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Potential Offshore Wind Energy Areas in California: An Assessment of Locations, Technology, and Costs

Walt Musial
Manager Offshore Wind
National Renewable Energy Laboratory

California Energy Commission Workshop on Offshore Renewable Energy
Friday, March 3, 2017
About the Study

- Conducted by the National Renewable Energy Laboratory
- Work began in July 2015
- Report was published Dec 2016
- Sponsored by BOEM to inform CA state energy planning
- Extensive peer review with over 160 comments
- All comments were resolved and documented

Floating Wind Energy Market Data

Source: NREL
California Offshore Wind Resource

Gross Resource Capacity – 1,698 GW

- None
- All area 0 to 200 nm

Technical Resource Capacity – 112 GW

- >1000 m
- < 7 m/s

- Water Depth
  - < 30m
  - 30 - 60m
  - 60 - 700m
  - 700 - 1000m
  - > 1000m

- No Competing Use Exclusions
- Competing Use Exclusions
  - 0 – 3nm: 48%
  - 3nm – 12nm: 38%
  - 12nm – 50 nm: 21%

96% of California’s offshore wind resource is deeper than 60 m, indicating site conditions for floating wind.
Siting Objective: Find representative sites that could potentially support future offshore wind for indicative cost analysis

Site selection criteria:

- Annual average wind speed greater than 7 m/s
- Water depths shallower than 1,000 m
- Suitable distance from shore (subjective)
- Lowest use conflicts (using Black and Veatch data circa 2010)
- Access to transmission on land (not required but evaluated)
- Suitable ports for installation and service (does not consider required improvements)

Study is not intended to be a prescreening exercise for future offshore wind development.
Site Selection Process

Filtered technical resource area

Overlaid Black and Veatch exclusions

Subtracted excluded area and selected high wind areas for analysis

Technical offshore wind resource

Technical offshore wind resource and Black and Veatch exclusion data layer

Technical offshore wind resource with lower conflicts showing reference sites
For each site:

- Distance from shore
- Hourly diurnal characteristics
- Geo-spatial assessment of cost variables including depth; distance from electric interconnect, construction and service; wave climate, wind resource
- Time varying cost projection applying current technology trends
- Annual energy and deployment capacity


California Offshore Wind Reference Sites Identified in Musial et al 2016
Site Distance from Shore - Viewshed

Distance from Shore: A primary siting factor

- No established quantitative cut-off criterion
- All sites have significant developable area >30 km (18 miles).

What wind turbines would look like at varying distances from the shore. (Illustration: P.S.E.G.)
https://green.blogs.nytimes.com/2008/10/03/offshore-wind-farm-approved-in-new-jersey/?_r=0

Distance from shore for California six reference sites
Diurnal and Monthly Power Output for Six Offshore Wind Reference Sites

Diurnal Characteristics
- Pattern is consistent from south to north
- Peak power from 17:00 to 19:00
- Low power around 9:00

Monthly Characteristics
- Southern sites peak in May
- Northern sites peak in July

Site 2 and Site 5 were selected to represent southern and northern California coastal regions respectively.
## Representative Sites – Site 2 and 5

<table>
<thead>
<tr>
<th>Offshore Wind Reference Area</th>
<th>2 - Channel Islands North</th>
<th>5 – Humboldt Bay Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Wind Speed (m/s) at 100-m hub height</td>
<td>8.86</td>
<td>9.73</td>
</tr>
<tr>
<td>Min, Mean, Max Significant Wave Height (m)</td>
<td>1.8/2.3/2.5</td>
<td>2.7/2.7/2.8</td>
</tr>
<tr>
<td>Min, Mean, Max Depth (m)</td>
<td>198/575/774</td>
<td>592/870/994</td>
</tr>
<tr>
<td>Construction Port</td>
<td>Port Hueneme</td>
<td>Fields Landing</td>
</tr>
<tr>
<td>O&amp;M Port</td>
<td>Port Hueneme</td>
<td>Fields Landing</td>
</tr>
<tr>
<td>Distance to O&amp;M Port (Straight Line –km)</td>
<td>127</td>
<td>78</td>
</tr>
<tr>
<td>Distance to O&amp;M Port (Avoids Land–km)</td>
<td>127</td>
<td>87</td>
</tr>
<tr>
<td>Interconnection Point</td>
<td>Goletta, CA</td>
<td>Eureka, CA</td>
</tr>
<tr>
<td>Distance to Interconnection (Offshore Until Landfall) (Straight Line–km)</td>
<td>69</td>
<td>80</td>
</tr>
<tr>
<td>Distance to Interconnection (Offshore Until Landfall) (Avoids Land–km)</td>
<td>69</td>
<td>87</td>
</tr>
<tr>
<td>Distance Cable Landfall to Interconnect (km)</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Area (km²) &lt;1,000-m depth</td>
<td>445</td>
<td>431</td>
</tr>
<tr>
<td>Total Potential Capacity (MW)</td>
<td>1,335</td>
<td>1,293</td>
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## California Technology Assumptions 2015 to 2027

