The Pennsylvania State University

Port Fourchon Offshore Wind Project
Project Development Report

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1.0 Executive Summary

The Happy Valley Energy Corporation (HVEC) presents this proposal for a 308.0 MW wind farm located off the coast of Port Fourchon, Louisiana under the name Port Fourchon Offshore Wind Project (PFOWP) consisting of 14 x 22 MW wind turbines. Upon analyzing the region's wind resource, environmental conditions, and competing uses, a site was selected approximately 13 km from shore. Site development and research for this project was conducted using both the Jobs and Economic development Impact model (JEDI) and the System Advisory Model (SAM). HVEC plans to sell the power generated by the project at an initial PPA price of $84.5/MWh to the utility Entergy to support the growth of their Shore Power program. The project would average an annual energy production of 1,009,242.6 MWh at a capacity factor of 37.4%.

2.0 Site Description and Energy Estimation

The lease block auction area off the southern coast of Louisiana was previously considered[1] resulting in selection of lease blocks 34 & 35, as shown in Figure 1. Factors which went into the selection of this site include the relatively uniform wind speeds in the region, proximity to a grid interconnection point as well as avoidance of other competing uses of the Gulf, including oil & gas infrastructure as well as vessel traffic and environmental considerations. As a result, HVEC plans to develop the two lease blocks (totaling 10,000 acres) to host a 308 MW wind project. The site selection, environmental impacts, wind resource assessment, selected turbine type and the overall detailed layout and energy production estimates of the 14 turbines is described in detail in the following sections.

2.1 Site Selection

Lease blocks 34 and 35 are located approximately 13.22 km to shore, with another 4 km to the closest interconnection point at the Leeville Entergy substation. Impacts to shipping lanes, reefs, archeological resources and boat traffic are minimal in the selected blocks. There is only one shipwreck and no coral reefs or specific environmental concerns in these blocks so transportation and installation of the turbines will not affect the surrounding environment. Block 36 was not selected due to gas pipelines running through the area as well as increased vessel traffic.

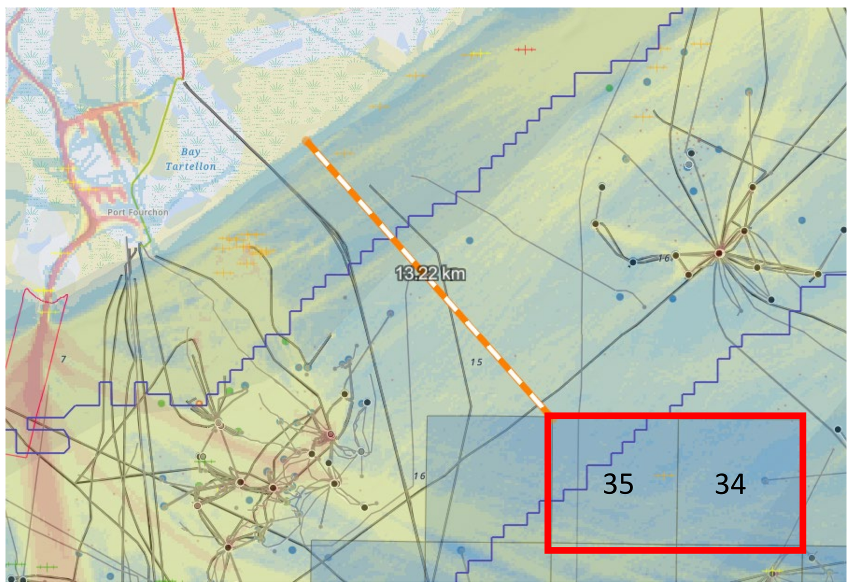


Figure 1: Lease blocks 34 and 35 with proximity of land

As shown in Figure 1, there are many activities occurring in the Gulf of Mexico such as fishing, oil and gas extraction, shipping, and vessel traffic, so ensuring that the wind farm does not interfere with such activities is crucial. Fishing occurs in moderate density near the site, seeing counts as high as 34 transits per year in the NW and SE corners of the combined blocks.[2] The final layout of the project should help mitigate impacts fishing in these regions. There are a few abandoned pipelines in the area, so care should be taken in laying cable to shore as there may be places where the electric cable would need to cross these pipelines. Vessel transit counts are quite dense overall in the region around Port Fourchon, shown as blue (less) to yellow/red (more) lines in Figure 1. The blocks selected had very low transit counts for cargo ships, and recreation vessels and minimal tug and toe vessel traffic, ensuring wind farm development should not obstruct these activities.[2] Only one shipwrecks is located in the lease block area (on the right side of block 35) and zero oil/gas platforms, meaning that construction should not be hindered by those obstacles.[2] There is also one abandoned oil/gas borehole in block 34, as well as an abandoned pipeline in the Eastern edge. Fortunately, selecting a location in lower vessel density allows for optimal wind farm function as well as preventing interference with vessel routes.[2]

2.2 Environmental Impacts and Mitigation

Species of Concern

Based on the Marine Cadastre[2] maps and NOAA,[3] there are several species to be aware of in the region. Leatherback sea turtles and loggerheads are listed as vulnerable.[4] Their habitat range lies mostly outside the leasing blocks of interest.[2,5] Although the likelihood is exceptionally low, there is still a possibility for at least a few turtles to migrate near the site. Green sea turtles and Kemp Ridley's Turtles are species of concern, as both are listed as endangered and their habitat consists of inshore and nearshore waters in temperate and tropical regions, falling in the leasing blocks.[6–8] The turtle's tendency to stay near coast for reproduction raises the likelihood that the sea turtle population could be high around or near the selected wind farm location.[9] Whale species also migrate through the Gulf of Mexico, although not to the same degree as other aquatic species, such as turtles. Blue Whales, Fin Whales, Sei Whales, and Sperm Whales tend to live in deep, offshore waters in the open ocean and are not a major concern in the area.[10–13] Likewise, the habitat range of coral reefs does not extend to the Northern coastlines in the Gulf, meaning no interference should occur.[14] Protected areas near the tip of southern Louisiana include two refuge islands: Queen Bess Island and Elmers Island.[15] The two protected areas will not be impacted by the transportation of the turbines because there are miles that separate both the wind farm location and the islands.

Hypoxic Zone

The Gulf of Mexico, specifically the area of interest, falls within the hypoxic zone where the ocean water has reduced oxygen levels and few organisms on the sea floor can survive. The hypoxic, "dead," zone develops off the Texas-Louisiana shelf during the warm summer months.[16] Nutrient-laden freshwater from the Mississippi river flows into nearly 7,000 square miles of the Gulf of Mexico.[16] Dead plant material falls from the surface of the river to deep water columns of the Gulf.[16] Bacteria consume the material using oxygen, meaning that no oxygen is left in the affected area. Fish and marine mammals can swim away from the oxygen lacking area with ease, but weaker organisms are affected and die because they are unable to migrate away from the area. Louisiana and other states along the Mississippi River path are trying to reduce the hypoxic zone by utilizing river diversions, which are restoration projects to sustain coastal wetlands).[16]

Mitigation Measures

Off the shores of the Louisiana coastline, the Greater Lafourche Port Commission and the Barataria-Terrebonne National Estuary Program use dredged materials to construct a 6,000-foot ridge that protects the shoreline and communities from surges and erosion.[17,18] This project also restored critical marsh and chenier ridge habitats, which are especially important for over 338 species of migrating birds.[18] Additionally, the Estuary Program provides vital lessons in plant propagation for restoring these habitats, constructing techniques, and planting and soil chemistry methodologies.[17] Similarly, Port Fourchon's Northern Expansion Project developed port property while enhancing the environment, creating an acre of new marsh for every acre of wetland impacted.[17] This project transformed open water into productive marsh habitats. Moreover, the Fourchon Beach Repair Projects successfully prevented beach erosion via regularly re-nourishing, repairing, and rebuilding to maintain and strengthen the coastline.[17] Any of these projects could be employed with the construction of the offshore wind farm, but the most effective might be the construction of a maritime forest ridge. By using dredged materials to create chenier ridges, we can transform material commonly seen as a waste product into ecosystems that shield wind from the full impacts of waves and storms. As an indirect benefit, coastal ecosystems and communities would also be protected by these ridges, preventing erosion and flooding damage.

