.4%, with an average capacity factor of 45.5% across all sites.

Of course, not all the technically possible OSW sites are economically feasible. The ReEDS model incorporates availability and quality of resource to represent a unique site-by-site investment cost. Figure 2 shows a site-by-site distribution of all-in OSW levelized cost of energy (LCOE) where costs are normalized by total gigawatt-hour (GWh) production for each site for the year 2035 [23]. Figure 2 illustrates that the lowest LCOE sites are in northern California and southern Oregon and that the highest costs occur both in the far north and far south. Note that some areas are excluded for development based on criteria for the reference access case, including technology depth limitations, military areas, protected zones, and shipping lanes [43]. Figure A-2 in the Supporting Information Appendix A shows the supply curve of available OSW sites for each of the three western coastal states.

2.3 | Characterization of Key Inputs

The potential evolution of western offshore wind depends on the evolution of the power system as a whole. The power system modeling includes the following key assumptions:

- Annual Technology Baseline (ATB) 2024: NLR's ATB publishes updated cost breakdowns and performance metrics for all generation and storage technologies on an annual basis. We adopt the "Moderate" or midline cost projections for all generation and storage technologies. For floating OSW, however, we consider the full range of ATB costs ("Conservative OSW Cost," "Moderate OSW Cost," and "Advanced OSW Cost") shown for a representative site in California in Figure 3 [24].

$$\text{MWh} = \text{megawatt} - \text{hour}$$

- Western interconnection only: For computational tractability and to focus on the West Coast for this study, we configure the capacity expansion model to consider only the footprint of the Western Interconnection for all scenarios.
- State electricity policy: For all cases, we capture existing policies in the West, which includes renewable portfolio standards (RPS) and clean energy standards (CES) for California, Washington, and Oregon [45]. Clean energy fractions are different for each state, with Washington specifying 100% by 2045, Oregon specifying 100% by 2040, and California specifying 100% by 2045 [40, 45–47]. In addition to California's RPS and CES, the state has also committed to reducing its emissions by 85% relative to 1990 levels by 2045,

FIGURE 2 | Offshore wind levelized cost of energy (LCOE) distribution for the West Coast. This represents 2035 costs from the moderate cost trajectory from NLR's Annual Technology Baseline (ATB) 2024 [24]. *Note:* The map shows only sites considered under the reference access case from [43].

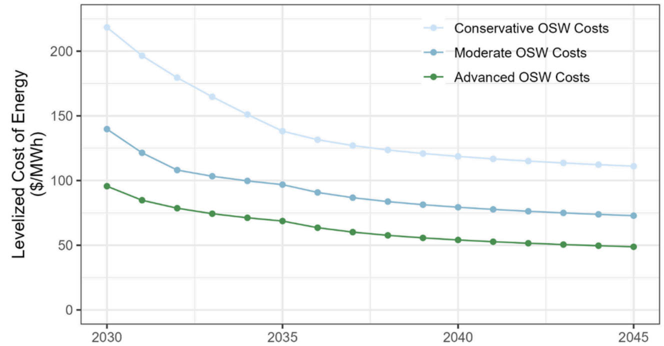


FIGURE 3 | Levelized cost of energy projections from the Annual Technology Baseline under advanced, moderate, and conservative assumptions on cost trajectory for floating OSW technology at a representative site in northern California near Humboldt County.

which means the state's electricity sector must achieve an emissions rate of less than 15 million metric tons (MMT) by 2045, including imports.

- Offshore wind requirement: The default assumption in ReEDS is consistent with CA AB525 and the subsequent decision by the California Public Utilities Commission to deploy 7.6 GW of OSW by 2037 [48]. Because our ReEDS formulation uses 5-year increments, this capacity is enforced in the year 2040 [49]. Note that the California Energy Commission's (CEC's) Strategic Plan for OSW (discussed in the Introduction) is not imposed as a hard target because it is not established in legislation.
- Demand growth: Although electricity demand has been relatively stagnant over the past decades in the United States, recent growth in consumption because of data centers, advanced computing, and electric vehicles is poised to continue [50]. However, the extent to which this demand increase will persist in the future is uncertain. We examine the sensitivity to three different load growth trajectories. In the lowest case, load grows to nearly 1300 TWh for the West in 2050, which corresponds to a compound annual growth rate (CAGR) of 2.31% between 2025 and 2050, shown in Figure 4 as the “Low Load Growth.” The medium and high growth cases correspond to CAGR of 2.64% and 3.36%, respectively, for the West under the same time frame [51]. The low load growth case is the ReEDS default and most consistent with California's demand outlook, making it the base case setting [52, 53].
- Siting for land-based renewable energy sources: We examined various siting scenarios for land-based wind and utility PV technologies because there is uncertainty in siting restrictions and barriers [43, 54]. Our base case assumes limited siting for land-based PV and wind; however, we also examine a scenario with reference access siting scenarios. The limited siting scenario has a technical potential for the Western Interconnection footprint of 11.39 TW of utility-scale PV and 1.98 TW land-based wind capacity, whereas the reference access case has 25.21 TW of utility-scale solar and 3.44 TW of land-based wind. Thus, the reference access case opens up roughly double the technically potential solar sites and not quite double the technically potential land-based wind sites.

