

ATOC-5570 Semester Project

Literature Review: Due Feb 15th

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Topic: Floating Offshore Wind Energy in California

1. (Krishnamurthy et al., 2021): This report aimed to highlight two potential offshore sites for wind farms off the coast of California. The source of data came from two lidar-equipped buoys: one near Morro Bay (50km off the coast; ocean depth 1100m) and another near Humboldt County (40km off the coast; ocean depth 625m). This study has been the first and only to perform a wind resource assessment at hub height (100m). The data collection period in Morro Bay determined that winds exceeded 3 m/s 85% of the time, and 12 m/s 25% of the time. Combining this distribution with the shore location of grid operations, makes the Morro Bay site an ideal location for providing CA with a reliable electricity. The collection period for Humboldt County only included the winter months (due to extreme wave events). Wind speeds experienced at the Humboldt site were above 3 m/s 82% of the time and above 12 m/s 27% of the time. More research is planned to relate sea state conditions and effects to the Marine Boundary Layer.
2. (Optis et al., 2020): This 2020 report wished to provide a wind resource assessment specifically for California that modelled 20 years (CA20) of data through the Weather Research & Forecasting (WRF) numerical weather prediction (NWP). This new dataset claims that there is a potentially of 200 GW of offshore wind energy, which is roughly 30% higher than a 2016 NREL assessment (Musial et al., 2016). Much time is spent explaining the updates to the assessment; among many are updated software models, excluding environment conflicts, and increased depth limit for floating turbines. The CA20 found higher mean wind speeds than a previous 7-year simulation dataset published in 2013. Moreover, CA20 reported increased windspeeds of 9.7% in Humboldt, 17.4% in Morro Bay, and 19.7% in Diablo Canyon, all promising call areas for floating wind farms.
3. (Sheridan et al., 2021): This report set out to assess large deviations in hub-height (90m) wind speed between observed offshore data and modelled data from reanalysis tools. One lidar-equipped buoys located off the coast of New Jersey collected data from Nov 2015 – Feb 2017, and a second, located off the coast of Virginia collected data from Dec 2014 – May 2016. Further, the report went to evaluate under what sea and atmospheric condition the reanalysis tools best fit the observed data. One note is that nearly all reanalysis products simulated mean wind speeds slower (< 1 m/s) than what was observed by both lidar buoys. Interestingly, biases were found during upwelling and downwelling events for the buoy in New Jersey, but not in Virginia, which has to do with the ocean depth. Since upwelling and downwelling are responsible for sea surface temperature variations near coasts, this implies that reanalysis tools' grid-resolution is paramount to accurately capturing how the temperature gradients impact offshore wind resources.
4. (Dvorak et al., 2010): This report, albeit relatively outdated was referenced by many of the more recent studies when it comes to assessing wind resources off California. The methods to determining viable offshore areas was informed by bathymetry from the National Geophysical Data Center's Coastal Relief model. Three depth categories were defined: 0-20m for monopiles, 20-50m for multi-leg, and 50-200m for floating turbines. Despite less mature weather models and lack of hub-height observation data, the report set out to determine potential sites based on

current technology, existing infrastructure, and construction techniques. To make up for the lack of in-situ data, NOAA's Mesoscale Model version 5 (MM5) weather model was run for different areas off CA's coast and validated with existing offshore buoys gathering surface wind speed. An example windfarm located Cape Mendocino was provided. The farm had the capacity to generate nearly 7 TWh of energy and offset 4.0% of carbon emitting electricity generation, circa 2014. It concluded that Northern CA has more viable areas than previously thought (a.k.a shallow water) and Southern CA would require floating wind farms.