In terms of direct mitigation measures of wind turbines themselves, a significant environmental concern is noise pollution.[19] Wind farm construction creates the most underwater noise in terms of the wind farm development process. Such noise can cause non-auditory injury, hearing loss, auditory masking, and behavioral disturbance in marine organisms. Injury-causing noise levels are more common at close range to turbine construction, as seen in Figure 2.[19] Behavioral altering noise levels effects extend significantly beyond the construction site location.[19,20]

To help prevent noise pollution from harming aquatic life, several mitigation measures can be taken.[19,20] Passive acoustic monitoring can be used to assess the frequency and distribution of marine life near wind farms, which can help understand potential impacts of sound intensity. Visual surveys, animal tagging, and aerial surveys can also be used to collect data and better analyze the density and movement of different organisms.[19,20]

Installation of bubble curtains has proven to be effective in reducing noise pollution, which reduces the spread of noise via placing a barrier of bubbles around the pile driver during construction.[19,20]

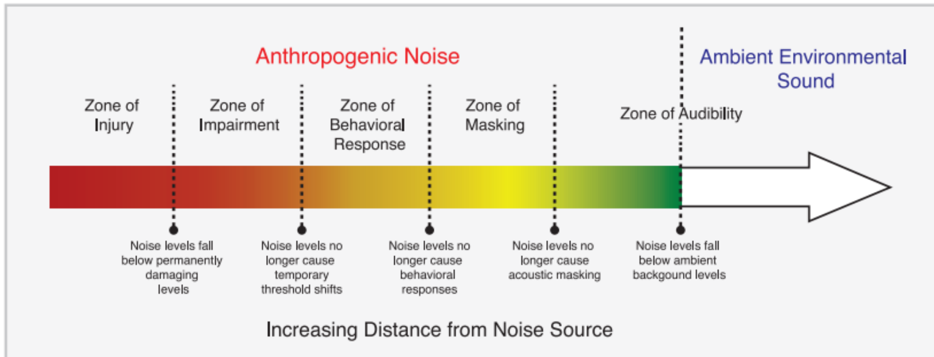


Figure 2: Diagram showing the zones of noise levels by increasing distance from the noise source.[19]

Another noise reduction technique would be to soft start, or gradually ramp up the pile driving energy to help avoid damage to marine organisms.[19] Furthermore, using time-of-year restrictions would limit pile driver activity to only certain times of the year where marine life is less likely to be near the construction location.[19] Lastly, employing trained protected species observers, who maintain exclusion areas for certain species, can protect these organisms and demand a cease to pile driving activity when the species comes near the construction zone.[19,20] Using a combination of these methods would be the best recommendation to reduce the noise pollution wind farm construction would produce, helping to protect marine life from behavior-altering or injury-causing noise.

2.3 Wind Resource Assessment

The region of interest is in the Gulf of Mexico off the southern coast of Louisiana. It was found from the Global Wind Atlas,[21] that the average annual wind speed at various points across the available lease blocks range from 7.11 to 7.14 m/s at a height of 150 m. This is a relatively consistent wind resource, contrasting the more 7-10 m/s wind resource gradient found off the East and West coasts of the US. Three locations were analyzed before selecting the final wind farm site for its proximity to the coast and transmission infrastructure, as described previously. Wind speed and wind direction data were downloaded from the Wind Toolkit[22], providing detailed wind characteristics. Figure 3 shows a 12x24 chart of monthly and diurnal mean wind speeds for the project location at an elevation of 200 m. Figure 4 provides seasonal mean wind speeds by direction, while Figure 5 shows both the wind directional frequency rose as well as the percent of total energy from each direction at 200 m. There is considerable variation in both the wind direction and wind speeds across the seasons, thus it was essential to conduct wind turbine placement optimization, which will be described later in this report.

Since the wind power in this region is lower than other parts of the country, and wind speeds in the atmospheric boundary layer increase with elevation, it is desirable to use taller towers to tap into the higher wind speed potential aloft. Thus, hub heights of 180 m and 200 m were considered for this project. Minimum clearance (22 to 28 m) would be required, which will be discussed in the next section. A long-term wind resource analysis was also conducted for the site to investigate potential extreme conditions that may impact turbine selection. MERRA2[23] data from 1985 to 2022 was downloaded within Windographer[24]

Mean Speed at 200 m (m/s)													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	All
00:00 - 01:00	9.227	8.298	8.598	8.544	7.411	5.861	5.381	5.455	5.72	6.736	10.128	8.806	7.51375
01:00 - 02:00	8.703	8.378	8.958	8.838	7.574	5.395	5.535	5.024	5.596	7.024	10.265	8.854	7.512
02:00 - 03:00	9.042	8.574	9.239	9.288	7.665	5.468	5.518	5.036	5.519	7.168	10.524	8.921	7.6635
03:00 - 04:00	9.404	8.906	9.174	9.483	7.678	5.466	5.672	5.275	5.555	7.156	10.118	9.107	7.7495
04:00 - 05:00	9.425	8.947	8.985	9.538	7.637	5.807	5.851	5.262	5.629	7.172	10.074	9.072	7.78325
05:00 - 06:00	9.479	8.829	9.05	9.518	7.618	5.805	5.784	5.644	5.483	7.282	9.965	8.993	7.7875
06:00 - 07:00	9.56	8.8	8.809	9.193	7.532	5.795	5.984	5.422	5.332	7.019	9.73	8.945	7.67675
07:00 - 08:00	9.566	8.396	8.71	9.217	7.319	5.999	5.976	5.235	5.281	6.958	9.784	8.892	7.611083
08:00 - 09:00	9.387	8.471	8.494	9.488	7.38	5.69	6.091	4.984	5.096	6.793	9.481	8.869	7.518667
09:00 - 10:00	9.191	8.082	8.492	9.264	7.031	5.46	5.869	4.834	5.003	6.748	9.604	8.922	7.375
10:00 - 11:00	9.284	7.973	8.44	9.209	6.945	5.006	5.659	4.702	5.02	6.728	9.646	9.149	7.313417
11:00 - 12:00	8.992	7.692	8.577	9.288	7.08	5.132	6.003	5.188	5.282	6.604	9.816	9.106	7.396667
12:00 - 13:00	9.036	7.6	8.744	9.424	6.877	4.746	5.665	5.239	5.346	6.676	9.848	9.156	7.363083
13:00 - 14:00	9.023	7.764	8.614	8.941	6.614	5.03	5.333	4.824	5.43	6.474	9.918	9.212	7.26475
14:00 - 15:00	8.924	7.754	8.254	8.62	6.17	4.573	4.719	4.428	5.541	6.656	9.854	9.048	7.045083
15:00 - 16:00	8.8	7.676	8.033	8.503	6.094	4.449	4.606	4.837	5.633	6.588	9.668	8.828	6.97625
16:00 - 17:00	8.559	7.453	7.71	8.135	6.052	4.315	4.634	4.439	5.702	6.429	9.159	8.554	6.76175
17:00 - 18:00	8.27	7.466	7.245	8.176	6.037	4.821	5.065	4.42	5.668	5.894	8.986	8.302	6.695833
18:00 - 19:00	7.904	7.514	7.214	7.9	6.134	4.856	5.493	5.014	5.848	5.65	8.853	8.382	6.730167
19:00 - 20:00	7.927	7.514	7.336	7.857	6.321	4.95	5.751	4.955	5.687	5.547	8.801	8.209	6.737917
20:00 - 21:00	8.1	7.893	7.539	8.092	6.351	5.215	5.644	4.926	5.993	5.473	9.191	7.976	6.866083
21:00 - 22:00	8.031	7.928	7.751	7.951	6.401	5.938	5.983	4.973	5.594	5.384	9.332	7.745	6.917583
22:00 - 23:00	8.274	8.108	7.892	7.933	6.593	5.8	5.525	4.907	5.482	5.607	9.43	8.019	6.964167
23:00 - 24:00	8.553	8.081	8.187	8.056	6.903	5.802	5.209	5.031	5.86	6.07	9.62	8.722	7.1745
All	8.860875	8.087375	8.335208	8.769	6.892375	5.307458	5.539583	5.00225	5.5125	6.493167	9.658125	8.741208	7.266594