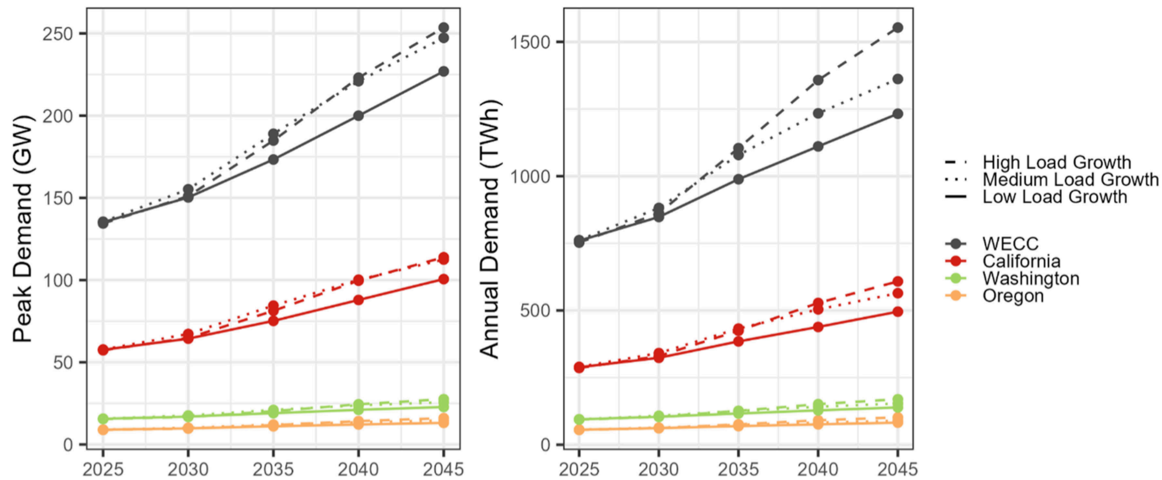


FIGURE 4 | Assumed load growth for the footprint of the Western Interconnection (Western Electricity Coordinating Council [WECC]) and the western coastal states assumed through 2050 for three load growth scenarios.

- Competing technology availability: We look at the interplay of the availability of various technologies by toggling on and off the ability to build various technologies that have seen limited recent deployment, such as carbon capture and storage (CCS), large-scale electrolyzers, hydrogen-fired combustion turbines (H2-CTs), and pumped storage hydro (PSH) because the cost, performance, and deployment potential for these technologies are uncertain, much like it is for OSW. In our base case, we disallow deployment of CCS, consistent with recent OSW integration studies [5, 37] and examine the sensitivity to availability of other technologies in a scenario.
- Hydrogen availability for use in hydrogen-fired combustion turbines and fuel cells: ReEDS is a power sector-only model. However, ignoring the evolution of other energy sectors can miss key interplays between electricity and fuels such as hydrogen. So, we consider hydrogen demand for the electricity sector endogenously (within the model). If hydrogen is chosen as a power system fuel, hydrogen must also be produced either via electrolyzers using electricity generation or from natural gas via steam methane reforming.[1]
- Any other assumptions not listed here are consistent with Standard Scenarios 2024 Mid Case[2,3] [57].

3 | Results and Analysis

3.1 | Evolution of the Power System for the Base Case Through 2045

This section focuses on the results of the base case scenario, whose assumptions are outlined in Table 1 and discussed in more detail in the previous section.

