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Comment Received From: Dr. Amol Phadke Dr. Nikit Abhyankar, Umed Paliwal, David Wooley
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Our New UCB OSW Working Paper Shows Benefits of 50 GW Goal by 2045

Additional submitted attachment is included below.

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Dear Commissioner Vaccaro and Chair Hochschild,

Offshore wind (OSW) is a critical resource for California to achieve its 2030 and 2045 greenhouse gas reduction goals, with unique characteristics that help increase the feasibility of reaching these targets. In particular, if California hopes to meet its deep decarbonization goals through electrification of transport, buildings, and industry, it will need new economic clean energy sources that produce electricity at a high capacity factor without major land constraints. Failure to recognize and plan for offshore wind's feasible contributions to a zero-carbon electricity system will result in under-procurement of these resources, which California cannot afford.

We are California-based energy system scientists with appointments at the University of California, Berkeley, operating in our capacity as private individuals. We have between us 75 years of experience in evaluating power systems and renewable integration issues, including rigorously researching the resource potential of offshore wind worldwide. Our research shows that the technically feasible potential of offshore wind in California is much higher than the goal CEC is considering for 2045, **as detailed in the attached working paper, "The Offshore Report: California"**.

We have reviewed the Draft "AB525 Offshore Wind Report," recently published by the California Energy Commission (CEC), and recommend CEC to consider a significantly higher preliminary planning goal of offshore wind (OSW) deployment (50 GW by 2045). There are several reasons why the goal contained in the proposed report (10 GW to 15 GW by 2045) is too low. In comparison, the UK, which has similar electricity demand as California has a goal of 50 GW of OSW by 2030 and China deployed 17 GW of OSW in one year (2021).

1. Maximum feasible capacity of OSW is likely to be an order of magnitude higher than the technical reference point considered by CEC

AB 525 asks CEC to "*Evaluate and quantify the maximum feasible capacity of offshore wind to achieve reliability, ratepayer, employment, and decarbonization benefits, and establish megawatt offshore wind energy megawatt planning goals for 2030 and 2045 by no later than June 1, 2022.*" However, CECs draft AB 525 Offshore Wind Report (henceforth referred as CEC Report), states on page 53, "*Based on existing studies described in this report, nearly 21.8 GW of offshore wind technical potential of the 201 GW of the gross resource estimate has been identified and examined for technical feasibility. This number does not represent the quantification of maximum feasible capacity of offshore wind as defined in this report and required by AB 525, it simply represents the offshore wind technical potential that has been studied.*" (Emphasis added). The CEC Report further states on page 56 that the "*maximum feasible capacity [is] to be determined in [the] strategic plan.*" Thus, the CEC appears to state that it does not currently fulfill the

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requirement of the AB 525 to "*evaluate and quantify the maximum feasible capacity of offshore wind no later than June 1st.*"

CEC uses a recent study by NREL (Optis, M, et al, 2020) as a source for these potential estimates. However, NREL (2020) shows that the technical potential is about **ten times higher** **(~200 GW)**, compared to the CEC determination of 21.8 GW. The CEC also understates the gross potential identified by NREL, which is about **eight times higher (~1700 GW)** than the CEC's reference of 201 GW. Even the 2016 NREL study (Musial et al., 2016) which applied several environmental and competing use exclusions found that the technical potential to be roughly 150 GWs. In order to determine the maximum feasible potential, the CEC should study this full 150-200 GW for feasibility, instead of limiting the planning goals to the 21.8 GW that have already been "*identified and examined for technical feasibility*", as described in page 53 of the CEC report. This could lead to a much higher value for technically feasible potential, as NREL has found.

We conducted a complementary analysis to NREL's offshore wind assessment, using the same state-of-the-art methods for site selection and resource estimation, and concur with NREL's recent (2020) finding that **OSW technical potential in California is 200 GW**. We find that California is blessed with tremendous OSW resources, including **120 GW of OSW with capacity factors greater than 50%**. These findings are detailed in the attached document, "The Offshore Report: California."

Our view is that the maximum OSW capacity is significantly higher than the reference potential considered by CEC and that CEC should consider higher 2045 planning goals that reflects the updated technical potential finding of 200 GW. **We suggest a 50 GW planning goal for 2045**. As detailed below, a 50 GW planning goal would reflect full consideration of the immense benefits to the grid of offshore wind.

2. Current OSW planning goals for 2045 are unlikely to add much to resource diversity and understate OSW's potential to meet California's electrification load growth.

The CEC notes that the SB 100 Agency Report "*concludes that offshore wind can contribute to increased resource diversity, which helps lower overall system costs.*" Setting a planning goal of 10-15 GW of OSW deployment by 2045 is a step in the right direction, but it falls short of providing much-needed additional resource diversity.

A recent report from Energy Innovation and GridLab details the reliability and deployment risks avoided by a diverse clean energy portfolio, which includes 4 GW of offshore wind and 2 GW of geothermal by 2030. The report also demonstrates this diverse portfolio performs better than a least-cost capacity expansion exercise against key stressors over 8 weather years, including low hydro, additional gas retirements, West-wide coal phase-out, extreme heat, and import limitations. It also mitigates the risk

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California cannot build, site, and interconnect solar and batteries at an unprecedented scale - a concern that persists beyond 2030 as electrification of vehicles, buildings, and industry takes off.

SB-100 Report estimates hitting 10 GW of OSW would supply less than 10% of the total clean electricity needs in 2045. This load forecast appears to significantly underestimate the clean supply needed to achieve CA's goal of a net zero economy by 2045. This is because the estimates of electricity demand appear to be based on achieving 80% economy-wide reduction in GHG emissions by 2050. Reaching the governor's goal of net zero emissions by 2045 will likely require additional electricity demand to supply hydrogen and high-temperature heat for industrial processes not accounted for in the SB 100 analysis. For example, the 2021 Princeton Net Zero America Study estimates California solar deployment to be about two times higher than projected by the SB 100 Report for comparable technology pathways. Hence the share of OSW generation would likely be lower than the SB 100 Report's estimate.

By contrast, deploying 50 GW of OSW would contribute significantly to resource diversity. Such a goal would meet 40% of demand in 2045, reducing the grid's reliance on deploying heroic levels of solar and batteries in an all-electric future. The impacts of higher levels of OSW deployment on a net zero grid portfolio in 2045 are detailed in the attached "Offshore Report: California."

3. CEC has not yet evaluated the benefits of higher levels of OSW deployment; our study shows significant benefits from higher levels of deployment.

AB 525 requires CEC to consider "*The need for reliable renewable energy that accommodates California's shifting peak load . . . [and] [t]he generation profile of offshore wind off the California coast*." Consideration of higher deployment, as detailed in our attached The Offshore Report: California, reveals that there are significant consumer and grid benefits of a significantly higher 2045 planning goal than 10-15 GW.

The CEC Report does not assess the benefits of deploying higher levels of OSW than what is evaluated in SB-100 Joint Agency Report, which limits OSW deployment to 10 GW (which is not the maximum feasible OSW capacity). Such evaluation should use similar methodology (capacity expansion and grid dispatch/production cost assessments) as those conducted in the typical CEC and CPUC planning processes/studies (e.g. the 2021 IRP plan). Reliance on the SB 100 study limits the consideration of grid benefits to the lowest end of an already conservative approach to a 2045 planning goal. We find that deployment of about 50 GW OSW by 2045 has significant benefits based on the results of detailed simulation of CA's power system for 30 scenarios of OSW deployment, up to 100 GW by 2045. We use robust capacity expansion (NREL's ReEDs) and dispatch (PLEXOS) models that simulate the hourly dispatch of over 6000 power plants (including 300 individual wind farms) and transmission flows over 80 corridors in WECC. Note that we have used NREL ATB technology scenarios recommended by the CEC Report.

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While this study, published as a working paper, is still undergoing external technical peer review, we have four key findings that support consideration of significantly higher planning goal by 2045 (such as 50 GW):

1. OSW deployment up to 100 GW by 2045 results in comparable wholesale electricity costs given recent and projected decline in OSW costs and high quality of CA OSW potential;
2. About 50 GW of OSW deployment results in one of the lowest wholesale electricity costs, while adding significantly to resource diversity, e.g., OSW and solar each can provide ~40% of the total electricity supply by 2045 as against over 70% provided only by solar in the SB-100 core scenario.
3. Such resource diversity would reduce the new solar capacity requirement by over 50% by 2045;
4. Significant OSW is economical in CA because CA has one of most favorable (summer and evening peaking) and abundant OSW resource, which provides consistent generation during winter months implying about 15-20% lower storage requirement;
5. More work is needed to evaluate the environmental, supply chain, and infrastructure impacts of an OSW resource at this scale.

4. The world needs CA leadership on OSW, especially on floating technology

Globally, it is critical to advance offshore wind technology and deployment to realize the multifold increase in clean power deployment required. Without ambitious OSW goals we risk not meeting global climate targets. By considering significant deployment of OSW, CA can not only ensure sufficient and diverse clean power supply for its own grid, but also spur national and global efforts to address the existential threat of climate change. As the state did with solar, CA needs to show greater leadership to advance this key technology (floating offshore wind).

We will be happy to answer any questions CEC may have or help CEC in their assessments.

Respectfully submitted,

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The Offshore Report: California

Plummeting offshore wind (OSW) costs can accelerate a diverse net-zero grid

Working Paper #1

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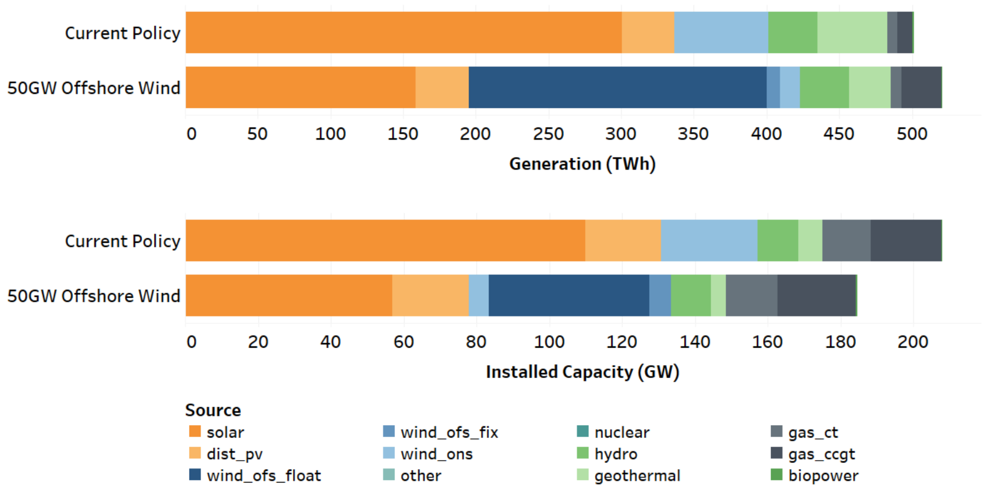
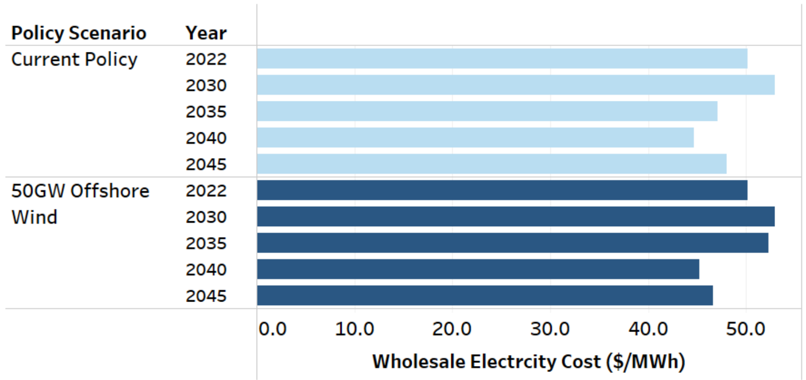
This working paper is circulated for discussion and comments. The paper has not been peer-reviewed or been subject to review by any editorial board.