Figure 3: Mean Wind Speeds Over a Year Against Diurnal Variation at 200 m

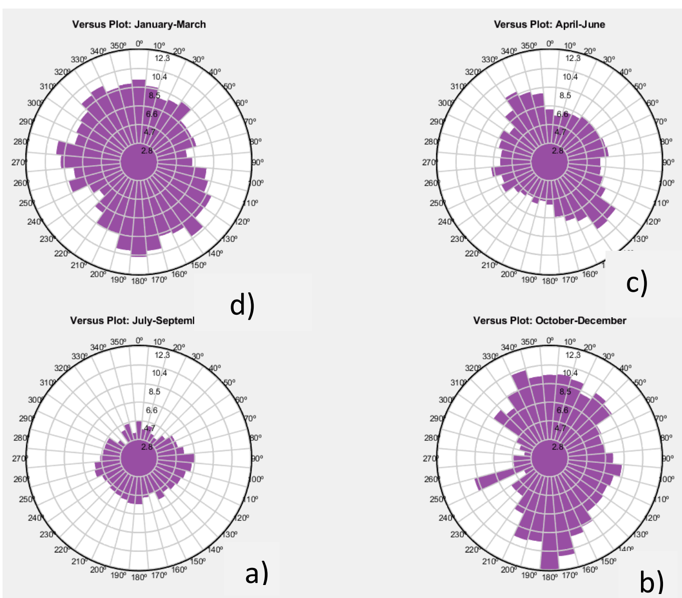


Figure 4: Seasonal Mean Wind Speeds by Direction, a) January – March, b) April – May, c) June – September, d) October – December.

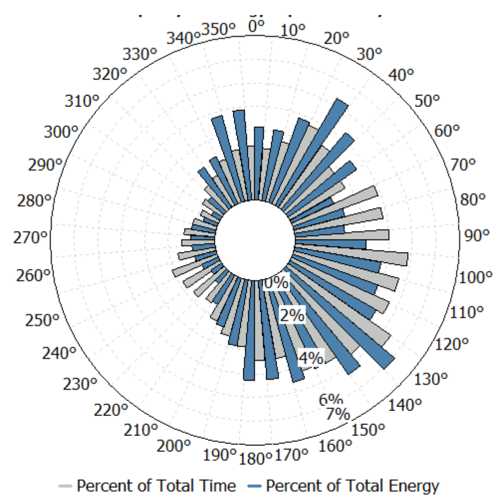


Figure 5: Wind Directional Rose at 160 m.

for a coordinate nearby; 29.00N 90.00W. The data that was downloaded from MERRA2 was at a hub height of 50 m, which was then extrapolated using a power law to get data for 180 m. The extrapolated MERRA2 data was then correlated with the on-site Wind Toolkit data at 180 m with a coefficient of determination of 99.2%. A linearized cumulative distribution function was also created to determine the annual extreme wind speed values from 1985 to 2022 for the chosen lease block area. This analysis indicates that the 50-yr extreme wind speed (V_{ref}) for this site at an elevation of 200 m is 38 m/s which is less than the V_{ref} values for the turbines evaluated. Since the wind power in this region is lower than other parts of the country, and wind speeds in the atmospheric boundary layer increase with elevation, it is desirable to use taller towers to tap into the higher wind speed potential aloft.

2.4 Turbine Technology

HVEC is projecting final construction to initiate in 2031, with 14 turbines total split across the two lease blocks. The offshore wind farm has an 8-year development timeline, which kicks off in 2023. The turbine technology that the team analyzed included 15 MW and 22 MW machines, representing state of the art technology of today as well as proposed future turbine technology. Specifically, the team evaluated the Vestas V236-15MW[25] and the IEA Reference 22 MW[26] machine which has a 280 m rotor diameter. It should be noted that there are no 20 MW+ scale turbines officially on the market yet, however projects in the 2030+ horizon are planning on using this scale of turbine for their designs.[27] The IEA 22 MW reference turbine is still under development by IEA Task 37 (including design teams at DTU and NREL), but was used as a model for scaling purposes.

A key factor in considering the 15 MW Vestas Turbine design was the availability of performance specifications from an industry professional[36]. The Vestas turbines also include a recyclable blade design and it is offered with an IEC 61400-3 class T [28](Typhoon) option, which rates it for use in 50-year return, 10 min-averaged, max wind speeds (V_{ref}) of 57 m/s, which would survive a strong category 3 hurricane.[29] Recall from the previous section that the site V_{ref} was determined to be 38 m/s. It is anticipated that the 22 MW turbine would also be available with this T rating. The power curves for both machines cut in at 3 m/s and cut out at 30 m/s, while ramping down from the max rated power starting at 23.5 m/s. Ultimately, the 22 MW machine was chosen for the PFOWP as it provided a considerably increased capacity factor for the project, which led to the best financial performance as well.

The wind farm foundation selection is based on bathymetry and geotechnical details. The depth of the water in the region selected is approximately 18-25 m. Generally, the technological options for this depth of water include monopile, gravity base, tripod, and jacket foundations. The cheapest option for a 20 m depth would be a monopile foundation, however it has been found that the seafloor is generally soft in this region and thus a twisted jacket foundation is recommended, which is also commonly used by the existing local oil and gas industry to mitigate threats from hurricane damages.[30] Using a twisted jacket as the foundation for the FPOWP will lower CapEx costs, which will be discussed further in the financial section.[31] The twisted jacket design allows for a more stable and secure connection to the seafloor when facing high hurricane windspeeds.