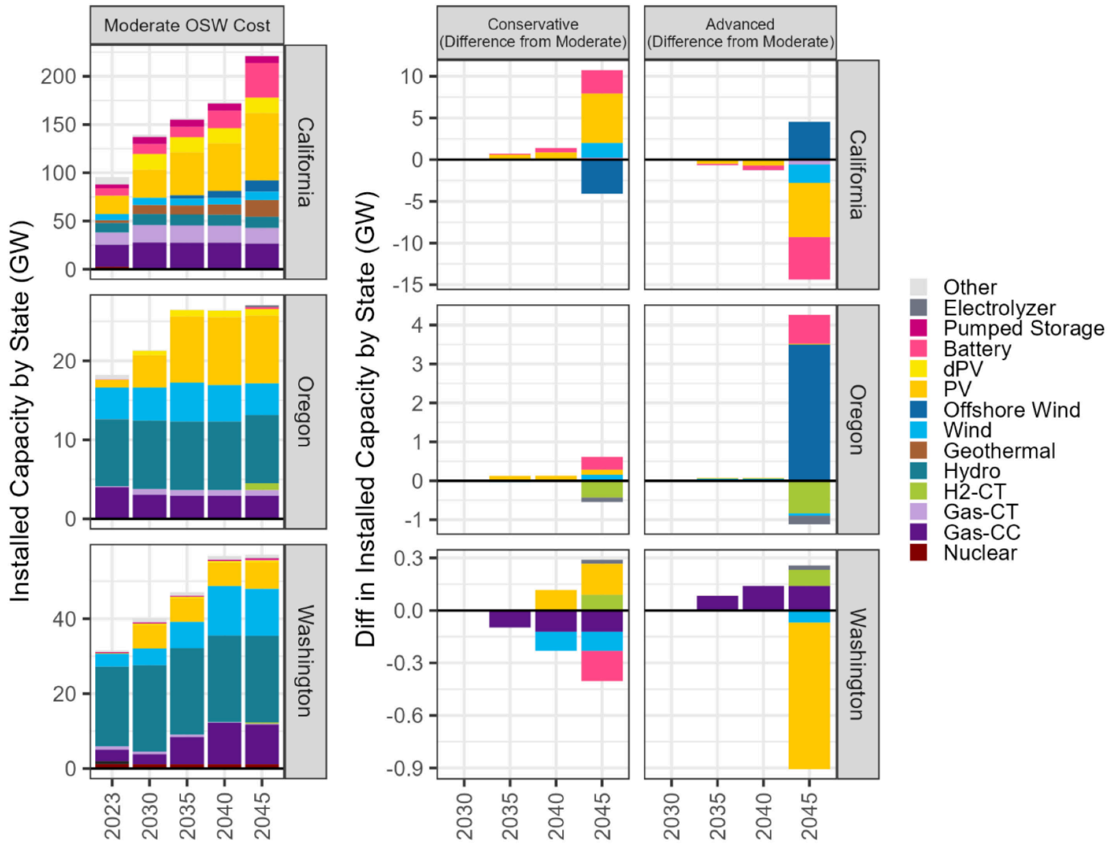
Figure 5 illustrates the total generation capacity by coastal state (California, Oregon, and Washington) for the base case. The first panel shows the system evolution using the Moderate OSW costs and illustrates that there is strong growth in storage in California and solar in all states through 2045 because of the renewable energy targets of the coastal states along with strong

TABLE 1 | The ReEDS assumption for the base case.

Assumption	Description
Load growth	Low load growth
Land-based wind and solar siting restriction	Limited siting
Technology availability	No CCS
Spatial scope	Western interconnection (Western Electricity Coordinating Council [WECC])
OSW cost	Advanced, moderate, and conservative
Cost and performance of other technologies	Moderate

cost competitiveness. These states also see growth in geothermal, gas combustion turbine (gas-CT), and hydrogen-fueled combustion turbine (H2-CT) technologies. In addition, future years continue to use existing capacity from hydropower and gas combined-cycle generation (gas-CC) and combustion turbine (gas-CT).

The first panel (moderate OSW costs) shows 11.7 GW of OSW installed in California by 2045 (where 7.6 GW by 2040 is set as a minimum target in the model). On different *y*-axes, the second panel illustrates the changes in installed capacity when using the conservative OSW costs and only the 7.6 GW of required OSW remains. The OSW is mostly replaced by solar and a small amount of storage. The third panel shows the changes in installed capacity under the advanced OSW cost scenario, which installs nearly 20 GW of OSW (16.3 GW in California and 3.6 GW in Oregon). Under the advanced OSW cost scenario, OSW replaces a combination of solar, storage, and H2-CT capacity. In the model, energy and capacity are exchanged between regions through transmission. So, OSW built in Oregon may be providing energy and capacity to California and vice versa. This also explains why Washington, which has



OSW Deployment in 2045 (GW)	California	Oregon	Washington	Total
Conservative OSW costs	7.6	0	0	7.6
Moderate OSW costs	11.7	0	0	11.7
Advanced OSW costs	16.3	3.5	0	19.7

FIGURE 5 | Installed capacity for each coastal state through 2045 for a base case scenario with low assumed load growth. *Note:* The different *y*-axis scales. The year 2023 is included in the middle panel for comparison with currently installed capacity. These data are taken from reported data rather than ReEDS [58].

no OSW capacity, changes slightly under advanced OSW cost because some OSW from the other coastal states is imported to serve Washington load.

What role does OSW play in the scope of the wider electricity system? We use the iterative ReEDS methodology to incorporate resource adequacy metrics to compare OSW with other technologies. To that end, Figure 6 shows the capacity factor of variously deployed technologies during three types of periods for 2045 for the base case. The first (open circle, labeled "rep-mean") is the average capacity factor during representative days. These are the conditions that are most representative of standard operations, analogous to average annual capacity factor. The other two shapes show capacity factor during a subset of the stress periods identified to have the highest risk (The selected "stress period" days for the base case are illustrated in Figure A-3 in the Supporting Information Appendix A). For OSW, the capacity factor during the five highest and single highest load hour(s) sampled in the stress periods is higher than the representative capacity factor, indicating increased availability during those times. In contrast, land-based wind shows reduced capacity factor during the riskiest hours. Solar is slightly more variable but generally shows lower capacity than OSW as well. This capacity factor approximation can be used to assign a resource's "capacity credit" or contribution to adequacy targets [59–61]. Generally, OSW has been shown to have higher capacity credit or firm capacity relative to other variable generation resources, and this analysis provides another example [19, 20, 62]. In this example, Figure 6 illustrates solar and wind both have capacity factor near the "rep-mean" (or lower) for the stress hours, whereas OSW has higher than "rep-mean" capacity factor during the stress hours. In fact, the capacity factor of OSW during stress times approaches that of the more flexible technologies (e.g., gas-CT and gas-CC).