<table>
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<tr>
<th>Substructure Technology</th>
<th>2015 Technology</th>
<th>2022 Technology</th>
<th>2027 Technology</th>
</tr>
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<tbody>
<tr>
<td>Turbine Rated Power (MW)</td>
<td>6</td>
<td>8</td>
<td>10</td>
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<tr>
<td>Turbine Rotor Diameter (m)</td>
<td>155</td>
<td>155</td>
<td>155</td>
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<tr>
<td>Turbine Hub Height (m)</td>
<td>100</td>
<td>112</td>
<td>125</td>
</tr>
<tr>
<td>Turbine Specific Power (W/m²)</td>
<td>318</td>
<td>314</td>
<td>303</td>
</tr>
<tr>
<td>Substructure Technology</td>
<td>Semisubmersible</td>
<td>Semisubmersible</td>
<td>Semisubmersible</td>
</tr>
</tbody>
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### California Floating Wind Technology Assumptions 2015 to 2027

- **Trends Indicate Continued Turbine Growth to 10 MW**: Largest Turbines will be Selected
- **Generic power curves used to calculate Annual Energy Production (AEP)**
Levelized Cost of Energy – Primary Source

\[ \text{LCOE} = (\text{FCR} \times \text{CapEx}) + \text{OpEx} \]

where:

- \text{FCR} = \text{fixed charge rate (\%)}
- \text{CapEx} = \text{capital expenditures ($/kW)}
- \text{AEP}_{\text{net}} = \text{net average annual energy production (kWh/yr)}
- \text{OpEx} = \text{average annual operational expenditures ($/kW/yr)}


Primary Source Document from 2016 DOE Offshore Wind Strategy
California LCOE Estimates and Adjusted European Strike Prices

Fixed-bottom strike prices from 2016 European bids indicate rapid price declines.

Source: Data derived from Garlick et al. (4COffshore) (2017)

* Grid and development costs added
** Grid costs added and contract length adjusted
Example Deployment Scenario: 2-600MW per site (7.2 GW)

- Site utilization 23% to 93% per site
- 400 km$^2$ per site (Array density 3 MW/ km$^2$)
- 35 TWh/year total energy production
- Approximately 13.5% of California’s 2014 electric energy demand

Future offshore wind can potentially contribute at multi-GW scale in California.
Conclusions

• CA technical offshore wind resource is 112 GW or 392 TWh/year; about 1.5x CA electric use
• 96% of OSW resource is deeper than 60 m, indicating site conditions suitable for floating wind
• Floating wind may be commercially ready by 2025
• Offshore wind can contribute at multi-GW scale in CA
• Onshore infrastructure is more abundant in southern California
• More severe wave climate results in higher LCOE
• Site similarities result in small LCOE variations.
  o Site 2 potential reduction from $182/MWh to $97/MWh
  o Site 5 potential reduction from $188/MWh to $100/MWh
Limitations and Caveats

• Economic potential is dependent on the level of policy support, technology attributes, the value of other market factors, and the prevailing electricity prices.

• Floating baseline cost ($187/MWh for 2015 floating wind) has higher uncertainty than fixed-bottom due to limited deployments.

• Cost declines assume that a mature supply chain develops.

• Sharp declines in fixed offshore wind cost and increasing floating wind innovation globally support the possibility of lower offshore wind costs over time.
Selected References