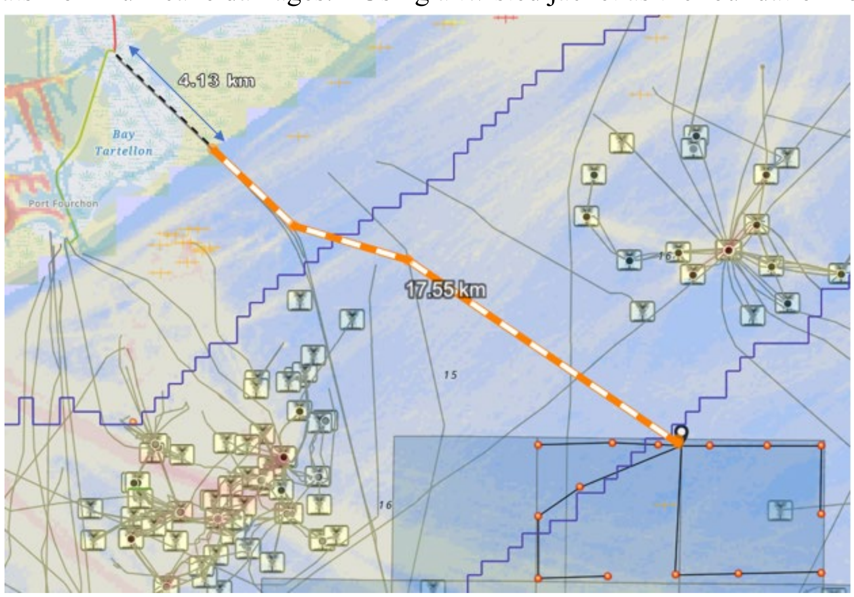


Figure 6: *Radial distribution system and interconnection route to shore. Each of the 14 orange dots is a 22 MW wind turbine, with four strings of turbines, each connected to the substation for onshore delivery.*

2.5 Detailed Layout

An optimization procedure was used to develop the final detailed layout in the two lease block region. This procedure is described in detail in Section 4.0. In the optimized layout, the two lease blocks are designed to have a total of 14, 22 MW wind turbines using a radial delivery system for grid interconnection. The radial structure uses an offshore substation to collect all the wires transporting energy into a concentrated point, then one cable is used to transport the accumulated energy to the onshore substation. Figure 6 shows the design for the detailed turbine layout within the lease blocks. The substation is placed at the top and in between the two lease blocks so that it is both close to shore as well as centrally located to each turbine. The wires that are connecting the turbines to the substation are XLPE 185mm 66kV[32] with a max capacity of 90 MVA, thus each string will be limited to no more than four turbines, or 88 MW. At the most conservative orientation, there is a minimum of 3D of spacing between each turbine, while considering the predominant wind direction from the southeast, the spacing is approximately 7D between rows (at least 1960 m for a 22 MW turbine).

Transmission Integration

The closest point to shore from the PFOWP is approximately 14 km from the northwest corner of block 35. To minimize transmission cable length, and minimize interactions with obstacles, such as the many pipelines and oil & gas platforms in the area, the cabling path to shore shown in Figure 6 was chosen, totaling 17.55 km. The project will utilize undersea HVAC cables, most likely two XLPE 500mm 132kV lines,[33] requiring a step-up transformer at the offshore-substation. This HVAC cabling will run from the offshore substation to shore, following along the same pathway as existing oil/gas pipeline and transmission lines where possible. From there, cabling will run 4.13 km on shore and connect to the Entergy Substation in Leeville, shown as a red line in the top left of Figure 6. This sits within Port Fourchon and is composed of a 21-mile, 115 kV transmission line running from Golden Meadows to this substation in Leeville. This line was recently upgraded to withstand 150 mph winds and it is designed to 230 kV standards. Using the nearest substation in the context of this project is imperative, as the capital costs associated with the purchase and installation of HVAC cables are very high.

2.6 Infrastructure

Access to Ports

There are considerations necessary for the location of staging and construction of an offshore windfarm. Seaports are required with infrastructure equipped to construct, assemble, and transport various components and materials to and from the offshore site. This includes heavy-duty wharves equipped to withstand the weight of heavy turbine components, manufacturing facilities nearby to ensure effective transportation of parts and assembly and lay-down areas large enough to stage and assemble components such as nacelles and turbine blades.[34]

For the offshore region under consideration, the most logical option for a construction and staging port would be the deep-water port of New Orleans. With 13,511 feet of berthing space available and six breakbulk terminals suitable for heavy lift and project cargo, New Orleans is suited to handle the requirements needed to facilitate the construction and assembly of an offshore wind farm.[34] More importantly, it has water depths of up to 50 feet, which is deep enough to allow for any installation vessel to have access to the port. This coupled with nearby manufacturing infrastructure and ample room for staging and assembling large components such as nacelles, makes New Orleans a clear choice.

Since southern Louisiana is a hub for natural gas and oil production, the smaller ports in the area are prime for the selection of a maintenance port. The most important characteristic for a maintenance port is proximity to the site to ensure a rapid response for operation purposes. As a result, Port Fourchon was selected as a maintenance port. Its proximity combined with its already significant industry traffic due to offshore oil and natural gas platforms in the region make it a logical choice.[35]

Survey, Installation, and Operations and Maintenance Vessels

The Bureau of Ocean Energy Management, BOEM, requires submission of Site Characterization Surveys among a Site Assessment Plan, Construction and Operations Plan (COP), or General Activities Plan (GAP). An Avian Survey will be conducted, as well as provide Archaeological and Historic Property Information and Geophysical, Geotechnical, and Geohazard Information.[36] There are many vessels available for surveying depending on what type of survey is conducted for the wind farm site.[37] The Merchant Marine

Act, also known as the Jones Act, is taken into consideration when looking at vessels for the farm. The act limits the transfer of cargo between U.S. ports to vessels that are registered and built in the United States. The U.S Coast Guard lists a Wind Turbine Installation Vessel (WTIV), but it is not compliant under the Jones Act. Due to complications with the Jones Act, the use of Feeder barges will be investigated.[38] This approach uses a barge for transport of the turbine components to the installation vessel.[1]

In September of 2022, a U.S and German firm announced the construction of a WTIV that is Jones Act Compliant. The Feederdock features a 3,000-ton crane and a maximum hook height of 182 meters. It also boasts the ability to install wind turbines up to 25MW. Construction is set to begin in 2023 and is set to be ready for use in U.S waters by 2026.[39] Although there is already a vessel called Charybdis under construction in the U.S that is Jones Act compliant, the Feederdock's capabilities exceed that of the Charybdis. Due to current uncertainty on the time frame of project completion though, further investigation on vessel availability is necessary.[40] For operation and maintenance (O&M) of the site a Crew Transfer Vessel, CTV, will be used. CTVs are used for day-trip O&M visits, and inspections.[38]

2.7 Risk Analysis

The most significant operating risk associated with offshore wind farms include cable failure, which results in failure of power generation.[41,42] Any mishaps where transmission cables are damaged or caught by vessels require timely and costly repairs.[43] These risks are being avoided by ensuring proper installation and design are employed.