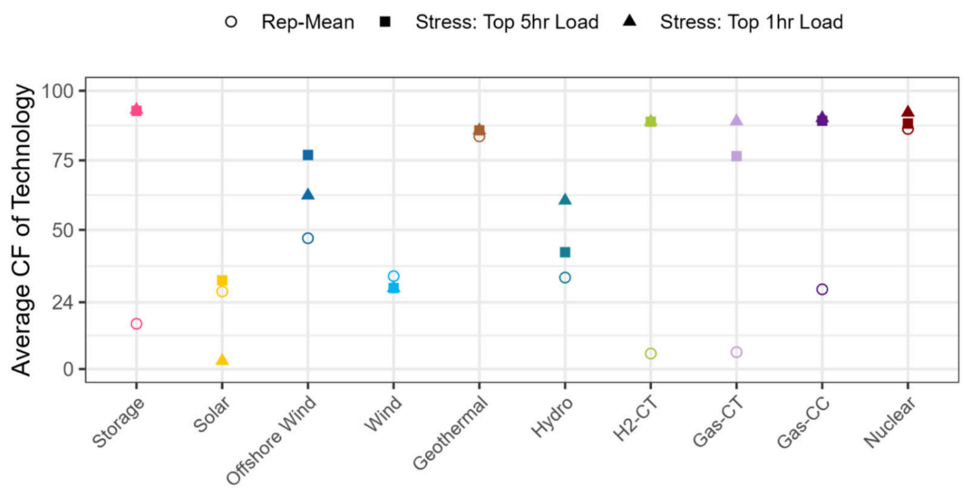


FIGURE 6 | Average modeled capacity factor (CF) during three types of time periods in 2045 for the base case: (1) rep-mean, the average during representative periods (typical days); (2) the top 5 load hours occurring in identified stress periods; and (3) during the single top load-hour occurring in a stress period. *Note:* Some generation categories have been removed or aggregated in the plot for clarity.

3.2 | Impact of Electrification on Offshore Wind Deployment

The base case discussed in Section 3.1 shows up to approximately 20 GW of OSW deployment under the advanced trajectory for the reduction of OSW capital costs. This section further examines the impact of load growth on potential OSW deployment. We consider each of the three load growth trajectories (low load growth, medium load growth, and high load growth from Figure 4) for the three levels of assumed OSW technology costs (conservative OSW cost, moderate OSW cost, and advanced OSW cost) for a total of nine scenarios.

Figure 7 shows the OSW deployment on the West Coast from ReEDS for these various scenarios. As discussed above, the minimum amount of OSW deployment is 7.6 GW by 2037 (enforced in 2040) due to coastal state policy. The results of Figure 7 indicate that only the minimum amount of offshore wind is deployed in the scenarios with the conservative OSW cost technology assumptions under the low and medium load growth assumptions, with 2 GW more deployed in the high load growth assumption. Under moderate and advanced ATB costs, deployment is higher than the requirement after 2040 in *all* scenarios. The high load growth scenario increases the expected OSW deployment because additional capacity and generation are needed in those cases to keep up with growing demand. Some of this generation capacity includes OSW. Overall, the various scenarios depicted in Figure 7 indicate potential OSW deployment between 7.6 and 23.3 GW on the West Coast by 2045. If floating OSW costs remain high (the conservative OSW cost case), the only deployment will likely result from mandates. However, the results show that more OSW growth might be expected if OSW costs align with either moderate or advanced OSW cost in the coming decades, under high load growth scenarios, and especially with combined lowest OSW costs and load growth.

Figure 8 illustrates the final 2045 installed capacity for the entire West across all nine scenarios compared to the 2023 generation fleet on the far left. The existing state policies and increasingly competitive costs of wind, solar, and batteries in the West lead

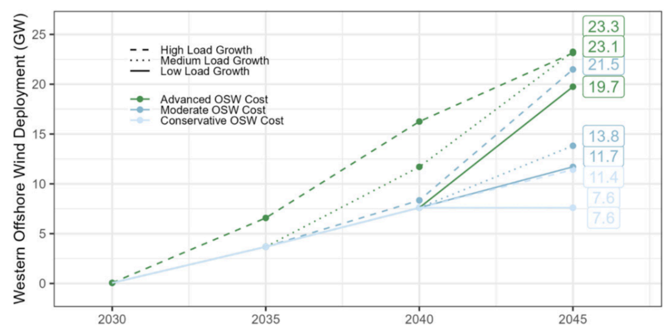


FIGURE 7 | Offshore wind deployment in the West for various load growth and OSW cost assumptions scenarios through 2045.

to sustained growth in those technology categories under all cases relative to today. Cases with higher load growth require more nameplate (GW) capacity to meet the system needs, which can lead to increased OSW as discussed above. The additional nameplate capacity required to meet the increased load growth is shown on the bottom panel. The bottom panel indicates that other generation technologies are more impacted by load growth. In all cases, a substantial amount of wind, solar, and H2-CTs helps provide extra capacity in the high load growth cases, with gas-CC and OSW also helping meet the need. In turn, the hydrogen fuel for H2-CTs must also be produced via electrolyzer, leading to higher generation requirements as well.