Recommendation to CEC for AB 525: Consider deploying up to 50 GW OSW by 2045

Significant OSW (upto 50 GW by 2045) can be deployed by 2045 to increase resource diversity without increasing wholesale electricity costs





Summary

<u>Challenge</u>: SB 100 plans rely on PV to achieve zero emission grid by 2045 without much resource diversity, which may lead to deployment and climate change induced risk

<u>OSW Opportunity</u>: Plummeting costs; scaled up deployment [UK auctions @$50/MWh; 50 GW target by 2030], GWs of floating OSW under planning globally; CA is blessed with high OSW potential

<u>Our study</u>: We consider latest OSW technology and cost trends to assess significant deployment in the CA grid by 2045 by conducting state-of-the-art capacity expansion (ReEDS) and production cost modeling (Plexos) of the CA-WECC power system

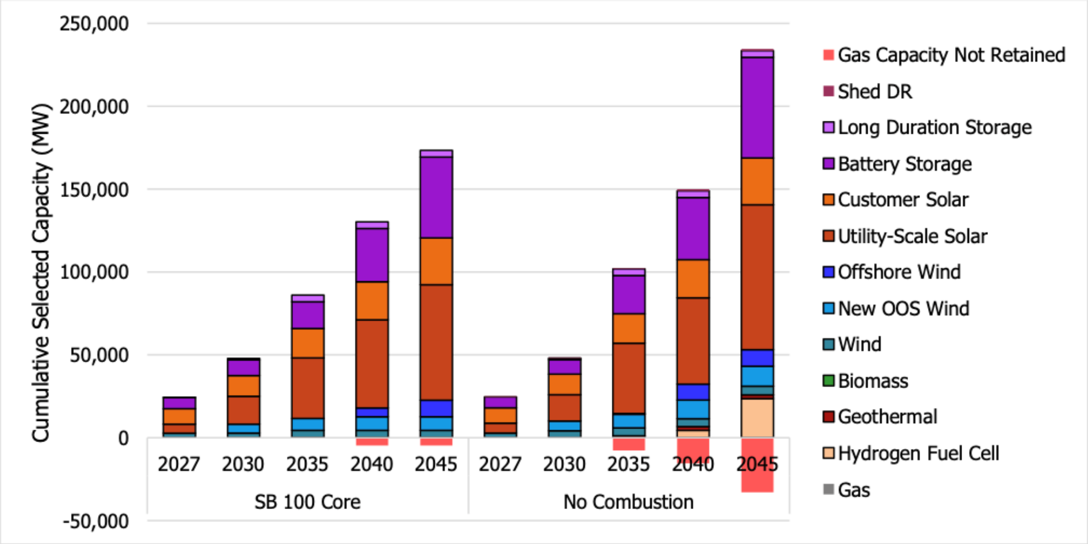
<u>Findings:</u>

<u>1. CA blessed with OSW resource:</u> ~200 GW technical; 120 GW> 50% cap factor; summer and evening peaking
<u>2. Strong policies required</u> for CA to achieve a diverse net zero grid with significant OSW
<u>3. 50 GW OSW can provide resource diversity for a net zero grid</u> without increasing wholesale electricity costs
<u>4. Grid with significant OSW is dependable</u> with less storage
<u>5. CA can become the global leader in the floating OSW technology</u>; massive potential & need in countries like Japan, Korea etc.

<u>Recommendation</u>:
Consider deploying upto 50 GW of OSW in California by 2045

SB 100 plans rely on PV and battery storage without much resource diversity; does not fully consider clean power required for a net-zero economy by 2045

Figure 8: Cumulative Capacity Additions for the SB 100 Core and No Combustion Scenarios



Source: CEC staff and E3 analysis

Study: Accelerated Timeline Scenarios

Source: CEC 2021 SB 100 Joint Agency Report

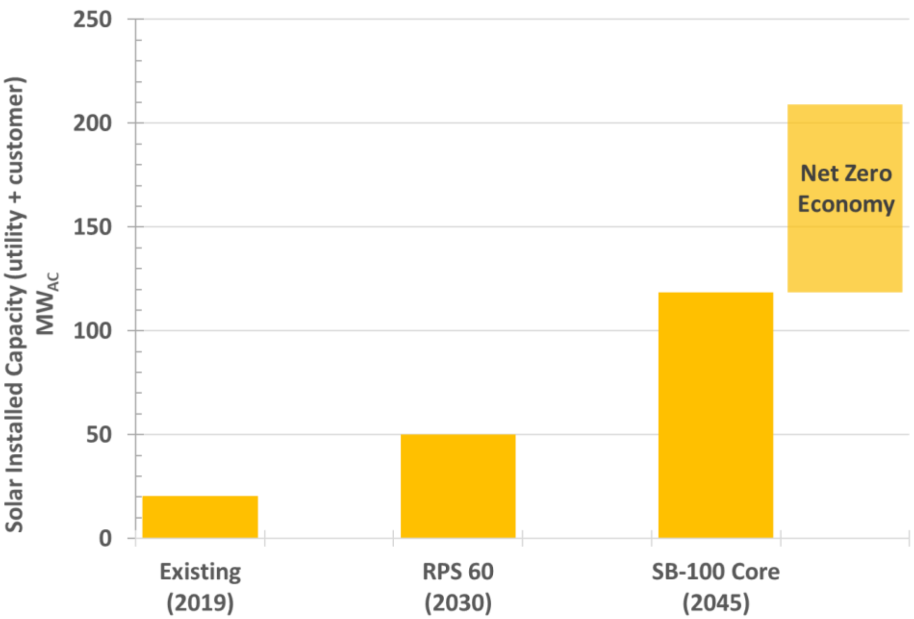
SB 100 Core and Study Scenarios:

>70% clean electricity from solar (120 GW) by 2045; wind limited to 10-15 GW.

Solar additions only support 80% economywide GHG emission reduction by 2050; could be significantly higher if net zero by 2045 goals are to be achieved

For example, Princeton Net Zero America Study estimates 230 GW to 280 GW of PV required to meet NZ goals in CA by 2050

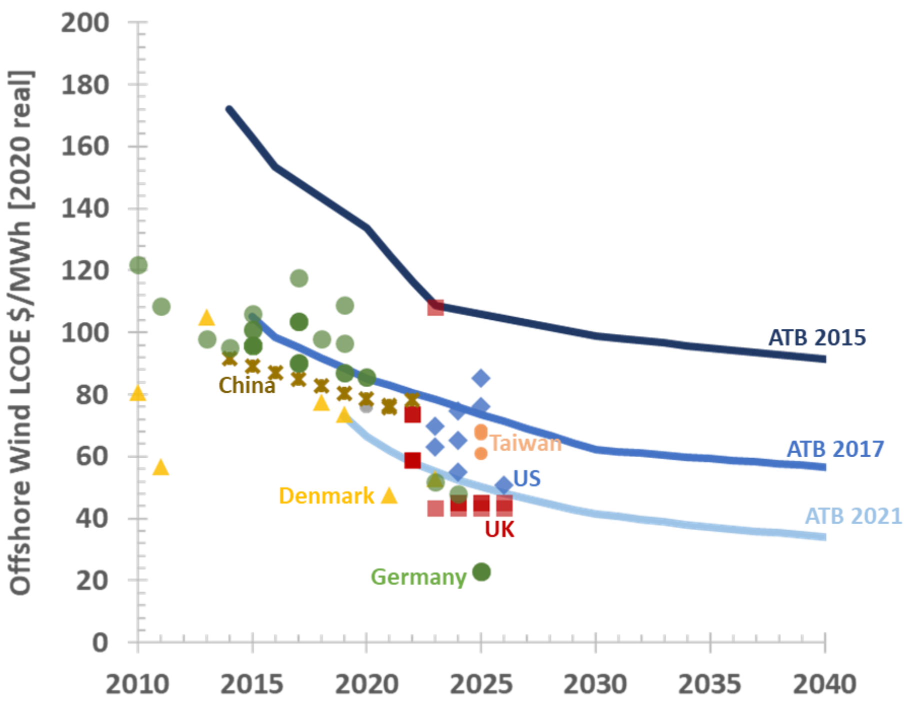
Solar dominant CA grid for a net zero economy may need ***double*** the solar capacity additions planned in the *SB-100* core scenario



- SB-100 core scenario plans a solar dominant grid with ~120 GW solar + ~50GW storage by 2045.

- However, if California relies only on solar for achieving net-zero emissions, solar capacity needed by 2050 would be in excess of 200-250GW + 50-100GW of storage.

Offshore wind costs have dropped much faster than anticipated; Several auction prices are ~$50/MWh



Solid blue lines

NREL Annual Technology Baseline (ATB) Low/Advanced-case cost projections made 2015–2021 for years through 2050 for fixed-bottom OSW projects. LCOE projections were revised downwards in almost every projection year during this period.

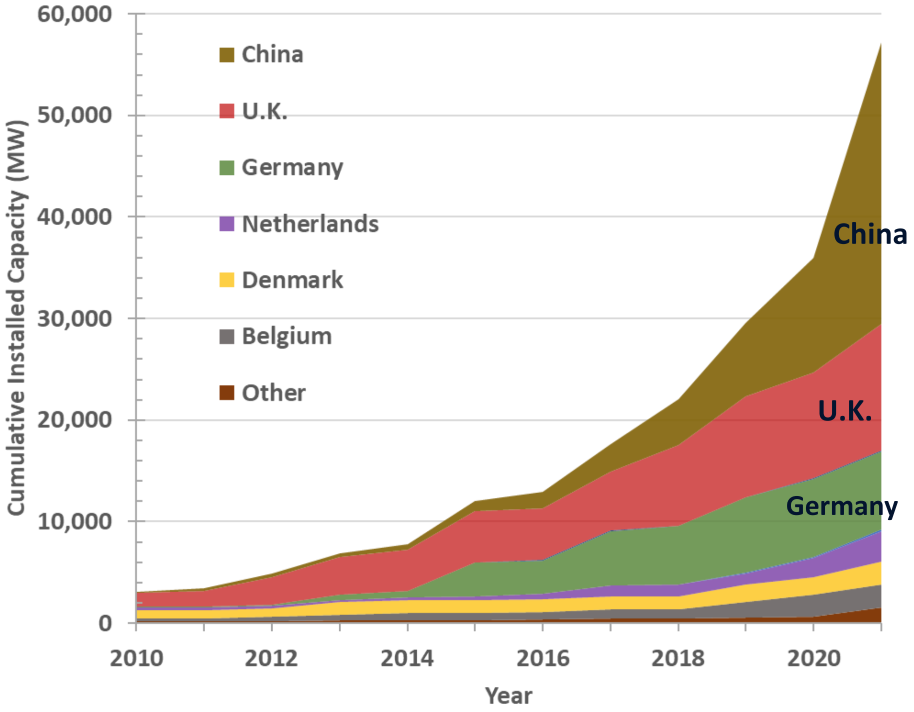
Colored dots

OSW auction prices are levelized (BNEF) and are mostly for fixed-bottom OSW projects.

Note

All numbers are expressed in 2020 real US $.

Globally, offshore wind installed capacity has reached about 60GW



Note: Most of the existing installations are fixed-bottom.

China installed ~17GW of offshore wind capacity in 2021

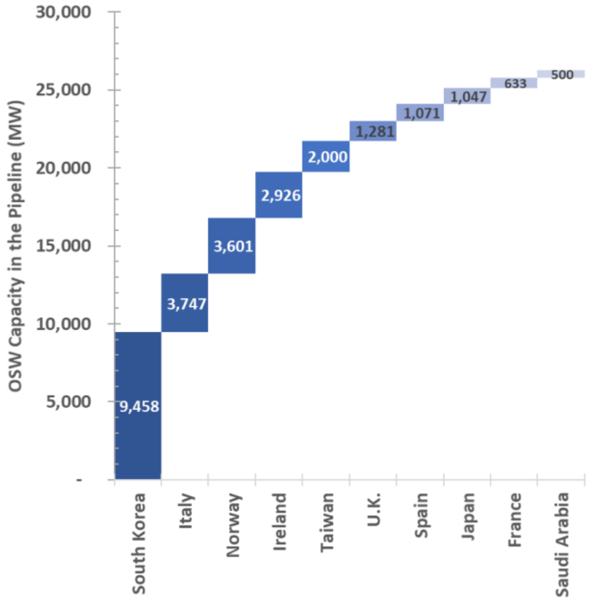
UK's electricity demand (~350 TWh/year) is similar order of magnitude of CA (~270 TWh/yr)

UK is planning to install 50GW of offshore wind (OSW) by 2030. Existing OSW = ~12 GW

We make a case for 50 GW OSW in CA by 2045 providing about 40% of the state's power supply of about 500 TWh/year in 2045

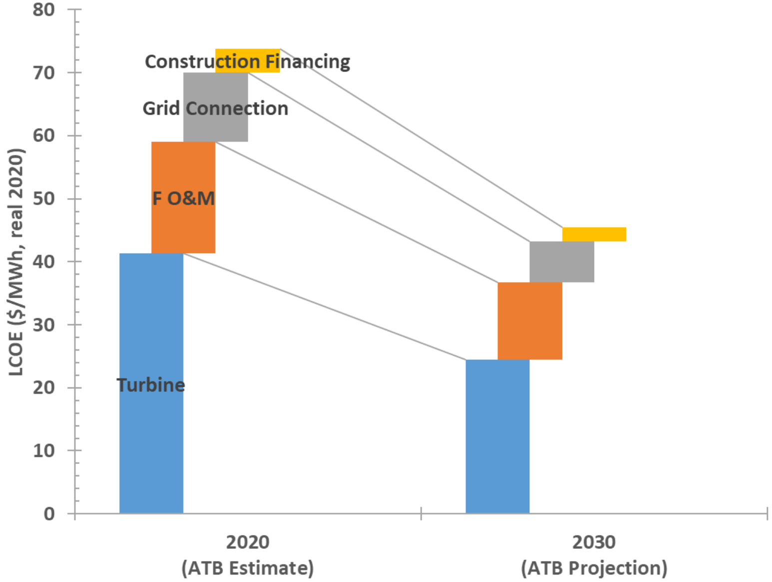
Globally, >25 GW of floating OSW is in the pipeline, while 40% cost reductions are projected by 2030

Floating OSW pipeline (Global)



Data source: DOE's Offshore Wind Market Report (2021)

Floating OSW LCOE (US)