The risks of offshore wind farm installation include heavy lifts, collisions, and damage.[42] The large and heavy parts that make up the farm as well as the specialized vessels that facilitate installation must be carefully handled to prevent causing damage from dropping parts or from collisions.[43] Following proper installation guides and safety protocols will help mitigate these installation risks. Foundations can become vulnerable from saltwater corrosion and marine species once installed, which can compromise the turbines.[43] Corrosion-resistant foundation materials can be used to help prevent saltwater corrosion, as well as safely removing organisms that attach to the turbines. Furthermore, sea floor bathymetry varies globally, meaning foundation expertise is pivotal to ensure safe installment of the foundations.[43] Employing people with regional expertise of the Gulf of Mexico's bathymetry will help secure stable installation.

Weather Related Risks

Weather risks of offshore wind farms are much greater than onshore wind farms due to the more severe weather conditions they are subject to.[41] Wave, wind, and current action can gradually erode the turbines, especially in an offshore environment.[43,44] Using erosion-resistant material will help guarantee the longevity of the turbines. Lightning strikes are also a significant concern as about 80% of insurance claims come from lightning strikes and lightning causes 60% of operational blade losses and nearly 20% of overall wind losses.[43,45] Lightning Protection Systems (LPS) can be used to dampen the voltage impacting the blades and decrease the likelihood of damage.[45]

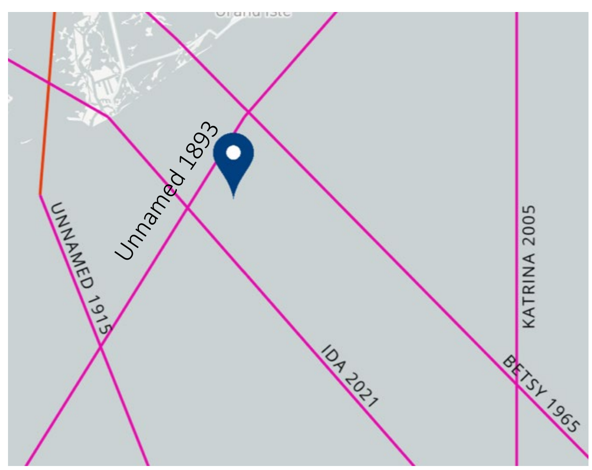


Figure 7: Hurricane history paths of Ida (2021) and Unnamed (1893), which are in proximity of the wind farm, which is marked.[46]

Another potential environmental factor occurs during hurricane season.[39] Various category 3, 4, and 5 hurricanes traveled through the surrounding areas of Port Fourchon as shown in Figure 7.[39] Various category 3, 4, and 5 hurricanes traveled through the surrounding areas of Port Fourchon as shown in Figure 7. Two category 4 hurricanes in particular, Unnamed 1893 and Ida, traveled through both of the selected lease blocks with top speeds of 66.88 m/s (130 kt).[46] The time gap between hurricane Ida in 2021 and Unnamed hurricane in 1893 is rather large (128 years), and the potential for another hurricane of that magnitude to pass through the same area during the 25 year lifetime of the FPOWP is a low potential risk. Hurricanes are a threat to wind turbines due to the high wind speeds affecting the turbine's structure. The turbine selected for preliminary consideration also has an IEC T-class (Typhoon class) that allows them to withstand winds as high as 57 m/s averaged for 10 minutes, or three second gusts of up to 79.8 m/s. The turbines have an anemometer sensor that automatically shuts down the system once wind speeds are above 25-30 m/s.[47,48] Shutting off the turbines above the maximum operating speeds mitigates the risk of the blades spinning faster, which damages not only the rotor blades, but the generator as well. Using a twisted jacket foundation for the turbines add more support to withstand high winds and hurricanes. An oil rig in the Gulf of Mexico used a twisted jacket foundation that was able to withstand and survive hurricane Katrina's fierce winds.[31] This impressive feat influenced the team to consider using the twisted jacket foundation for support and mitigation of damages post hurricane. Entergy is also implementing a 10-year hardening strategy of transmission lines to withstand hurricanes. The utility engineered a 115 kV transmission line extending from Golden Meadows to Leeville.[49] The transmission line is now able to withstand 67 m/s, the wind speeds of a category 5 hurricane.[49] As mentioned earlier, hurricanes also pose a threat, but are mitigated through the twisted jacket foundation, shutting the system off once a certain wind speed is reached, and hardening the interconnection line. Supplying backup power for the turbines to quickly yaw to point into the wind can help reduce hurricane risk.[44] Wave heights above 2 meters pose a risk to maintenance delays.[50] Breaking waves in the shallow water are another concern but should be addressed by selecting a Jacket foundation.

Military Zones

The selected lease blocks are inside the limits of a very large military airspace which spans the Gulf Coast region from Houston, TX to New Orleans. This is a risk as wind farms can potentially interfere with military procedures including acting as obstructions to training routes and interfering with radar.[51,52] Even though most flight paths are above turbine height and radar interference can be avoided by upgrading systems or issuing site changes, the project would notify the Department of Defense (DoD) Clearinghouse of the proposed wind farm well in advance of commencement of construction.[51,52] Once informed, the DoD Clearinghouse receives input from affected military branches and bases and will work with developers to either mitigate or eliminate potential national security impacts from the project.[51] Final approvals or denials are ultimately determined by the military.[51,52] Approval by the DoD Clearinghouse is essential in ensuring the FPOWP will not interfere with military procedures.

3.0 Financial Analysis

3.1 Capital Expenditures (CapEx)

To develop an initial cost for the project, HVEC used the JEDI (Jobs and Economic Development Impact) model.[53] The model includes turbine component, substructure and foundation, electrical infrastructure components, assembly and installation, ports and staging, development, and engineering and management costs. In total, the CapEx is reported to be $933,240,000 or $3030/kW. The costs are broken down in detail based on results from the JEDI model in Table 1. Applying this CapEx value into the Financial Analysis, which was run using System Advisor Model (SAM)[54], the project's overall net capital cost is $1,058,445,568. The difference is made up of financing and development fees totaling $125,205,568. Turbine cost components include Nacelle/Drivetrian, Blades, and Towers. The total cost of Turbine Components is $429,330,000.00 and $1316.00/kW. Turbine Component costs are 43.4% of the total cost. The Balance of System (BOS) cost includes substructure and foundation using twisted jacked and scour protection. The Twisted Jacket parameter was selected for our substructure type due to the reasons mentioned in section 2.5. The Scour Protection parameter is necessary for our offshore turbine as scour affects the foundation length, natural frequency, and J-tube of the structure.[53,55] The total BOS cost is $429,330,000, with $1127.5/kW. BOS costs are 37.2% of the total cost. The soft costs include commissioning, construction finance, construction insurance, contingency, and decommission. The total Soft Cost is $193,500,000 and $586/kW. Soft Costs are 19.35% of the total cost.