3.3 | Impact of the Availability and Cost of Competing Technologies

There is much uncertainty about the future cost of generation technologies. For example, solar PV, land-based wind, and battery technologies have experienced dramatic reductions in capital costs over the past couple of decades [63, 64]. Many technologies (including floating OSW, geothermal, concentrating solar power, CCS, electrolyzers, and hydrogen fuel cells) still have great uncertainty in their cost competitiveness in the coming decades [24]. Because of these uncertainties, we also

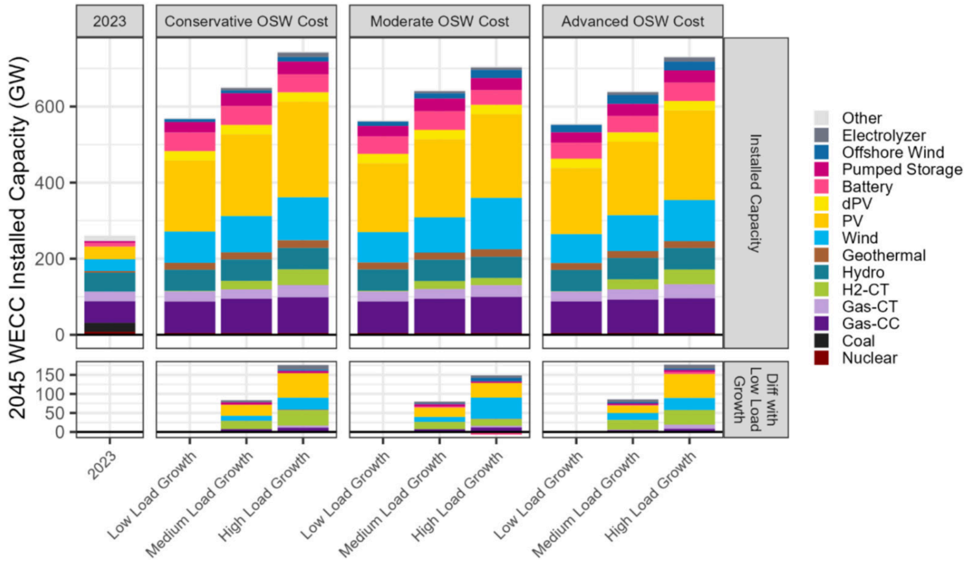


FIGURE 8 | Technologies deployed in the year 2045 in the West by scenario "other" category includes concentrating solar power (CSP), net imports from Canada, biopower, and steam plants. The 2023 panel indicates reported data, not ReEDS results [58].

TABLE 2 | Description of the technology availability scenarios evaluated in this section.

Scenario	Description
Base	No CCS; limited siting options for land-based wind and PV
No nascent tech	No CCS, no H2-CT, no new SMRs, no electrolyzers, reference siting options for land-based wind and PV
Tech renaissance	No restriction on technologies; reference siting options for land-based wind and PV

examine several sensitivities that vary the availability of alternative technologies. For our base case (the configuration considered in Sections 3.1 and 3.2), we assumed no investment in CCS technologies and limited siting availability for land-based wind and solar. However, given the uncertainty in the availability of new technologies, we also consider two additional scenarios, shown in Table 2. The second scenario disallows nascent technologies besides OSW, including CCS, H2-CT technology, small modular nuclear reactors (SMRs), and electrolyzer and steam methane reforming for hydrogen production. In addition, we consider a "technology renaissance" scenario, which allows any technology to be deployed.

Figure 9 shows each of the three technology scenarios combined with three load growth and OSW cost trajectories considered in the previous section. The left panel shows the same scenarios as Figure 7 for comparison. The middle panel restricts technologies under the no nascent tech scenario and shows lower OSW deployment across all three cost trajectories. The tech renaissance, which allows all technologies, shows even lower OSW deployment. In both cases, trade-offs with other technologies are occurring but with different mechanisms.

Figure 10 shows the 2045 installed capacity for the West for the no nascent tech scenario along with a comparison to the base case in the bottom panel. This plot shows the technology restrictions in the no nascent tech case largely impact technologies other than OSW. These scenarios indicate wind, solar, and storage replacing the H2-CT/electrolyzer technology from the base case. In some cases, the loss of H2-CT/electrolyzer technologies also results in slightly less OSW capacity, indicating that the increased requirement for electricity to create H2 fuel was encouraging some OSW deployment. Because the no nascent tech case also removed the siting restrictions of land-based wind and solar energy, we see more growth in those technologies as well. In addition to the cases shown in Figure 9, we also included a variation on these scenarios along with the no nascent tech and tech renaissance scenarios and ended with *slightly* more OSW deployment—anywhere from 0 to 2 GW extra deployment depending on scenario. This indicates that OSW deployment is more sensitive to the availability of *other* competing technologies rather than land-based renewables siting under these conditions. We also note under high load growth that some growth in nuclear capacity is also shown; this seems to be a slight replacement for OSW because slightly less OSW is generally shown under the no nascent tech assumptions, though not exclusively.