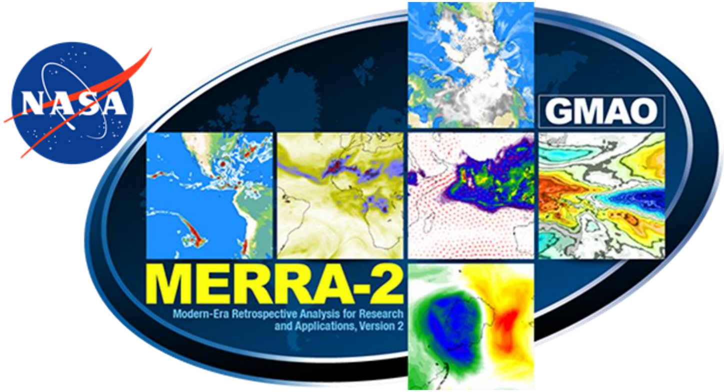


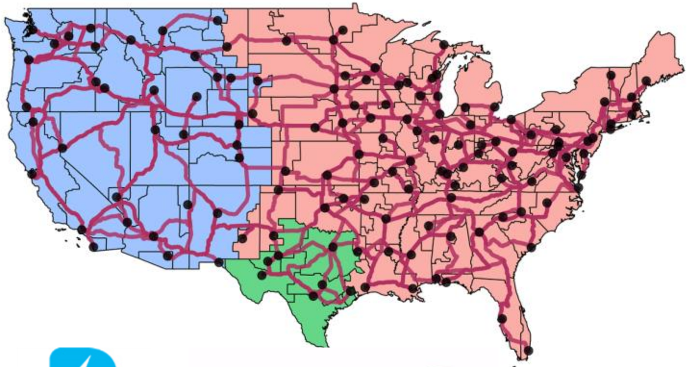
Data source: NREL Annual Technology Baseline (2021) - Advanced case
See also Beiter et al. 2020 (NREL)

Data and Methods Summary

Offshore Wind Potential Assessment

- Estimated @150-meter hub height for 15 MW turbines;
- Used NASA MERRA- 2 satellite data w/ NREL SAM model;
- 600 MW wind farms modeled at 800 individual sites off the CA coast, selected after several exclusions





ReEDS

PLEXOS BY ENERGY EXEMPLAR

Power System Assessment

- WECC-wide simulation with CA specific targets
- Capacity expansion: NREL ReEDS v2021 (134 regions across the US; 35 in WECC; 4 in CA; 320 transmission corridors in US)
- Hourly dispatch: Plexos (>5,000 individual power plant level hourly dispatch in WECC)
- Cost projections: Fuel prices from EIA AEO 2021; clean technology costs from NREL ATB 2021

Overall 30 scenarios modeled with all combinations of the following parameters

CA Policy	Rest of the US Policy	CA OSW Deployment by 2045	Clean Technology Costs	Fossil Fuel Prices	Demand
SB-100 (NZ by 2045)	**No new policy**	***Least Cost***	Low (NREL ATB Low)	**Reference** (EIA Annual Energy Outlook 2022)	**High Electrification** (470 TWh by 2045)
	NZ by 2045	25 GW	**Base (NREL ATB Mid)**		
		50 GW	High (NREL ATB High)		
		75 GW			
		100 GW			

Core Scenarios for Analysis

Meet SB-100 goal in California by 2045 using one of the following two pathways:

1. Current Policy

- OSW deployment per the least cost capacity expansion
- Rest of the US continues with current policies
- Base technology costs (NREL ATB Mid Case)
- ⇒ Solar supplies ~70% of electricity supply by 2045

2. 50 GW Offshore Wind Case

- CA OSW deployment is 50 GW by 2045
- Rest of the US continues with current policies
- Base technology costs (NREL ATB Mid Case)
- ⇒ OSW and solar each supply ~40% of electricity by 2045

Key Findings

1. CA has one of the world's best offshore wind potential: 200 GW technical; 120 GW at >50% capacity factor; summer and evening peaking

2. Strong policies required for CA to achieve a diverse net-zero grid with significant OSW

3. Significant OSW (upto 50 GW by 2045) can be deployed to increase resource diversity without increasing wholesale electricity costs

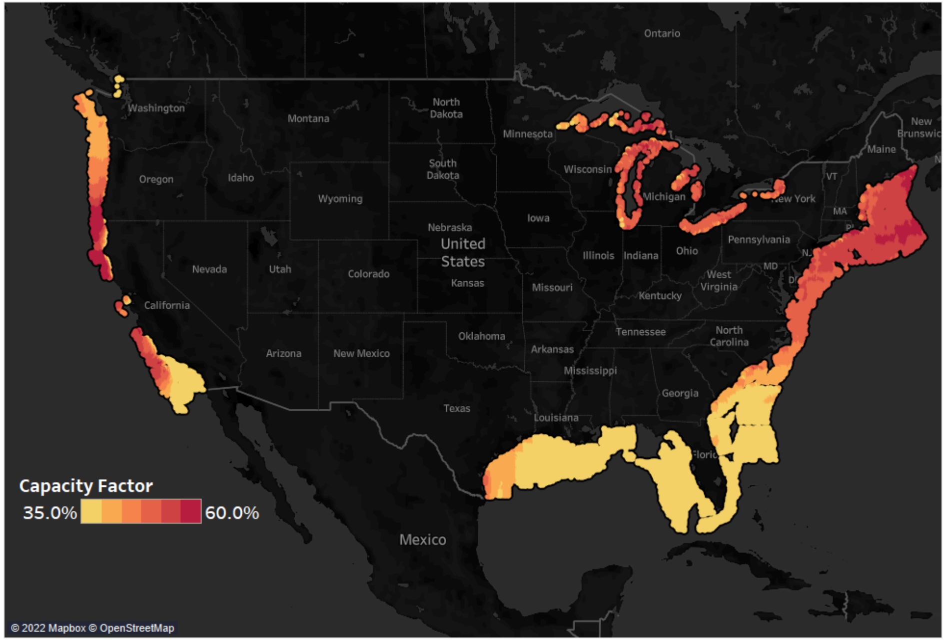
4. Grid with significant OSW is dependable with less storage

5. CA can become the global leader in the floating OSW technology; massive potential & need in countries like Japan, Korea etc.

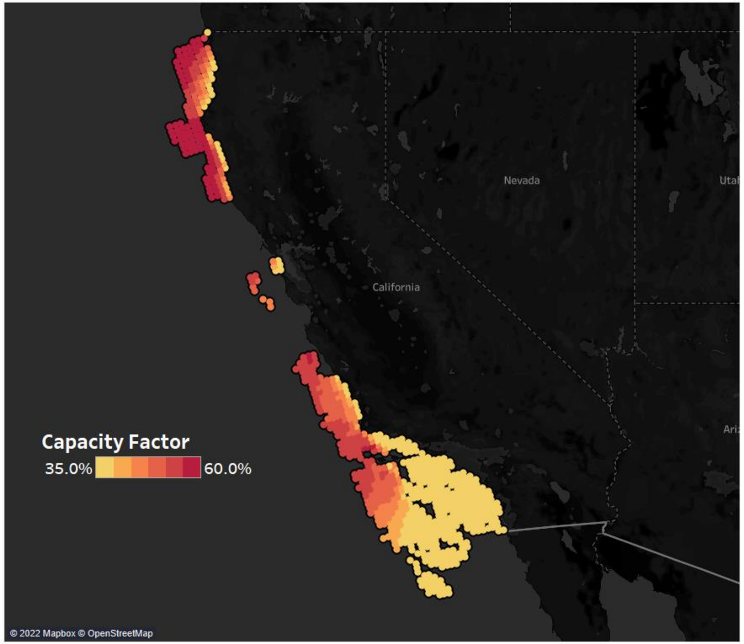
Finding #1: CA has one of the world's best offshore wind potential: 200 GW technical; 120 GW at >50% capacity factor; summer & evening peaking

1.1 Significant offshore wind potential in the US and California

U.S. OSW potential is well spread out with >1000 GW at a capacity factor >50%



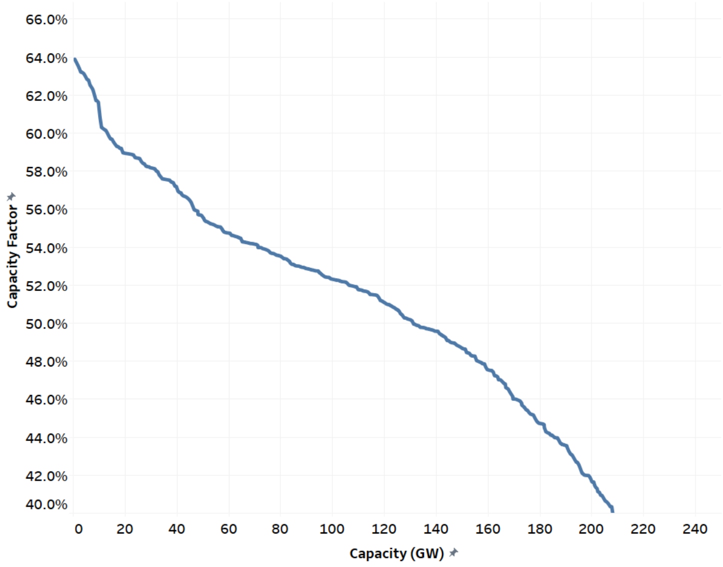
Most of the CA OSW potential is floating with >120GW at capacity factor >50%



1.2 CA has some of the best offshore wind potential in the world

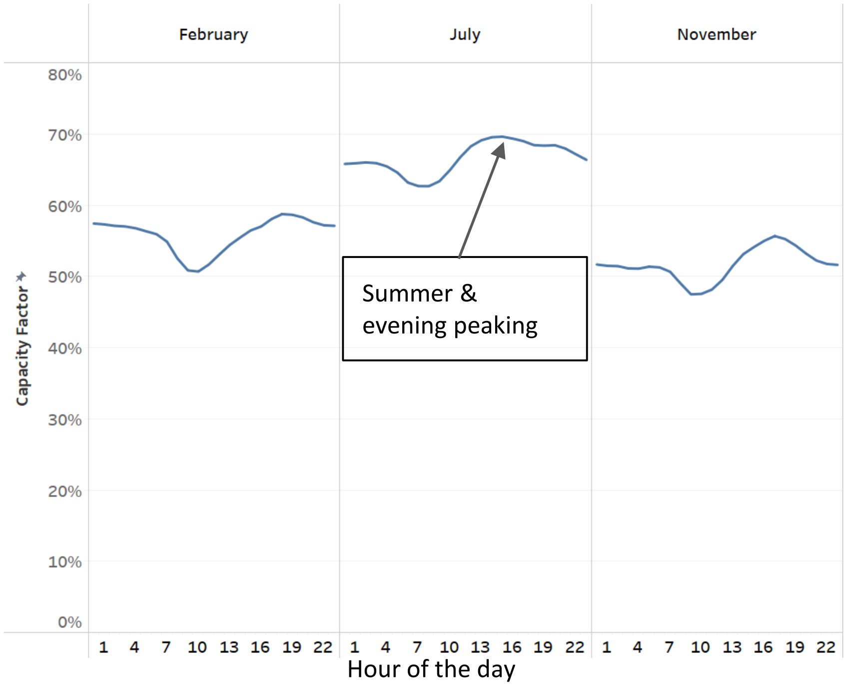
200 GW technical; 120 GW w/ capacity factor >50%; summer & evening peaking

Offshore wind supply curve



Our estimates are similar to the NREL California offshore wind potential study (Optis M, et al, 2020)

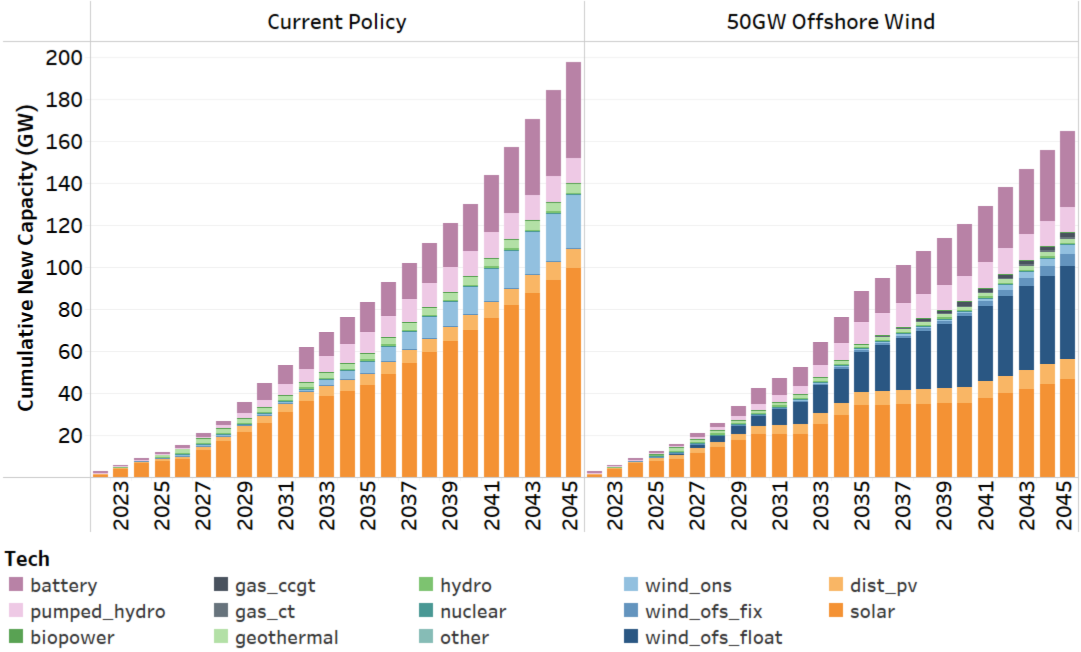
Hourly generation profile shows complementarity with solar and load