Table 1: *Breakdown of Capital Expenditures for Offshore Wind turbine on a 200 m Tower*

CAPITAL EXPENDITURES (CapEx)			
Category	**Cost**	**Cost Per kW**	**% of Total Cost**
Turbine Component Costs			
Nacelle/Drivetrain	$265,188,000.00	$861.00	28.4%
Blades	$79,464,000.00	$258.00	8.5%
Towers	$60,676,000.00	$197.00	6.5%
Total		**$1,316.00**	**43.40%**
Balance of System Costs			
Substructure and Foundation	$120,299,613.00	$390.60	12.9%
Electrical Infrastructure Components	$65,912,349.00	$214.00	7.1%
Assembly and Installation	$29,004,452.00	$94.20	3.1%
Ports and Staging	$2,518,543.00	$8.20	0.3%
Development and Other Project Costs	$107,974,789.00	$350.60	11.6%
Engineering and Management	$21,560,000.00	$70.00	2.3%
Total		**$1,127.50**	**37.20%**
Soft Costs			
Commissioning	$12,381,857.00	$40.00	1.3%
Construction Finance	$51,497,269.00	$166.40	5.5%
Construction Insurance	$12,381,857.00	$40.00	1.3%
Contingency	$88,924,245.00	$287.30	9.5%
Decommissioning	$16,321,539.00	$52.70	1.7%
Total		**$586.00**	**19.4%**
Total Capital Cost	**$933,240,000.00**	**$3030**	**100%**

3.2 Annual Operational Expenditures (OpEx)

According to the Offshore Wind Market Report: 2022 Edition,[56] Operational Expenditures (OpEx) predicted by analysis for offshore wind projects are estimated to range from $59/kW-year to $89/kW-year for U.S. projects with a commercial operation date (COD) between 2021 and 2030. Whereas, reported OpEx for the Dominion Offshore Wind Energy Project, which has a projected COD of 2026, are listed at $50/kW-year. A $70/kW-year OpEx value was applied to the FPOWP analysis as a conservative estimate considering the most recent U.S. project statistic. This OpEx cost includes preventative maintenance, corrective maintenance, operating facilities, EHS (environmental, health and safety) monitoring, insurance, spare parts, and any leases costs not included in the CapEx. A 1% per year escalation was included in the OpEx to account for increasing costs with project age.

3.3 Supply Chain Analysis

The Port of New Orleans will act as the staging, construction, and assembly port for the project while the Port of Fourchon will serve as the operations and maintenance Port. As mentioned previously, the port of New Orleans was chosen due to its room to assemble parts, as well as its access to nearby manufacturing facilities and transportation options, such as river, road, and rail. Initially, Port Fourchon was considered for the staging, construction, and assembly port, but due to its shallow depths, New Orleans was chosen to facilitate the docking of installation vessels.

The project will begin with the arrival of the components such as the tower, blades, and nacelles. Although there is no 22 MW turbine on the market, the Vestas V236-15MW turbine will be used as a reference turbine for supply chain purposes, as it is currently the largest manufactured turbine on the market. Since the project will be using 22MW turbines (based on the V236), the nacelles will be sourced from the Vestas Nacelles Factory in Brighton, Colorado. Although there is a blade factory located in Windsor, CO, currently they only manufacture blades for smaller MW turbines, so the blades will be sourced from a factory in Taranto, Italy, as Vestas recently announced that it will produce the blades for the V236 there.[57] The Vestas blade factory in Denmark could also be considered. It is worth noting though that by the start of construction in 2031, the blade factory in Windsor, CO could support the construction of 22 MW turbine blades. The towers will be manufactured at a wind tower manufacturing facility located in Pueblo, Colorado, which builds more wind turbine towers than anywhere else in the world.[58]

The assembly of the largest components will be conducted at the port, although due to the size of the components, full construction of the turbine will be conducted on site. Due to the size and weight of some of the parts, heavy duty cranes and other heavy cargo infrastructure will be used to offload the larger parts. Loadout areas for nacelles, towers, and blades will be utilized for assembly. Depending on the vessel/method chosen for installation, partial or full construction of the turbine will be completed. Although further investigation regarding vessel availability, the Feeder dock installation vessel, which is set to be operational in U.S waters by 2026 seems promising. Once construction is completed, parts of the turbine will be loaded onto an installation vessel with mooring and dynamic array cables being used.[59]

Once the turbine components are loaded onto an installation vessel, the actual construction and assembly of the turbines will begin on site. The construction will begin with the attachment of the turbine tower onto the twisted jacket foundation, which is installed first on the sea floor. From there, the nacelles and blades will be attached as well. According to ONP Management, if an installation vessel such as the Feederdock is utilized, "a European installation methodology will be used with its U-shaped global heavy lift jack-up installation vessel, paired with Jones Act articulated tug barges docking inside the installation vessel before jacking up."[60] This is a method that is preferred by offshore wind industry professionals.[60] Once the turbines are installed, operations and maintenance will be conducted from the O&M port of Port Fourchon using the CTV's.

3.4 Financing Plan

The financing plan for the FPOWP assesses the capital and operating expenditures, assumed structure, and rates for the financial model developed in the National Renewable Energy Laboratory (NREL) System Advisor Model (SAM). The financing and ownership plan for the 308 MW FPOWP is centered around a PPA Partnership with Debt structure, with 41.94% financed via debt and 58.06% financed via equity. The Developer, HVEC, is investing 20% of the required project equity while equity partners will invest the remaining 80%. The project's proposed equity partners include Bank of America Corporation, JPMorgan Chase, and Santander. This group will be agreeing to a 95/5 tax flip and 95/5 cash flip structure, meaning the equity partner banks will assume 95% of the project's tax and cash benefits until year 3. After the flip year, the equity investors will only assume 5% of both the cash and tax benefits with the remaining 95% going to the developer, HVEC. The investors can expect to see a return on investment of 10.98% at year 3 and a total IRR of 11.58% at the end of the 25 yr project at a value of $22,427,002. Meanwhile HVEC anticipates a NPV of $30,768,872 in addition to a 5% development fee ($46,662,000). The development fee is planned to be used toward meeting most of the lease block bid price. All these terms are based on meeting a Debt Service Coverage Ratio (DSCR) of 1.3 and an initial PPA price of $0.0845/kWh, which will escalate at a rate of 2% per year. The project will generate an average annual energy production (AEP) of 1,009,242.6 MWh each year.

In the past decade, many large banks have pledged to help reach the United Nations' Sustainable Development Goals (SDGs) and/or have created their own sustainability targets. Bank of America Corporation has committed $1.5 trillion through 2030 to sustainable business such as renewable energy projects.[61] JPMorgan Chase has committed $2.5 trillion through 2030 and Santander has committed $220 billion through 2030.[62,63] These three banks were also participants of a 9-bank financing team for the Vineyard Winds offshore project in Massachusetts.[64] With this, HVEC is confident that there is an opportunity for a partnership with these banks to be the projects tax-equity investors.

***Table 2**: Summary of Financing Fees*

Financing Fee	Value
Equity Closing Cost	$4,000,000
Debt Closing Cost	$4,439,346
Upfront Construction Loan Fee	$9,332,400
Total Fees	$17,771,746

The debt financing plan as well as construction financing assume a 5% interest rate. This rate follows the 10-year treasury bond rate, which is currently around 3%-3.5%.[65] The project will benefit from a construction financing loan at a rate of 5% for 12 months before construction. Total debt borrowed for this project is $443,934,624. A summary of all of the financing fees can be found in Table 2.

Figure 8 highlights the PFOWP's cumulative cashflow over the 25-year lifetime of the project for both the Developer and the Equity partners. It can be seen that the investors' cumulative NPV becomes positive in year 3, the flip year.