Likewise, Figure 11 shows the 2045 installed capacity for the tech renaissance scenario, along with a comparison to the base case in the bottom panel. The impacts of this scenario (relative to the base case) are simple—generally, gas-CC with CCS is deployed to meet the states' emissions targets, replacing variable renewable generation sources (including OSW), batteries, geothermal, and some H2-CT/electrolyzer capacity. ReEDS includes incentives associated with the Inflation Reduction Act, which expanded and extended the credit for carbon dioxide capture and storage.[4] Figure 11 shows the impacts of this incentive because the model will choose to build CCS if the technology is enabled.

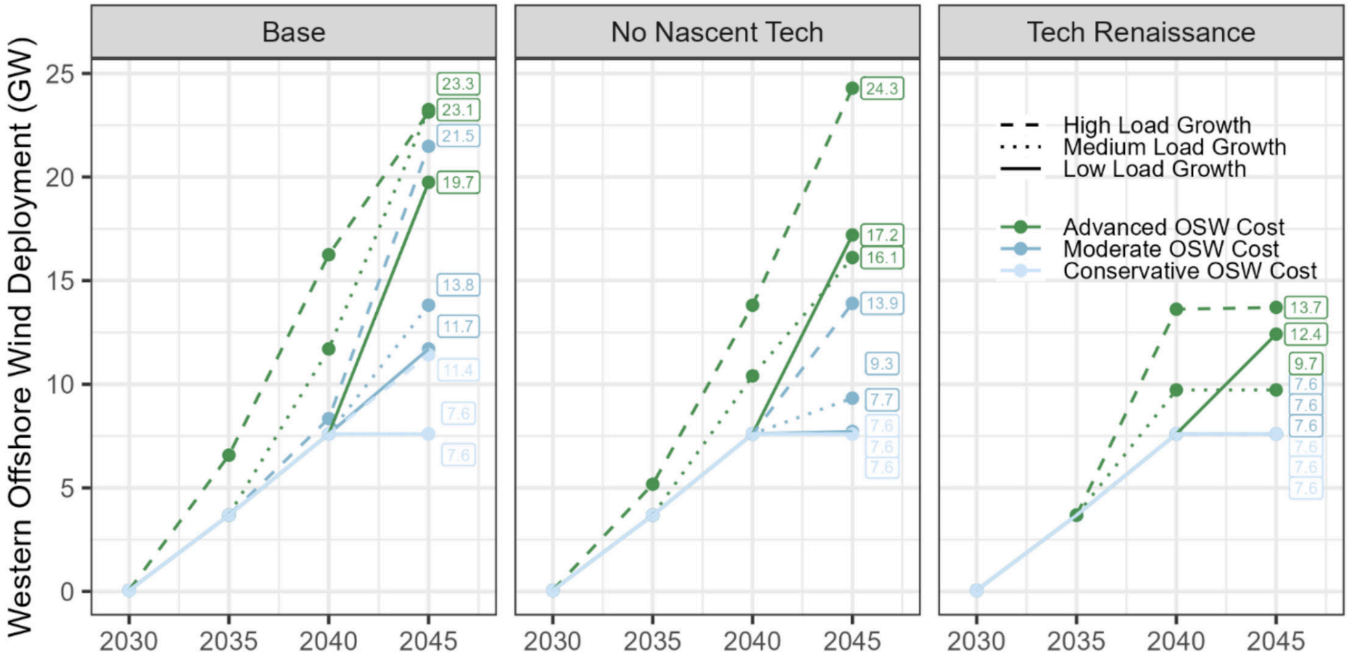


FIGURE 9 | Offshore wind deployment in the West for various load growth, emissions reductions, and OSW cost assumptions scenarios through 2045. The left panel shows the base technology case (the same shown in Figure 8), whereas the middle panel shows further technology restrictions. The right panel has no technology restrictions.