Finding #2: Strong policies are required for CA to achieve a diverse net-zero grid with significant OSW

2.1 Strong policies are required for CA to achieve a diverse net-zero grid with significant OSW

Cumulative new capacty addition (GW) in CA (2022-2045)



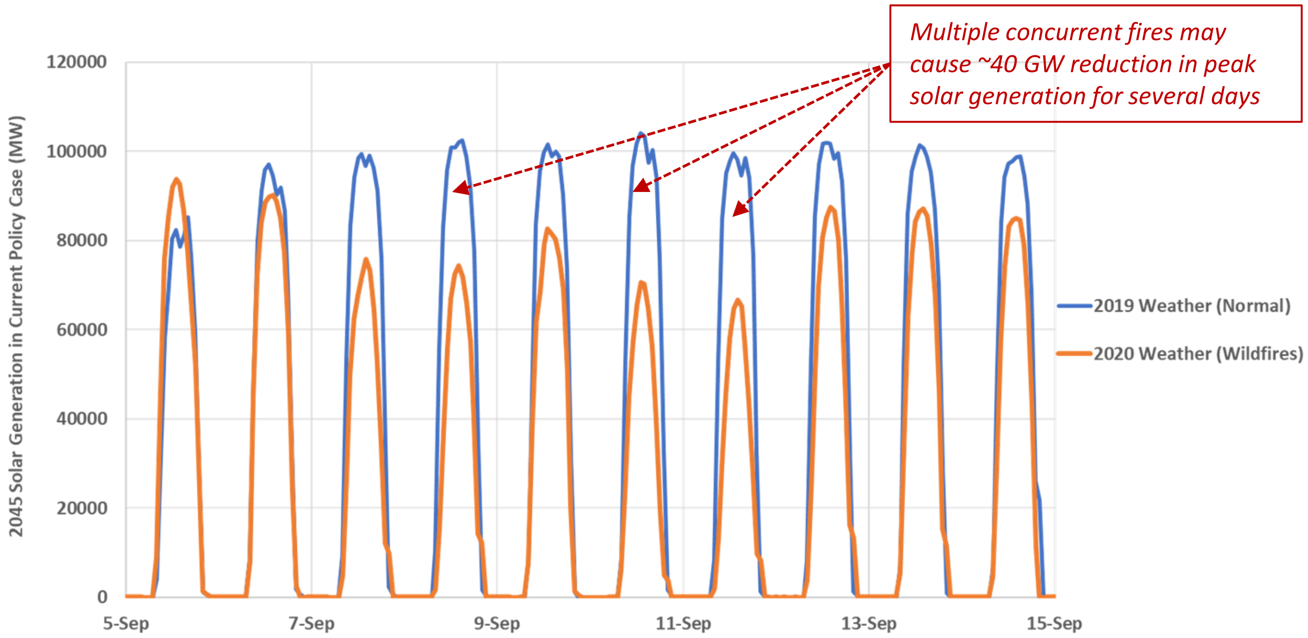
The Current Policy case assumes continuation of current state and federal policies which leads to a solar PV dominated zero emission grid in California by 2045.
(130 GW Solar + 53 GW storage)

The **50GW OSW case** results in a more diverse zero emission grid.
It reduces the solar (77 GW) + storage (44 GW) deployment.

Strong policies would be required for significant OSW additions
(~5 GW total by 2030 and ~3 GW/yr after 2030)

2.2 A solar only system faces increasing wildfire risk; which can be mitigated with a more diverse portfolio

Chart shows simulated solar generation in 2045 in the Current Policy Case, using 2019 (normal) and 2020 (wildfire risk) weathers

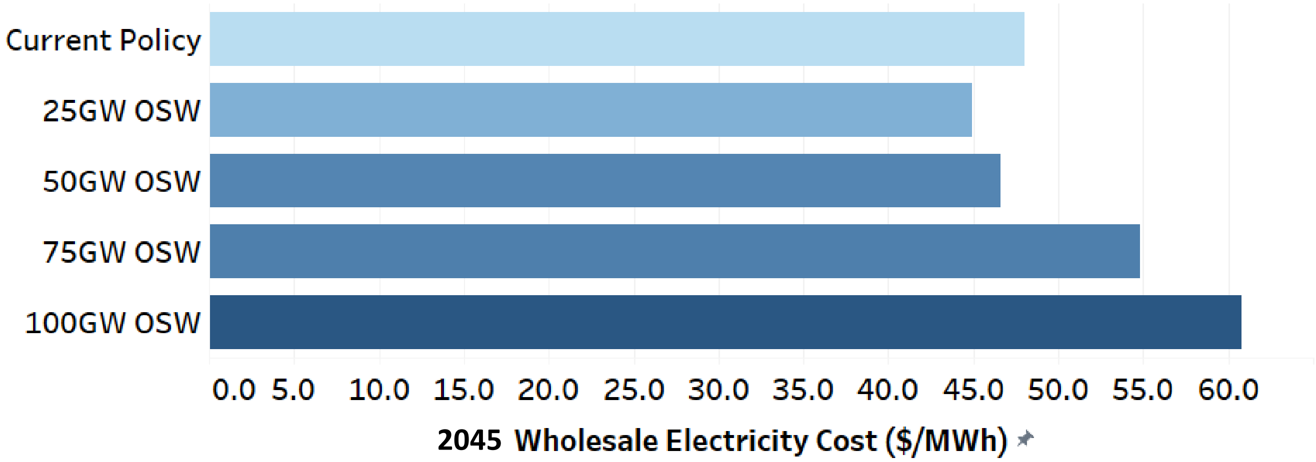


In 2020, due to multiple wildfires in September, CA solar generation dropped by ~15-20% for over a week.

In the **Current Policy Case**, the peak solar generation risk in 2045 due to wildfires could be as high as **35-40GW.**

Finding #3: Significant OSW (upto 50 GW by 2045) can be deployed to increase resource diversity without increasing wholesale electricity costs

3.1 Deploying up to 50GW of OSW by 2045 increases resource diversity without increasing wholesale electricity costs (1/2)

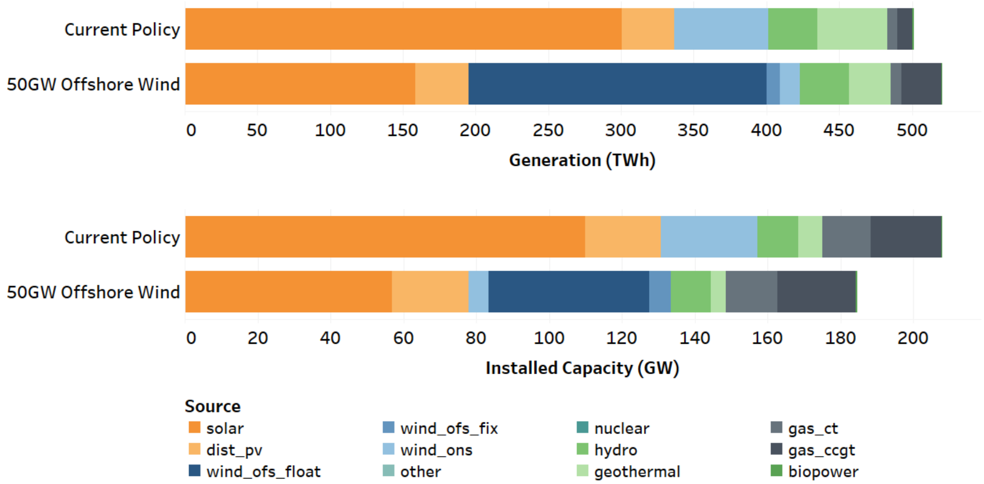


All cost numbers are in 2020 real $.

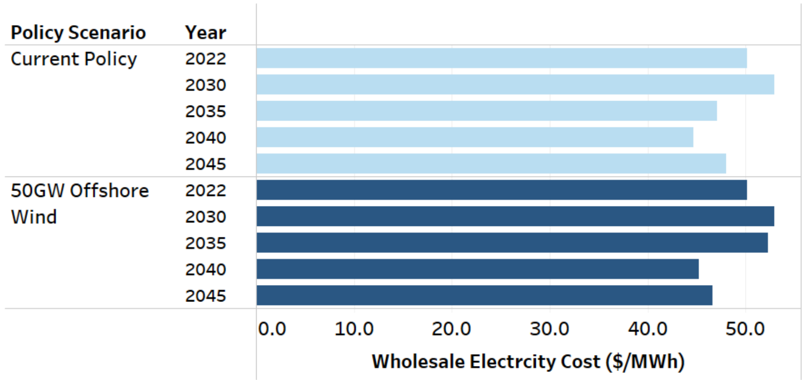
Wholesale electricity cost includes the fixed and variable costs of all (new + existing) power plants in the state, out-of-state import-export costs/revenue, and new bulk transmission as well as interconnection costs.

3.1 Deploying up to 50GW of OSW by 2045 increases resource diversity without increasing wholesale electricity costs (2/2)

Annual generation and installed capacity in 2045

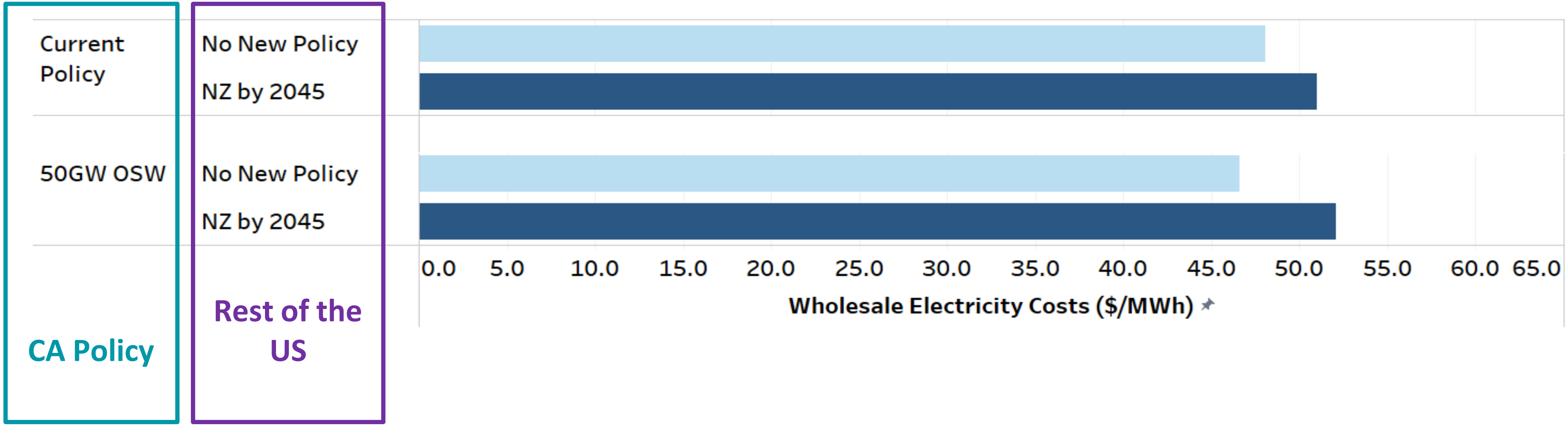


Average wholesale electricity cost
($/MWh, 2020 real)



Average cost reduces compared to today; comparable with the Current Policy case

3.2 If rest of the US also achieves a net-zero grid by 2045, wholesale electricity costs still do not increase beyond 2022 levels

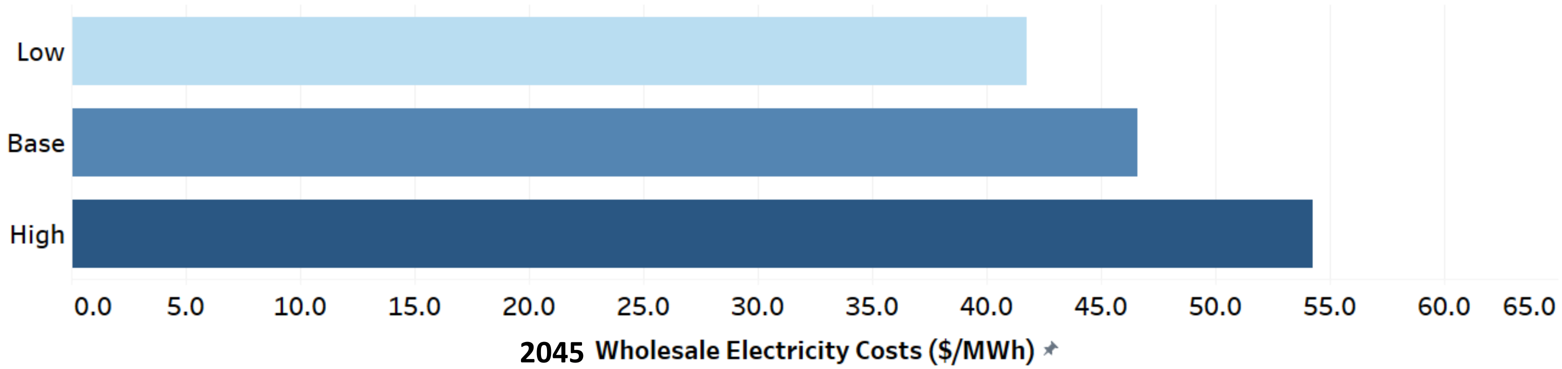


All cost numbers are in 2020 real $.