5. (Musial et al., 2016): This study was published by NREL in the hopes that the research will assist key stakeholders when planning offshore wind projects in California. Since this report was a predecessor to (Krishnamurthy et al., 2021), it helped describe the decision process in site selection off the coast of California. Initial criteria included but not limited to, annual mean wind speeds greater than 7 m/s, access to major transmission lines, and suitable ports for installation. The report found that there is more than 110 GW of potential wind energy off the coast of California, but only 5.1 GW are in waters less than 60m deep. Further, the assessment notes that much of the shallow water wind resources may not be available because of local populations and animal species. Out of many conclusions, the glaring reality is that floating wind turbines were in their infancy in 2016 so a lot of the cost modelling is speculative and leaves a lot of "wiggle-room" for construction and O&M strategies to develop over time.
6. (Yue et al., 2019): This report highlights the importance of multiple data sources when planning for offshore wind projects. When it comes to offshore wind resource assessments, there always seem to be gaps in data or high cost-barriers to validating simulations. This study focused on a wind farm site in the Changhua area on the west coast of Taiwan. At the site, a mast meteorological tower, 95m above sea level was installed 6km off the coast in 15m deep water. To accompany the mast data, data from MERRA-2 satellite program and weather data from Taiwan's Central Weather Bureau were used in the study. This combination of short-term and long-term measurements were inputs to WindSim when it came to generate a wind plant layout. Overall, the wind direction correlation between MERRA ranged from 0.78-0.81, whereas correlation to local weather measurements were closer to 0.9. Wind speed correlation was 0.32-0.63 for MERRA and 0.75 from CWB. The results make sense because the mast was located offshore, whereas MERRA data points were either inland or much further out to sea. Likewise, the CWB data came from an onshore weather station. The fact that long-term data is rarely found at the location of a proposed wind farm means multiple data sources and observation should inform simulations.
7. (Liu et al., 2008): This older report was referenced by more recent assessments for California offshore wind potential. The study leveraged 8 years of data from the Physical Oceanography Data Active Archive Center, from the QuickSCAT program. The data has a 12.5km resolution and focused on high wind speed events, which in the past has aided maritime shipping. Despite, the low resolution of this dataset, it presented an ideal area off Cape Mendocino, later referenced in (Dvorak et al., 2010). At the time of this report, the data provided insight to regions that might have high wind power density. Overall, remote sensing from satellites would be ideal for wind resource assessment, but the resolution would need to be very high.
8. (Stoutenburg et al., 2010): This novel study proposes a co-located energy plant that utilized the strong offshore wind resources in northern California and wave energy. As of 2010, both floating turbines and wave energy generators were emerging concepts, but today this cohabitation could help both penetrate renewable energy portfolios. The data used is from NOAA's National Data Buoy Center (NDBC), where 20 buoys contained nearly 30 years of wind and wave data off California's coast. One limit is that the wind data was only capture 5m above the surface, and the authors used a logarithmic law with a neutral atmospheric conditions assumption to get 80m hub-

height windspeeds. Wave energy is highest in Northern California and runs nearly parallel to the coast. Conversely, wind and wave energy rapidly fall off in Southern California as the coast refracts eastward. The data shows that while the capacity factor for wind energy tends to cycle annually, the wave energy tends to be relatively constant. Also, during the summer, the rated power output for wave energy is independent of diurnal cycles, unlike wind energy. Like other studies, this hybrid concept of energy generation was limited to existing buoys and historical data, therefore the goal was not assess an optimal location for a wind plant.

9. (Jonkman & Matha, 2011): This report explores the dynamics of floating wind turbine using NREL's OpenFAST simulation software. OpenFAST can run a nonlinear time-domain simulation that incorporates models that analyzing the coupling between turbine, hydrodynamics, wind effects, and mooring. Embedded in this study was the comparison between the nonlinear time-domain simulation, and a new linearized state-space feature from OpenFAST. The analysis of a 5-MW baseline turbine and platform showed similar results between the linearized and nonlinear motion output. It was most accurate at low frequency and low amplitude waves with some divergence at high amplitude and higher frequency waves. The benefit to a linearized model will aide in floating turbine dynamics, structural characterization, stability analysis, and control system design.

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