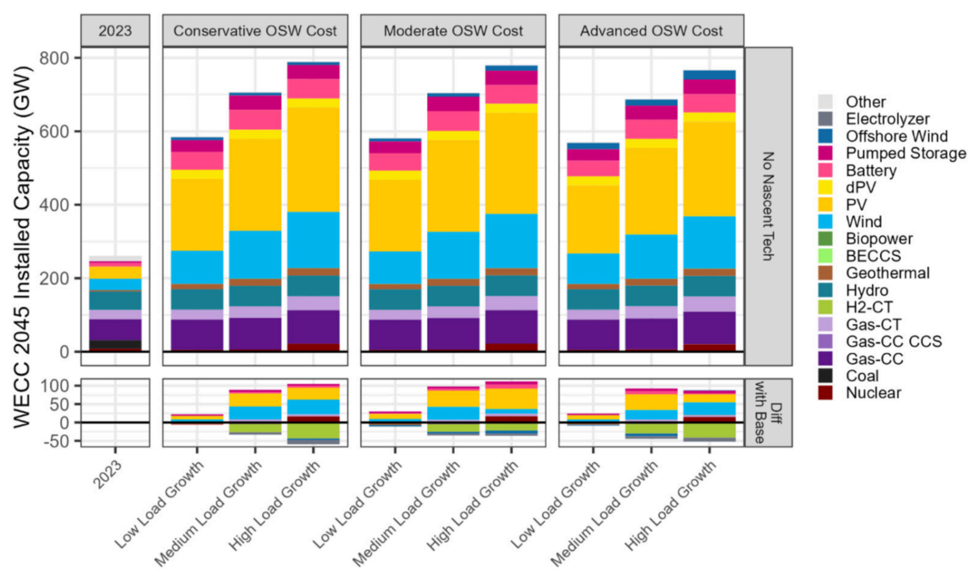


FIGURE 10 | The 2045 installed capacity in the West under the no nascent tech case (top panel), including currently installed capacity on the far left; comparison with the base case (bottom panel).

3.4 | Other Key Drivers

In this section, we examine other factors that can encourage or inhibit the growth of OSW generation on the West Coast. Table 3 explains some of the other drivers that are examined either alone or in combination with drivers previously shown (OSW capital cost, load growth trajectories, and technology restrictions).

Figure 12 illustrates the OSW deployment through 2045 under the full sweep of scenarios showing a large range of deployment scenarios while highlighting a few notable cases. The highest observed deployment (38.5 GW by 2045) occurs under the combination of advanced OSW costs, 100% emissions reduction by 2045, no nascent technologies, and limited siting for land-based wind and solar. In this case, the options for other low-emitting or nonemitting technologies are impaired, leading to overall greater OSW deployment. A similar case without the limited siting assumption shows a reduction of approximately 5 GW of OSW (33.3 GW in 2045). A further reduction of approximately 6 GW of OSW (27.6 GW) results from the moderate OSW costs trajectory. This case is notable because it reaches the highest deployment of all scenarios with moderate OSW costs considered.

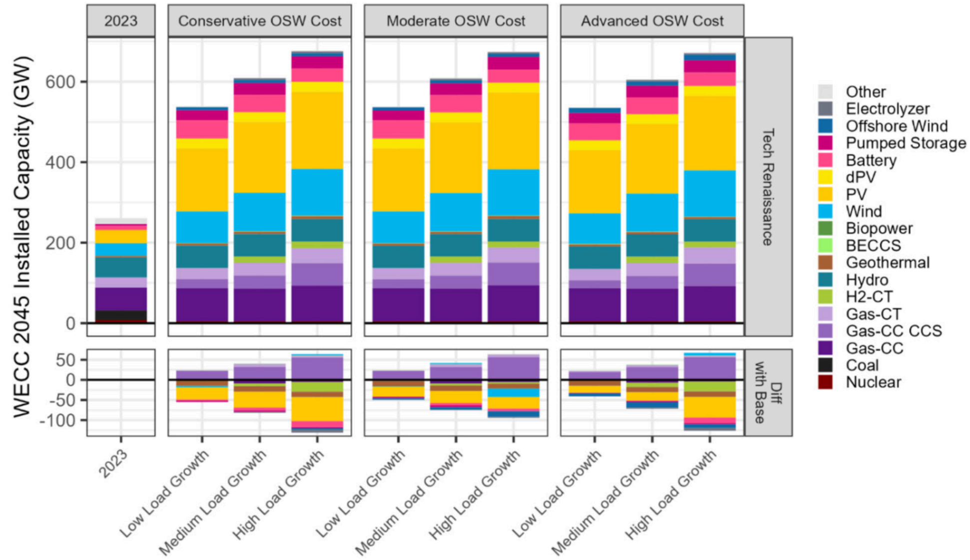


FIGURE 11 | The 2045 installed capacity in the West under the tech renaissance case alongside the currently installed capacity on the far left (top panel) and comparison with the base configuration (bottom panel).

TABLE 3 | Description of the technology availability scenarios evaluated in this section.