Wholesale electricity cost includes the fixed and variable costs of all (new + existing) power plants in the state, out-of-state import-export costs/revenue, and new bulk transmission as well as interconnection costs.

3.3 If OSW costs fall rapidly (ATB Low) CA benefits from even lower wholesale electricity costs

Clean Technology Costs
Low (NREL ATB Low)
Base (NREL ATB Mid)
High (NREL ATB High)

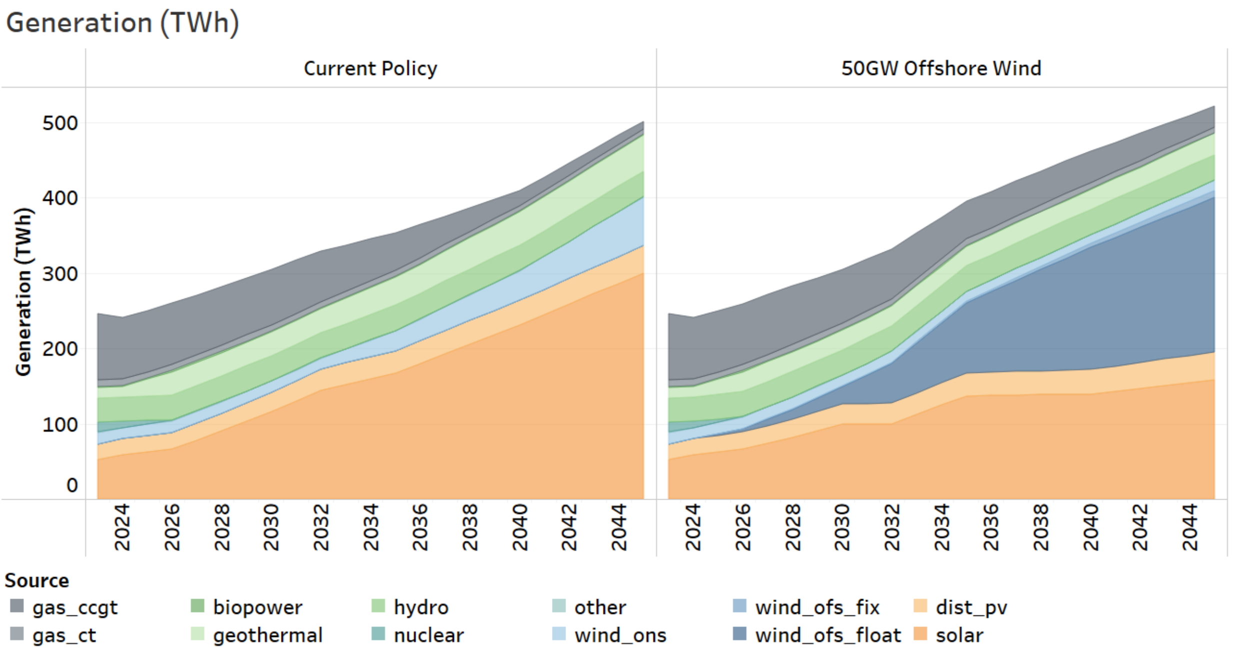


All cost numbers are in 2020 real $.

Wholesale electricity cost includes the fixed and variable costs of all (new + existing) power plants in the state, out-of-state import-export costs/revenue, and new bulk transmission as well as interconnection costs.

3.4 Significant OSW additions lead to a more diverse grid

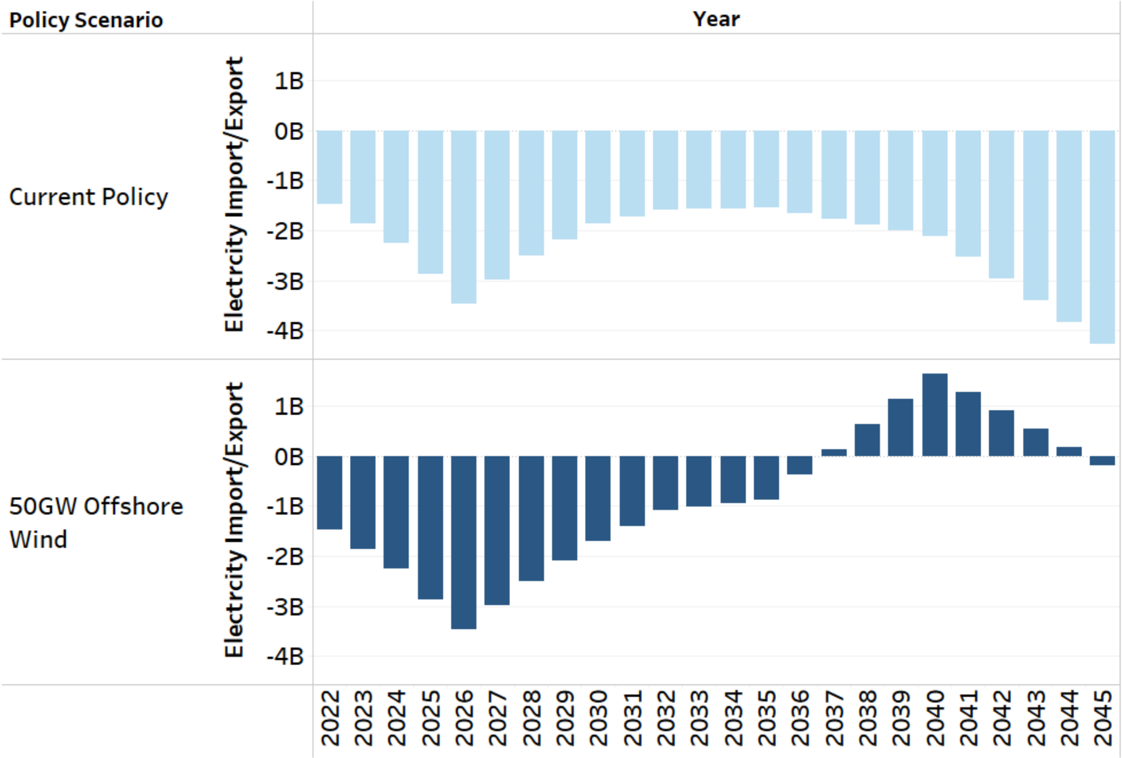
Annual energy generation in CA (Current Policy and 50 GW OSW Case)



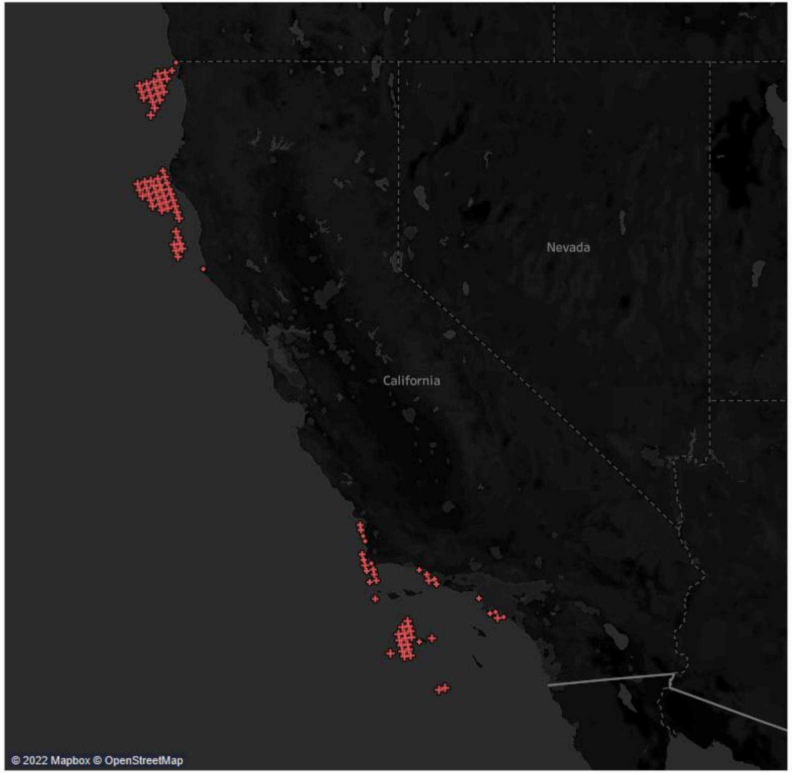
The Current Policy case leads to a solar PV dominated grid by 2045.
Solar provides 70%, onshore wind 10% and other clean resources provide 15% of the total electricity supply.

50GW OSW case leads to a more diverse grid. OSW and solar each provide ~40% of total electricity supply, onshore wind supplies 5%, and other clean resources supply 15% by 2045.

3.5 Offshore Wind will significantly reduce unspecified electricity imports



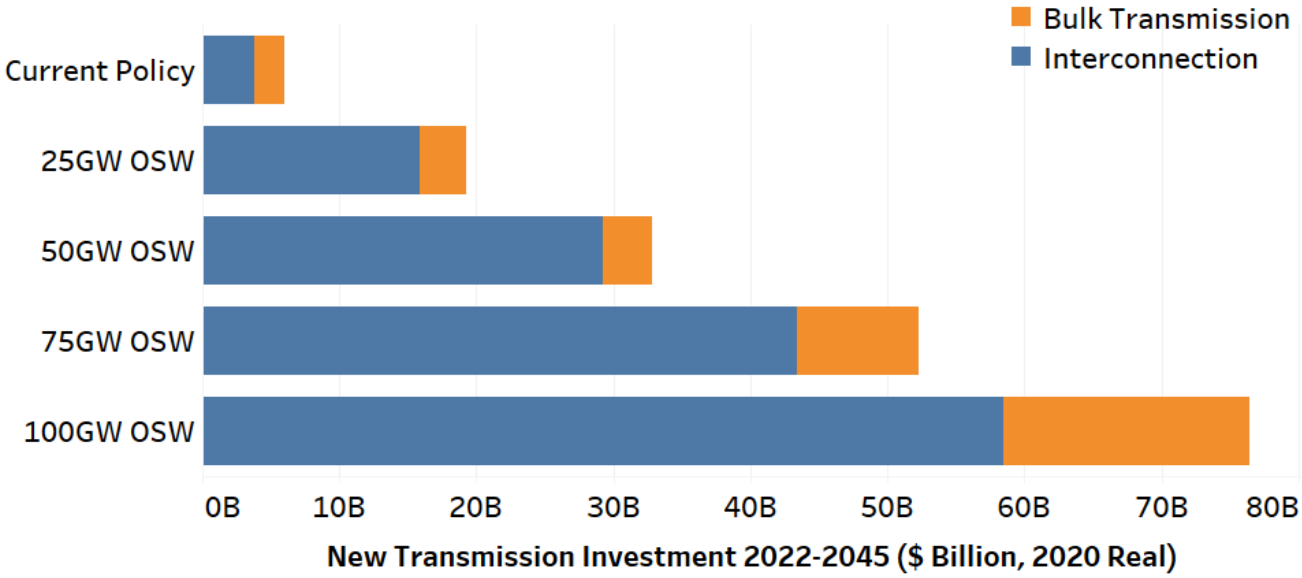
3.6 In the 50GW OSW Case, OSW installations span in the north as well as in the south



Not to scale

Each point shows a wind farm of 40 turbines (600 MW).