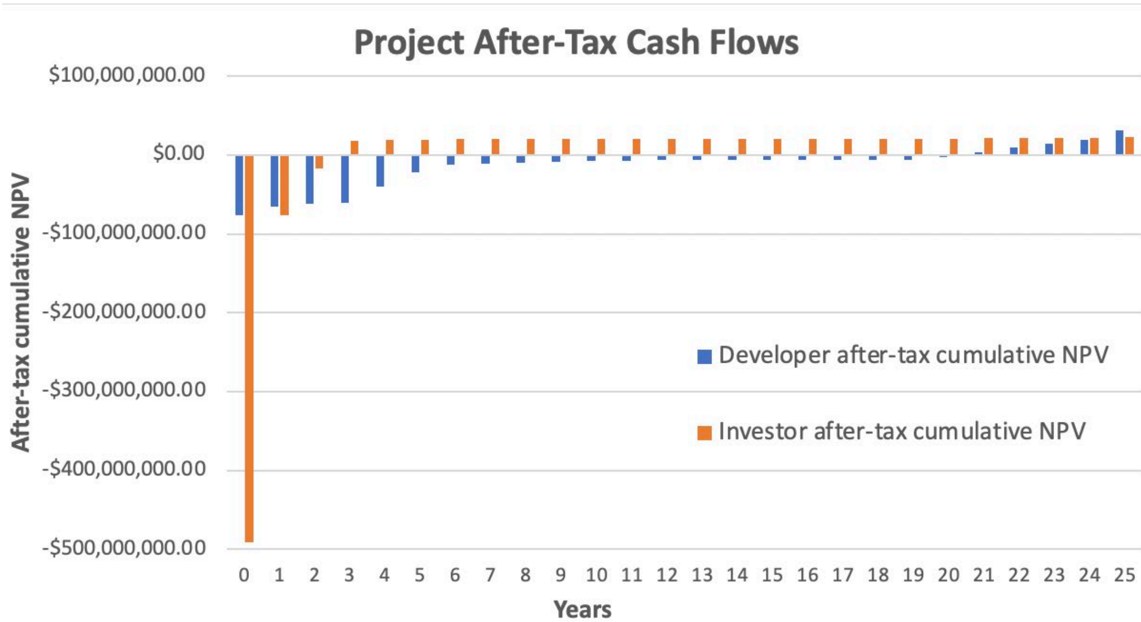


Figure 8: *Cumulative developer and investor after-tax cash flow.*

3.5 Key Assumptions & Incentives

Incentives

The Inflation Reduction Act (IRA) extended Production Tax Credits (PTC) and Investment Tax Credits (ITC) for offshore wind projects that begin construction prior to January 1, 2026.[66] The ITC is 6%, with the ability to increase up to 30% if the project pays prevailing wages and meets apprenticeship requirements. HVEC plans to initiate construction in 2024 for the purpose of establishing safe harbor to secure the current ITC rate for the first 10 years of operation.[67] This will require a 5% investment in the project which is expected to be met by the offshore lease block bid. The PFOWP will meet stated wage and apprenticeship requirements to qualify for the full 30% ITC for this project[68] and additional 10% bonus will also apply as it is assumed that the project would qualify for this incentive due to minimum domestic content requirements. Current offshore wind projects have a threshold of 20% of manufactured materials which is expected to increase in 2025.[69] The project also plans to make use of the 5 yr MACRS (Modified Accelerated Cost Recovery) Deprecation federal incentive.

Taxes & Rates

HVEC used the following rates in the SAM financial analysis. An income tax rate of 27%, combining Louisiana state tax rate of 6% and the federal income tax rate of 21%.[70] A Louisiana sales tax rate of 4.45%. HVEC assumed a 3% inflation rate for the 25-year analysis period and using a real discount rate of 4.75% gave a nominal discount rate of 7.89%.[71,72] In Louisiana there is currently no property tax rates for renewable energy.[73]

3.6 Market Conditions

As mentioned earlier, the total amount of energy that the PFOWP will generate, on average, each year is 1,009,242.6 MWh-year, achieving a capacity factor of 37.4%. This will enable the project to sell power at a PPA price of $84.5/MWh, with an annual escalation rate of 2%.

By using a PPA, HVEC can minimize risk from fluctuations in the wholesale market. However, because the offtaker is locking into a PPA, this can pose a risk if wholesale prices drop lower than the agreed price. The U.S. Energy Information Administration reported an average retail price for electricity to be \$88.2/MWh (2021), making our PPA price competitive on a national scale.[74] However, the Regional Transmission Operator in this region is MISO (Midcontinent Independent System Operator) and the grid interconnection for the project will be with the local utility Entergy. For reference, typical residential electricity rates for Entergy Louisiana customers are \$47.7/MWh[75] with a \$10/MWh Entergy Green Selection option providing Renewable Energy Credits[76] for residential customers. Comparing this to the PPA price from the PFOWP at \$84.5/MWh does not look as favorable for the project. However, this is not the market of interest.

Docked marine vessels at Port Fourchon are able to help protect the surrounding environment by replacing fossil fuel-generated ship power with Entergy's Shore Power product.[77,78] The ships can plug into the electrical grid, rather than continuously burning diesel oil and contributing to emission pollution.[79] Entergy's initial Port Fourchon Shore Power installation, built in 2020, allows for accommodations of 10 Edison Chouest Offshore (ECO) vessels.[78] The company projects that the Shore Power product will reduce net carbon emissions by 42%, reduce sulfur oxides by 48%, and reduce nitrogen oxides by 98% compared to if the 10 ECO vessels were docked and using their own engines.[77–79] Entergy was the first U.S. utility with a voluntary carbon reduction commitment (in 2001), with a goal of achieving net-zero carbon emissions by 2050 and has a portfolio of 240 MW of renewable generation.[80] It is proposed that the power generated by the PFOWP will be sold as a part of Entergy's new Shore Power product, allowing it to increase its capacity from the current 10 vessels and add to its rapidly growing renewable energy portfolio.

As teams were not able to reach out to stakeholders as a part of this study, the specific electric rate that Shore Power is being sold for at present is unknown. In the absence of this information, the equivalent rate to run a ship on its own engines was estimated, using Shore Power references from Europe,[81] to consider the relative marketability of the PPA price for the PFOWP. The most recent estimates found were from 2017, indicating that the cost of running MGO (Marine Gas Oil) for power at shore was around 125 Euros/MWh (\$138/MWh) and thus Shore Power would be cost effective at a rate of 115 Euros/MWh (\$127/MWh).[81] The price of MGO was around \$14/mmBTU in late 2017.[81] Historically, MGO prices follow trends in Brent Crude Oil (where MGO is consistently ~500 Euro/mt higher)[81], and Brent Crude prices are higher today than in 2017. Thus, since the project's PPA price of \$84.5/MWh is certainly competitive to the 2017 European Shore Power rates and considerably less (31%) than the cost of running ship power on MGO alone. Therefore, the conclusion is that power generated from PFOWP is considered highly marketable to supply Shore Power as an offtaker.