Driver	Description
Base	Default settings
10× transmission cost	A 10× multiplier is applied to the capital cost of transmission
100% by 2045	This scenario reaches zero carbon dioxide emissions from the electricity sector in 2045, with a linear trajectory from 2022 through 2045
Limited access siting	This scenario applies the limited access case with reduced ability to site land-based wind and solar (note this case is included under the base case scenario but not under the no nascent Tech or tech renaissance cases from Section 3.3)

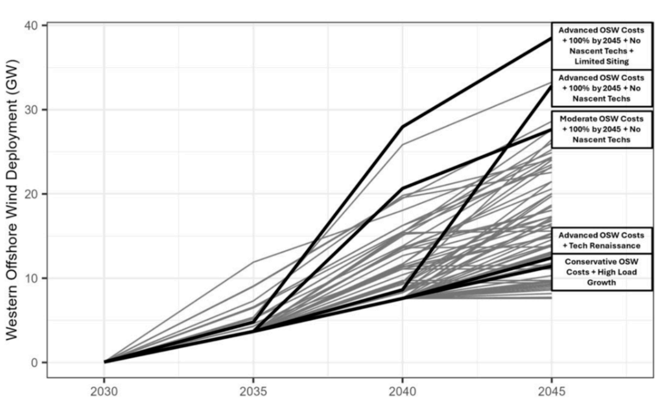


FIGURE 12 | OSW deployment in the West under the full range of options considered in this study through 2045.

The 100% emissions reduction case drives the highest observed deployments (in combination with other factors) and the highest observed deployment *without* the emissions target results from combining advanced OSW costs, high load growth, and no nascent technologies, and limited siting for land-based resources (25 GW). Conversely, combining advanced OSW costs with the tech renaissance case results in the lowest observed deployment with advanced OSW cost assumptions (12.4 GW), and the highest deployment under the conservative OSW cost assumptions (11.7 GW) results from the high load growth scenario. Although a handful of cases exceed 25 GW of deployment by 2045, most cases fall between the mandated 7.6 and 25 GW—and extremely high deployment requires several OSW-favorable conditions in combination.

4 | Conclusion

This analysis examined key opportunities, drivers, and potential hurdles for OSW deployment on the US West Coast using ReEDS, a state-of-the-art capacity expansion model. ReEDS considers detailed information about technology costs, siting constraints, existing policy at any level, and overall system resource adequacy to assess OSW as an investment option along with existing and other potential resources. This study uses ReEDS to explore how OSW costs may be an important barrier to the development of substantial OSW infrastructure off the West Coast. However, multiple scenarios under moderate projections for OSW cost reductions do show substantial OSW deployment, driven by the coastal states' renewable energy goals. We also find that OSW can contribute to meeting resource adequacy targets for the coastal states, supplying more electricity during the most stressful grid conditions relative to land-based wind and solar energy, due in part to higher overall capacity factor but also showing generation patterns that better correlate to times of system stress in the region. Cost reductions relative to the conservative OSW cost assumptions will likely be necessary to achieve the economic deployment of OSW in the West because scenarios assuming conservative OSW cost lead to no or very limited OSW beyond the mandated amount. Another potential driving factor for generation capacity generally, including OSW, is demand growth. Meeting higher expected load in the coming decades on the West Coast could create conditions more favorable for OSW deployment as more generation capacity is required to keep up with demand.

Another key consideration is the availability of competing technologies. Especially under cases with substantial load growth, additional generation capacity may be necessary in the West, with various technologies vying for market shares. Our scenarios indicate that the highly uncertain future of technologies such as CCS and hydrogen-fueled combustion turbines may provide either an opportunity or a barrier to further OSW growth on the West Coast, depending on how relative costs and performance evolve. We also note that restricted siting of land-based technologies (wind and solar) does impact OSW growth but not to the same degree as these more flexible generation technologies. In other words, excluding CCS and H2-CT technologies leads to a much larger growth in OSW deployment than reduced siting options for land-based wind and solar under these assumptions.

Overall, the future for any technology on the electric power grid is uncertain. Growth in utility-scale PV and land-based wind has outpaced most expectations, and even more recent growth in grid-scale battery deployment indicates how technology cost reductions can lead to rapid growth. Reductions in OSW capital costs are likely required to achieve sizeable deployment of OSW, and policy drivers—such as the California mandate—may impact offshore wind deployment in the West as well.

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Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Peer Review

For transparency, the peer review documents associated with this article are available at https://doi.org/10.1002/we.70137.

Endnotes

[1] This analysis was completed before the passage of the One Big Beautiful Bill Act (OBBBA; [55]), so the analysis includes a 10-year incentive for clean hydrogen for up to $3/kg (kg; [56]). Note that the OBBBA changes the date of availability for hydrogen tax credits, which could impact hydrogen technology deployment.

[2] Similar to the hydrogen production tax credit, the recently passed OBBBA impacts federal tax incentives for certain generation types such as wind and solar and thus could change the results of this study [55]. However, since we consider a range of technology prices and availability, the impacts of the incentives may still fall within the range of scenarios.

[3] ReEDS does not consider demand-side resources such as flexible or price-responsive demand as part of its least-cost optimization. Future work should examine the potential role of load flexibility in ReEDS.

[4] As mentioned above, this analysis was completed before the passage of the One Big Beautiful Bill Act, which could have impacts on CCS technology incentives [55].

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Figure A-1:** Map showing the 35 modeling regions used in the Western Interconnection subset of the ReEDS model. **Figure A-2:** Western United States offshore wind supply curve in the three western coastal states for 2035, plotting levelized cost of energy (LCOE) vs. available capacity. **Figure A-3:** Stress periods identified in the base case for the model solve years of 2035, 2040, 2045, and 2050.