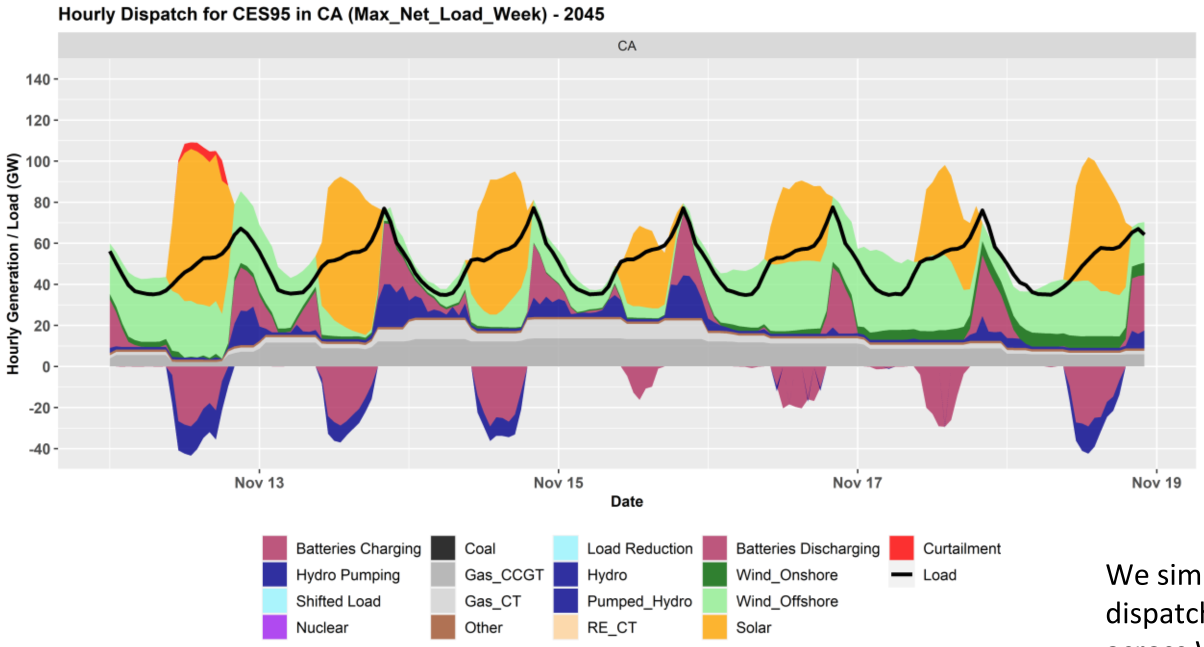
3.7 Transmission investment requirement for a zero emission grid (2022-2045)



Finding #4: Grid with significant OSW is dependable with less storage

4.1 Grid with significant OSW is dependable with less storage

CA dispatch in the 50GW Offshore Wind Case during the highest residual load week (2045)



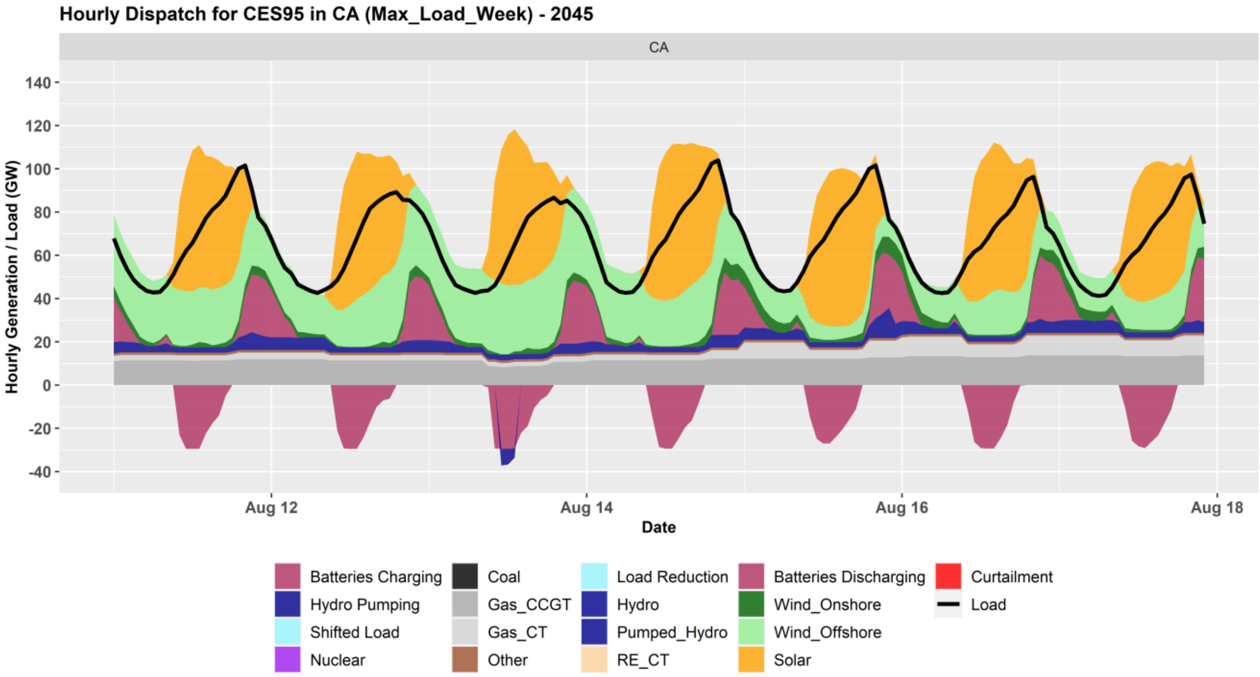
In the 50 GW OSW case, residual load in 2045 will be the highest in fall / early winter due to reduction in solar generation and 1-2 days of low wind generation.

The grid is still dependable as the system dispatches gas to make up for this shortfall.

We simulated hourly system operations and dispatch in 2045 at individual power plant (6,000 across WECC) and across 80 transmission corridors.

4.2 Grid with significant OSW is dependable with less storage

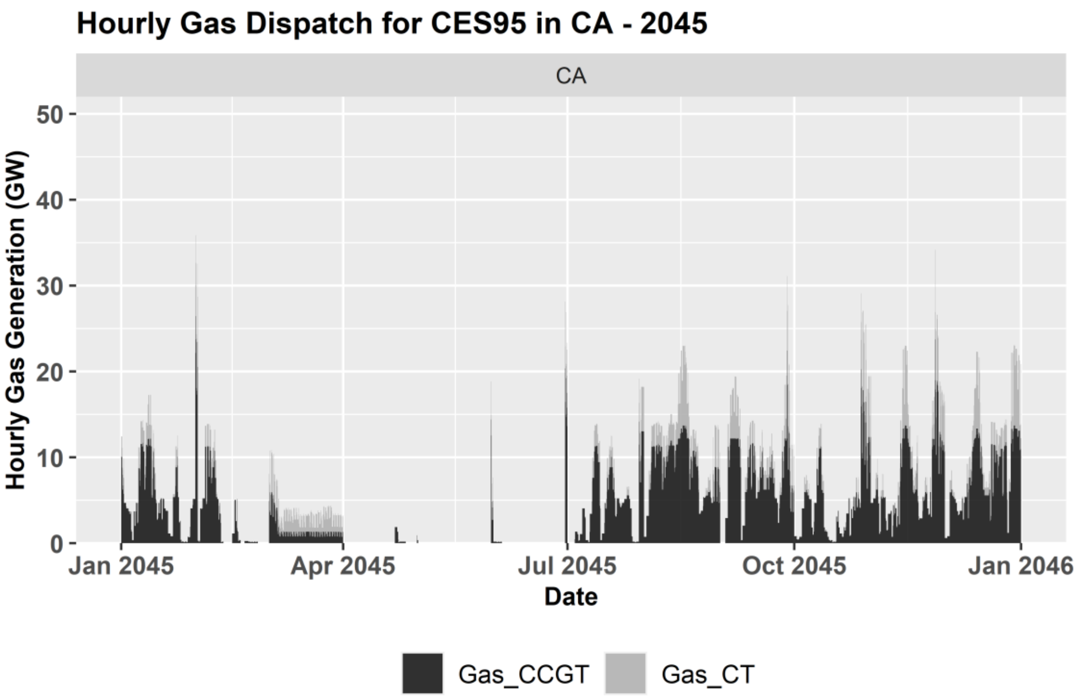
CA dispatch in the 50GW Offshore Wind Case during the peak load week (2045)



The system peak load would nearly double by 2045 (~100 GW on August 15 at about 6 PM).

Solar, OSW, and battery storage work in tandem to meet the peak load.

4.3 ~35GW of gas may still be needed in 2045 for maintaining grid reliability in all scenarios



~35GW of gas may still be needed in 2045 for maintaining grid reliability

Average capacity factor of gas is ~10%

~15GW gas will be dispatched for <1% of the time (88 hours/year).

With flexible load (DR or TOU/peak rates), gas capacity requirement may reduce significantly.

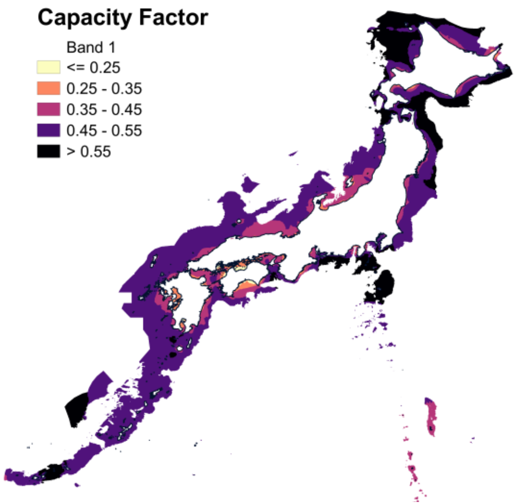
These findings are similar to the SB-100 core scenario results.

Finding #5: CA can become the global leader in the floating OSW technology

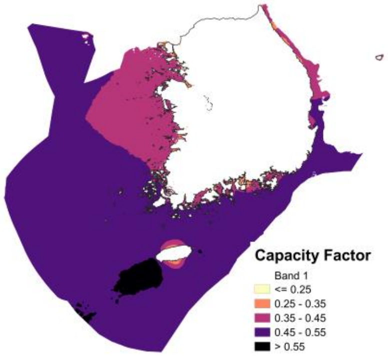
5. Significant global opportunity for floating OSW

e.g. in Japan and Korea, OSW is critical even for short-medium term decarbonization

Japan : 750 GW OSW potential with capacity factor >50%



Korea : 650 GW OSW potential with capacity factor >40%



Both countries have poor quality of land-based wind (~20-25%) & solar (~15-18%) resources, and high (~70% of energy) + expensive imports (~$8-15/mmbtu)

Recommendations

- **Consider deployment of upto 50 GW of Offshore Wind in California by 2045**
  - Critical for increasing the resource diversity & minimizing grid risk, especially in a net-zero economy
  - Wholesale electricity costs do not increase
  - Other countries like UK have already set similar targets in the 2030 timeframe (UK target 50 GW by 2030)

- **Need to evaluate supply chain, employment, and environmental constraints/impacts**

- **Further work required to assess the implications for grid reliability and transmission**

- **Develop strategic global partnerships with countries like U.K., Japan, and Korea**
  - CA can be a global OSW technoogy leader; significant climate and commercial benefits

Appendix 1:
Marginal Contributions of This Study

CEC draft AB-525 Offshore Wind Report does not assess the maximum feasible offshore wind potential in California

AB-525 requirement:

The law directs that on or before June 1, 2022, the California Energy Commission (CEC) shall "evaluate and quantify the maximum feasible capacity of offshore wind to achieve reliability, ratepayer, employment, and decarbonization benefits and shall establish megawatt offshore wind planning goals for 2030 and 2045."

Draft CEC AB-525 Report *(pp 53)*:

Offshore Wind Technical Potential

Based on existing studies described in this report, nearly 21.8 GW of offshore wind technical potential of the 201 GW of the gross resource estimate has been identified and examined for technical feasibility. This number does not represent the quantification of maximum feasible capacity of offshore wind as defined in this report and required by Ab 525, it simply represents the offshore wind technical potential that has been studied.

Source: Draft AB-525 Offshore Wind Report (emphasis added)

Summary of the marginal contributions of this study

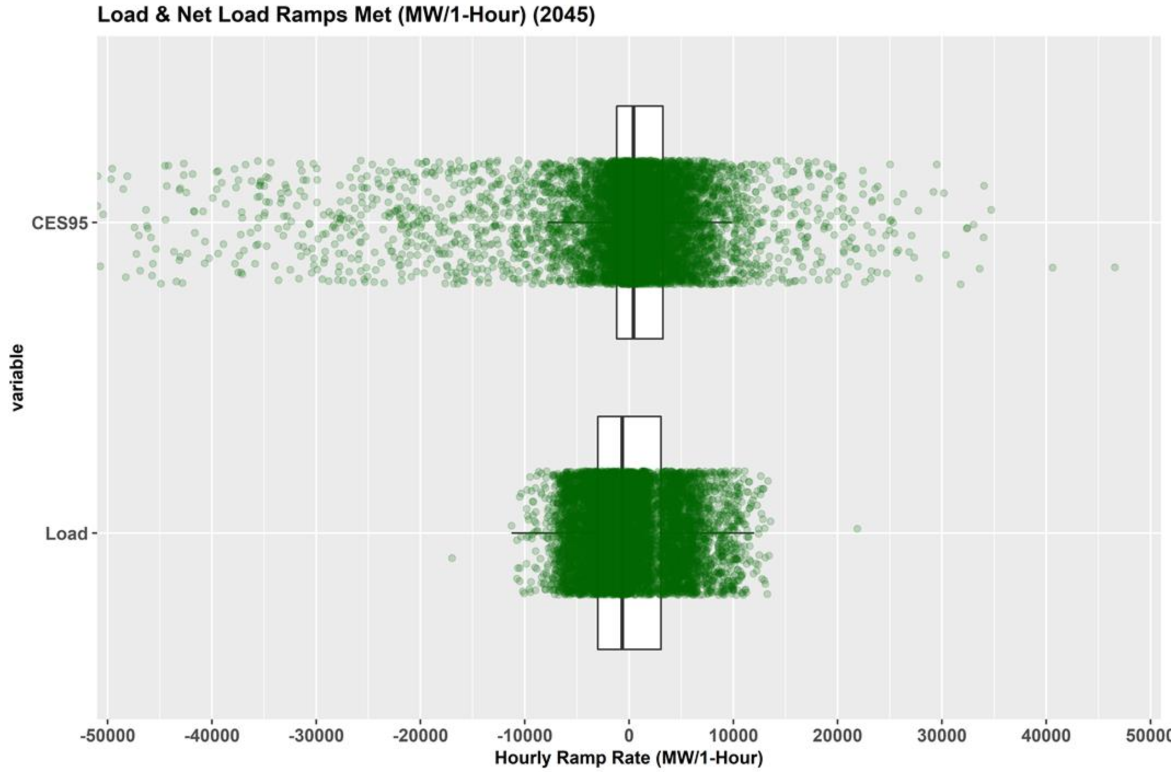
	CEC AB-525 and SB-100 Reports	UCB CA Offshore Wind Report
Zero emission for 100% retail electricity sales	Y	Y
Load w/high electrification	Y	Y
Load w/economy-wide net-zero emissions	N	N
Updated OSW potential	N	Y
Assessment of significant OSW in CA grid	N	Y
High resolution capacity expansion assessment	N	Y
Hourly grid dispatch assessment	N	Y
Bulk transmission assessment	N	Y
WECC wide assessment	N	Y

Marginal contributions of this study

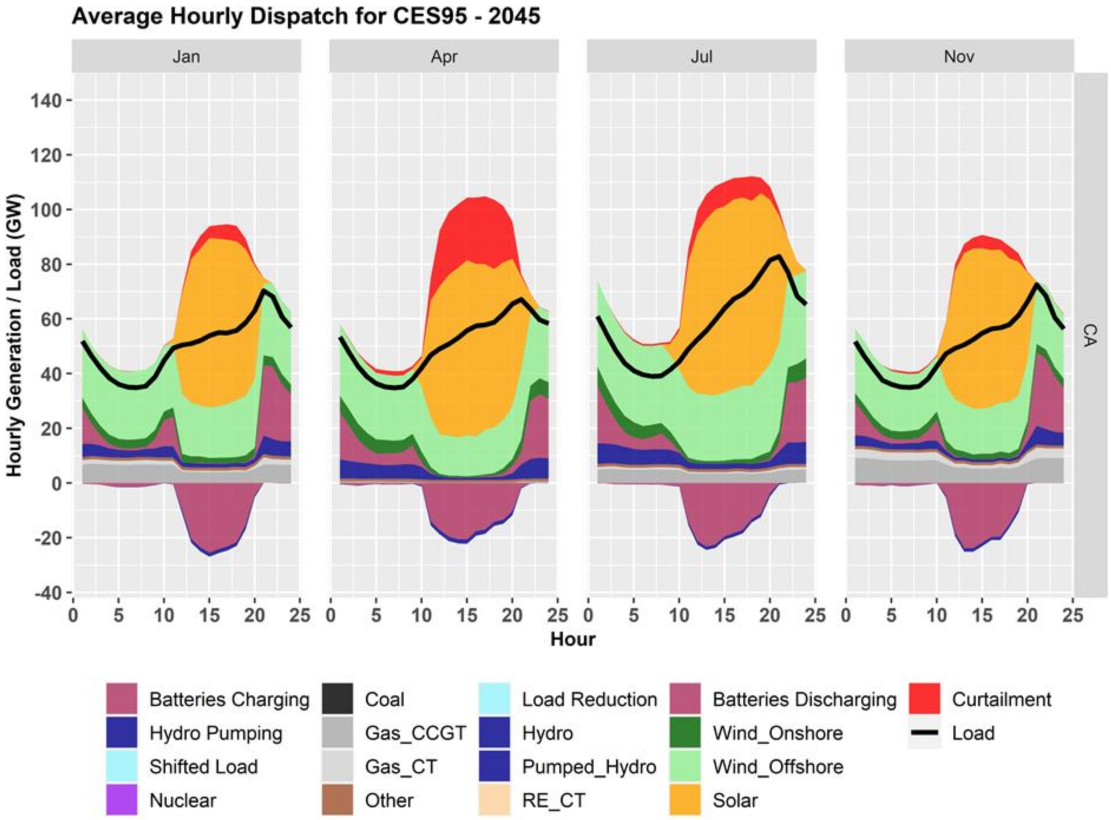
	CEC AB-525 and SB-100 Reports	UCB CA Offshore Wind Report
Zero emission for 100% retail electricity sales	**Y**	**Y**
Load w/high electrification	**Y** (load by 2045 = ~440 TWh)	**Y** (load by 2045 = ~470 TWh)
Load w/economy-wide net-zero emissions	**N** (80% GHG reduction by 2050)	**N** (90% GHG reduction by 2050)
Updated OSW potential	**N** (OSW potential of 21.8 GW ONLY from the current call areas)	**Y** (OSW potential of >200GW per NREL, not limited to the current call areas)
Assessment of significant OSW in CA grid	**N** (Max OSW deployment = 10GW by 2045, which would be ~8% of supply)	**Y** (OSW deployment of 25 to 100 GW by 2045)
High resolution capacity expansion assessment	**N** (Single region model for CA)	**Y** (4-regions in CA; 35 across WECC)
Hourly grid dispatch assessment	**N** (No dispatch simulated)	**Y** (Houly dispatch at power plant level in PLEXOS)
Bulk transmission assessment	**N** (OSW transmission assessment per CAISO transmission plan ~3GW OSW by 2032)	**Y** (WECC-wide bulk transmisson & interconnection assessment in ReEDS)
WECC wide assessment	**N** (Single region model for CA)	**Y** (35 regions across WECC, including major interstate flows)

Appendix 2:
Additional Modeling Results

Ramping requirements will increase significantly by 2045, however, the grid will be able to meet them due to high battery storage capacity



Average hourly dispatch in CA in key months (50 GW OSW Case)



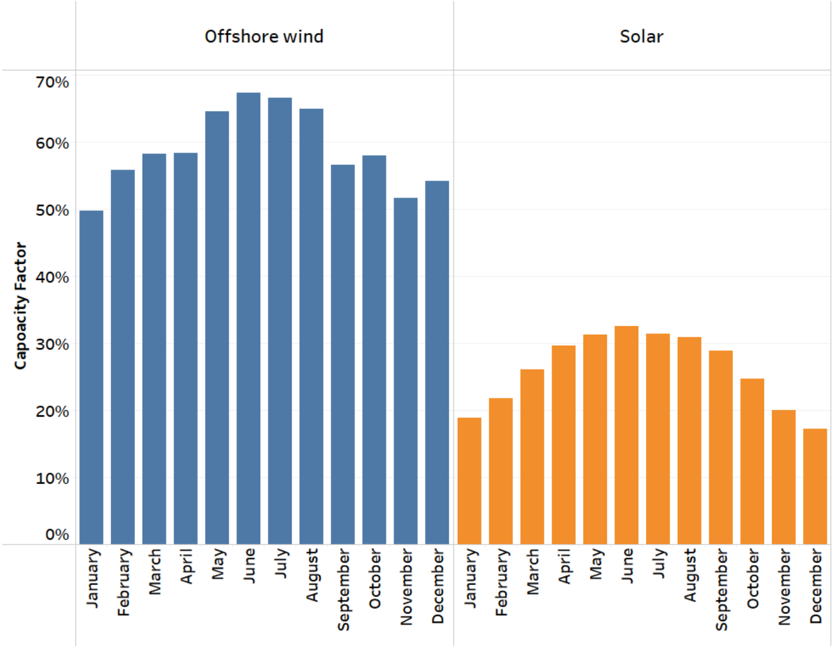
Solar and offshore wind have complementary profiles, which helps in reducing the battery storage requirement to a certain extent.

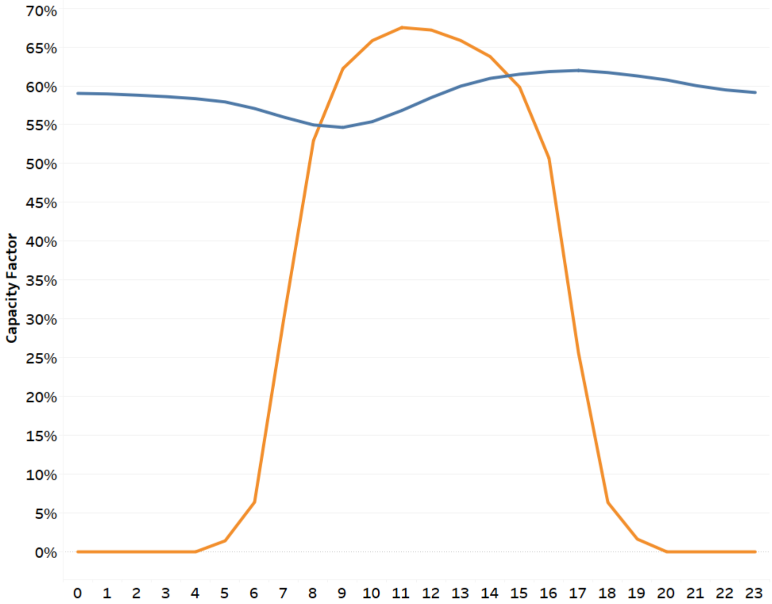
The state avoids most of the unspecified imports from out-of-the-state.

RE curtailment will be the highest in spring.

Batteries charge and discharge almost every day (~250 full charge/discharge cycles in a year).

Monthly and average hourly capacity factors in CA for OSW and Solar





Appendix 3:

Excerpts from CA Offshore Wind Potential Study by NREL (Optis, M, et al, 2020) and CA Floating Offshore Wind Cost Study by NREL (Beiter, P, et al, 2020)

NREL CA OSW Potential Estimates

Table B. Comparison of Gross and Technical Potential Estimates from 2016 Report and This Report

Metric	2016 Report	This Report WIND Toolkit	This Report New CA20 Data Set
Minimum average wind speed ($m \cdot s^{-1}$)	7.0	7.0	7.0
Maximum water depth (m)	1,000	1,300	1,300
Array density ($MW \cdot km^{-2}$)	3.0	3.0	3.0
Gross potential (km^2)	566,058	566,058	566,058
Gross potential (gigawatts [GW])	1,698	1,698	1,698
Technical potential (km^2)	49,916	64,048	67,067
Technical potential (GW)	150	192	201

Table 9. Technical Potential Estimates from CA20 Data Set by Wind Speed Bins. Northern and Southern Potentials are Split Based on a Line at 37.8^o, Which Runs Through San Francisco.

Bin ($m \cdot s^{-1}$)	Northern CA (MW)	Southern CA (MW)	Total (MW)
7.0–7.5	2,845	14,636	17,480
7.5–8.0	3,086	16,106	19,192
8.0–8.5	3,540	19,787	23,327
8.5–9.0	4,233	21,388	25,621
9.0–9.5	5,313	33,465	38,778
9.5–10.0	6,972	26,836	33,808
10.0–10.5	12,268	549	12,817
10.5–11.0	15,540	0	15,540
11.0–11.5	8,404	0	8,404
11.5–12.0	6,234	0	6,234
Total	68,435	132,767	201,202

Table 10. Technical Potential Estimates from CA20 Data Set by Distance to Shore. Northern and Southern Potentials are Split Based on a Line at 37.8^o, Which Runs Through San Francisco.

Bin (Nautical Miles)	Northern CA (MW)	Southern CA (MW)	Total (MW)
<3	6,643	9,094	15,737
3–15	36,364	53,143	89,507
>15	25,428	70,530	95,958
Total	68,435	132,767	201,202

Source: CA Offshore Wind Potential Study by NREL (Optis, M, et al, 2020)

NREL CA OSW LCOE Estimates

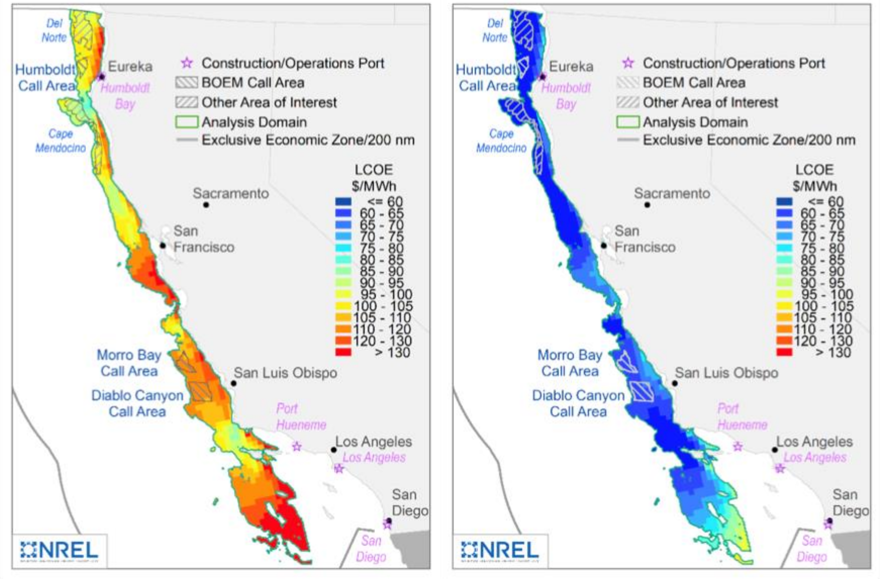


Figure ES-1. LCOE estimates (mid-case CapEx scenario) for the analysis domain offshore California estimated for a 2019 COD (left) and 2032 COD (right)

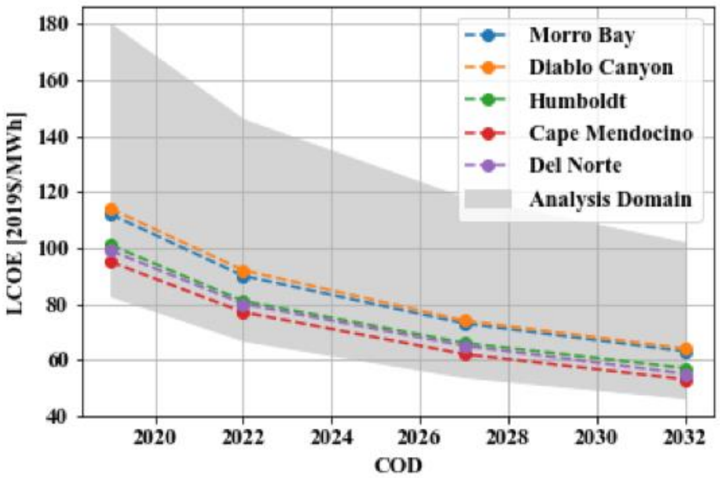


Figure ES-2. Estimated LCOE trajectory between 2019 and 2032 (COD)

Source: CA Offshore Wind Potential Study by NREL (Optis, M, et al, 2020)

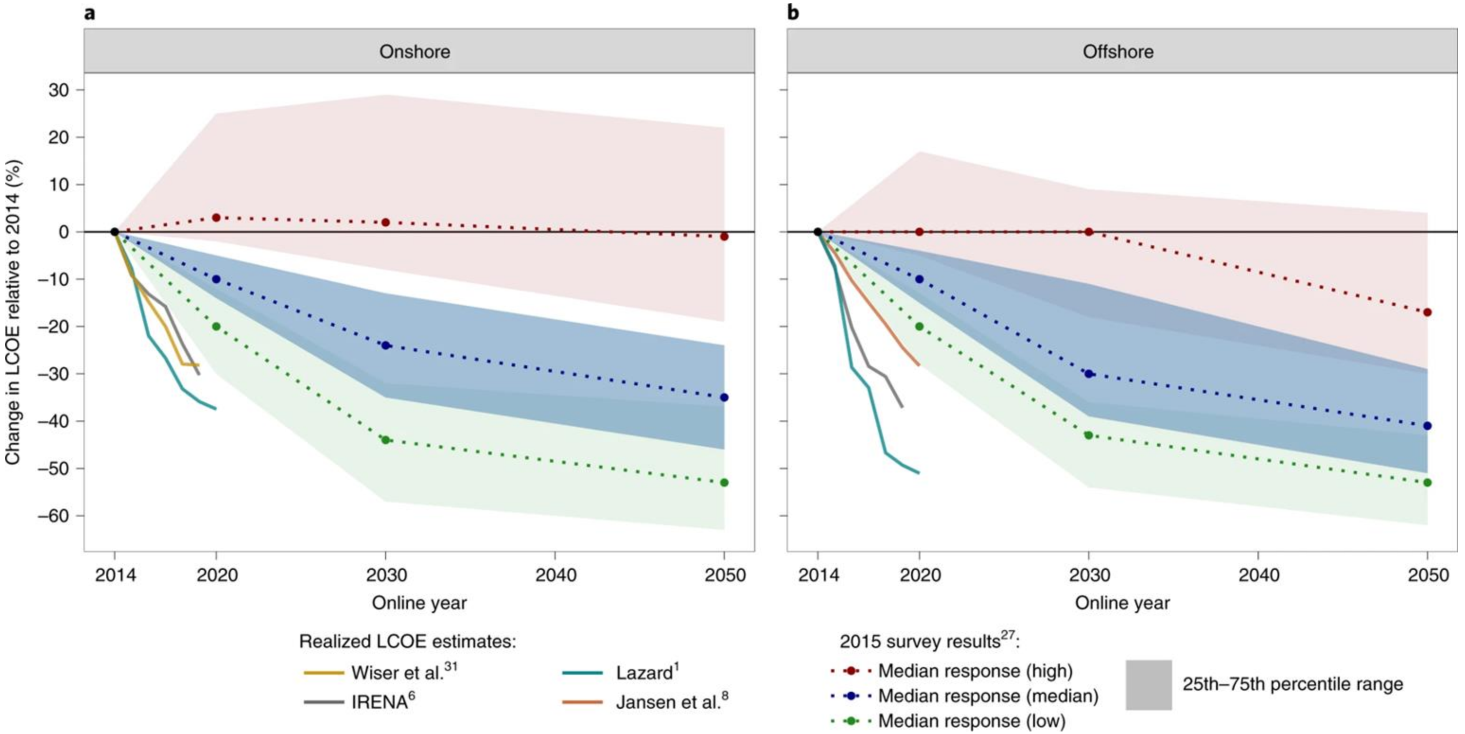
Table 18. Comparison Between the 2019-2020 IRP and NREL Cost and Performance Values

	Net Capacity Factor (%)		CapEx ($/kW)		OpEx ($/kW-yr)		LCOE ($/MWh)	
	2019–2020 IRP	**NREL 2020**	**2019–2020 IRP**	**NREL 2020**	**2019–2020 IRP**	**NREL 2020**	**2019–2020 IRP**	**NREL 2020**
COD	**2030**							
Morro Bay	55	49	3,791	3,139	71	64	76	67
Diablo Canyon	46	48	4,042	3,128	71	63	96	68
Humboldt	52	53	3,791	3,064	71	62	81	61
Cape Mendocino	53	55	3,791	2,976	71	64	79	57
Del Norte	52	55	3,791	3,076	71	64	81	59

Source: CA Floating Offshore Wind Cost Study by NREL (Beiter, P, et al, 2020)

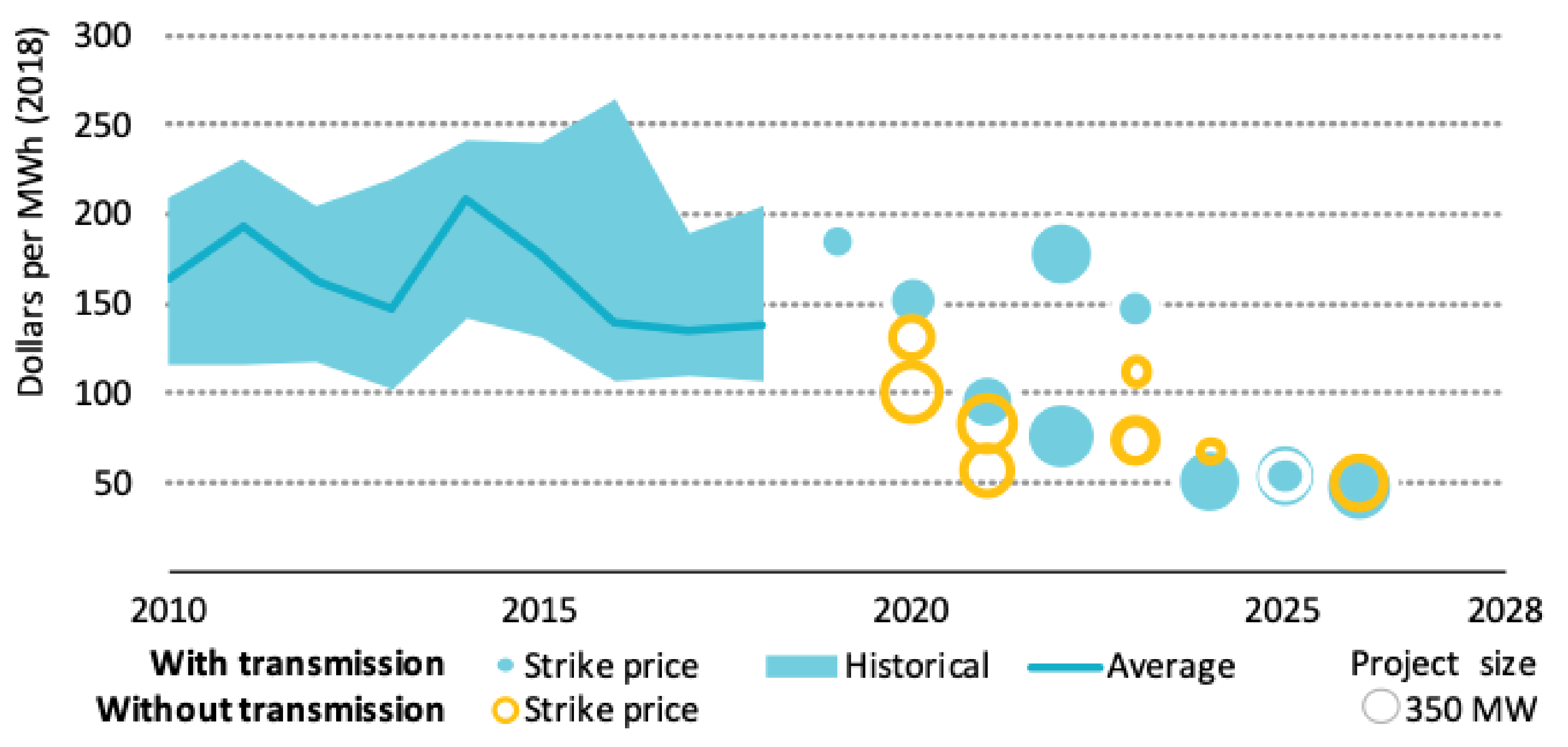
Appendix 4:
Additional Material on Global Perspectives on OSW

OSW cost reductions have occurred much earlier than most aggressive predictions of cost reductions



Results from the 2015 expert elicitation compared with recent published estimates of realized LCOE [(Wiser et al 2021)]

Figure 8 ▹ Historical LCOE of offshore wind and strike prices in recent auctions in Europe



Source: [IEA Offshore Wind Outlook 2019]

Offshore Wind Market Report: 2021 Edition

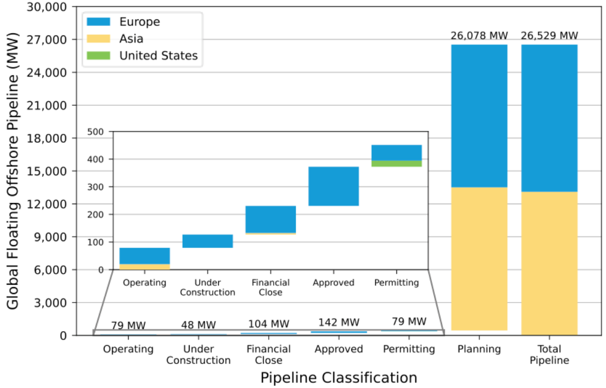


Figure 18. Total global floating offshore wind energy pipeline

There are currently 11 floating offshore wind energy projects installed around the world representing 79 MW of capacity. Five projects (59 MW) are installed in Europe and six (20 MW) are in Asia. There are an additional 15 projects representing approximately 293 MW that are currently under construction or have achieved either financial close or regulatory approval. Four projects (79 MW) have advanced to the permitting phase, and another 87 are in the early planning stages (26,078 MW). Overall, the 2020 global floating offshore wind energy pipeline represents approximately 26,529 MW of capacity.

Source: DOE's Offshore Wind Market Report (2021)

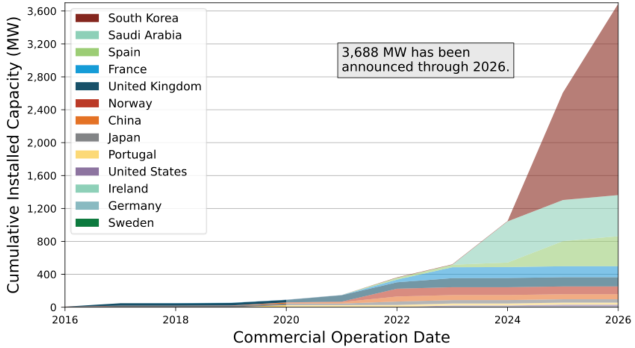


Figure 20. Cumulative floating offshore wind capacity by country based on announced COD through 2026

Offshore Wind Market Report: 2021 Edition

Table 14. Global Floating Offshore Wind Energy Pipeline

Country	Operating (MW)	Under Construction (MW)	Financial Close (MW)	Approved (MW)	Permitting (MW)	Planning (MW)	Grand Total (MW)
China			5.5			68	73.5
France	2			113.7		517	632.7
Germany			2.3			8	10.3
Ireland						2,926	2,926
Italy						3,747	3,747
Japan	19.006					1,028	1,047.006
Norway	2.3		91.6			3,507	3,600.9
Portugal	25					125	150
Saudi Arabia						500	500
South Korea	0.75					9,457	9,457.75
Spain			2.225	8	25	1,036	1,071.225
Sweden	0.03			10			10.03
Taiwan						2,000	2,000
United Kingdom	30	48	2	10	32	1,159	1,281
United States					22		22
Total	79.086	48	103.625	141.7	79	26,078	26,529.41

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