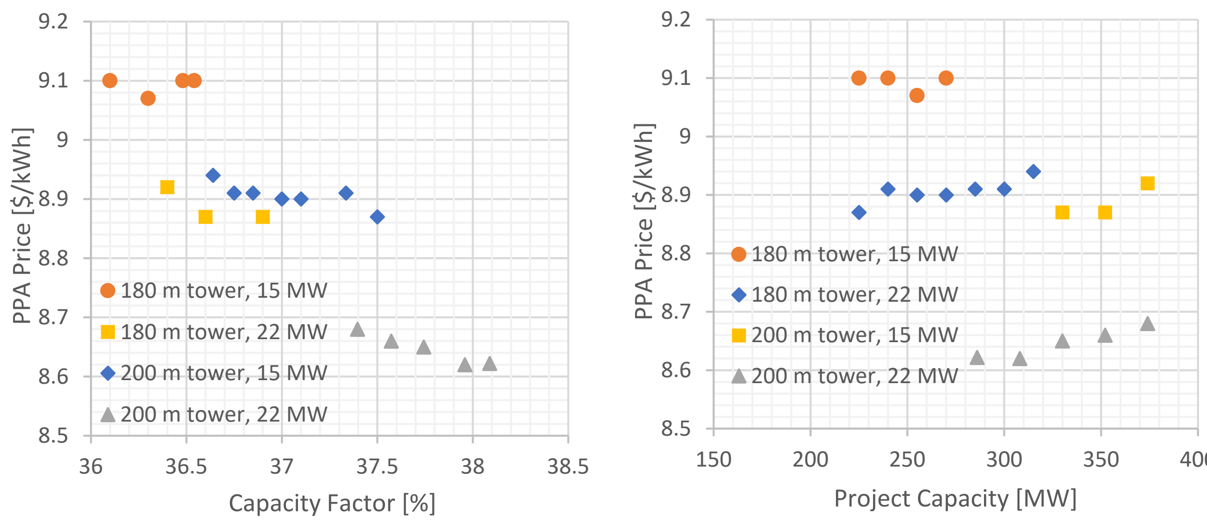
4.0 Optimization Process

The size of offshore wind turbines over the next decade are expected to continually increase due to higher wind energy at increasing hub-heights leading to higher capacity factors as well as larger rotors. Thus, turbine size and hub height were the parameters that HVEC investigated to optimize the turbine selection and layout for the PFOWP under the given wind resource conditions at the site. Turbine layout optimizations were paired with a financial analysis to determine which combination delivered the best overall performance and lowest PPA price.

The individual turbine location optimization for the selected lease blocks was performed by the Furow wind layout micro-siting tool. Parameters such as wind speed and direction were gathered from Wind Toolkit[22,82] and then converted into a format the was readable for Furow. Then the exact coordinates of the selected lease blocks were inputted into Furow, thus allowing for the creation of the Clima Object. Additionally, the turbine power curves must also be supplied to Furow in order to simulate the farm performance. Wind turbine models for the V236 15 MW and an IEA Reference 22 MW turbine were used. Simulations were then performed with both turbines, and heights varying from 160 m to 200 m and number of turbines in the farm from 13-21. All simulations were run for 10,000 iterations. The wake model used was Jensen with a maximum wake length of 20 D and a maximum radial distance of 3. For these comparison tests the default

Furow wake decay factor of 0.075 was used. After deciding on the best number and size of turbines based on the comparison, one final optimization was ran on 14 x 22 MW turbines. The final simulation ran for just under 80,000 iterations and used a wake decay constant of 0.04 (calculated from Frandsen's wake decay factor equation using a hub height of 200 m and a roughness of 0.002m) which is more accurate for the ocean environment.

Once the optimized layouts were identified in Furow, the resulting AEP and layouts were entered into the financial analysis tool, SAM. Each case was run with similar financial output expectations, including an investor IRR of ~11%, a Developer NPV of $57 million and the lowest possible PPA price. Additionally, a CapEx increase of $15/kW was added for 180 m towers and $30/kW for the 200 m towers (for a total of $3030/kW as described in the CapEx section earlier). This cost was estimated based on the cost of rolled steel and projecting tower costs from existing literature. Results from this optimization analysis are shown in Figures 9a and 9b for cases involving the two turbines as well as two potential hub heights (180 m and 200 m, as 160 m was quickly found to be inferior).



a) b)

***Figure 9 a) & b)**: PPA Price [$/kWh] vs a) Project Capacity and b) Capacity Factor*

As seen in Figure 9a, the 15 MW turbines on 180 m towers had the lowest capacity factor while the 22 MW turbines with a 200 m tower had the greatest capacity factor (37.4-38.1 MW) which also led to the lowest PPA prices ($8.6-8.7/kWh). Another comparison is shown in Figure 9b between the project size (which is indicative of the number of turbines in the project area) and the PPA price. Once again, the 22 MW turbine with the 200m tower experienced the lowest PPA prices, but now as a function of project size, HVEC was able to determine the optimal project capacity of 286 – 308 MW, or 13-14 turbines. Considering there wasn't a significant difference in the PPA price for these two cases, a 14 turbine, 308 MW project was considered for the final site design analysis.

The individual turbine location optimization was performed by the Furow micro-siting tool. Once the lease blocks were selected the location data was imported into Furow. Parameters such as wind speed and direction were gathered from Wind Toolkit[22] and then converted into a format that was readable for Furow. Then the exact coordinates of the selected lease blocks were inputted into the map thus allowing the creation of the Clima Object. Additionally, the turbine details must also be given to Furow in order to simulate the farm performance. The previously mentioned 15 MW and 22MW turbines were used. Simulations were then performed with both turbines, and heights varying from 160m to 200m and number of turbines in the farm from 13-21. All simulations were run for 10,000 iterations. The Wake model used was Jensen with a maximum wake length of 20 D and a maximum radial distance of 3D. For these comparison tests the default

Furow wake decay factor of 0.075 was used. After deciding on the best number and size of turbines based on the comparison one final optimization was ran on 14, 22MW turbines. The final simulation ran for just under 80,000 iterations and used a wake decay constant of 0.04 which is more accurate to the ocean environment.[74] Between the financial analyses conducted as a part of the site design optimization and the final design, there were also some changes. For instance, an OpEx of $50/kW-year, debt interest rate of 4%, and higher inflation rate were initial assumption which were updated to values described previously for the final detailed financial cashflow analysis.

5.0 Auction Bid

The amount HVEC is willing to bid on lease blocks 34 and 35 is $50 million. The total bid is based on the overall project scope of 10,000 acres for both lease blocks. The bid amount is derived from an estimated price per acre to be around $5,000. The price per acre is based on the rate range for offshore leasing blocks in the New York Bight lease sale on February 25, 2022. The winning bids ranged from $765 million (71,522 acres) to $285 million (43,056 acres).[83] From the lease sale, HVEC compared the price per acre range of $10,700 to $6,500[83] and estimated $5,000 per acre in the Gulf of Mexico. Overall, the bid amount based on the price per acre was adjusted for the Gulf of Mexico area due to its lower wind speeds and being a newer area to develop. The bid price ensures that HVEC maintains attainable returns to stakeholders, yields an attractive profit, and remains competitive with other potential bidders in the lease auction.

References

1. Happy Valley Energy Corporation. *PSU_2022-12-08_PD_Preliminary Site Design*. (2022).
2. Marine Cadastre. Marine Cadastre National viewer. Preprint at https://marinecadastre.gov/nationalviewer/.
3. U.S. Department of Commerce. National Oceanic and Atmospheric Administration. *NOAA* https://www.noaa.gov/.
4. World Wildlife Fund. Leatherback Turtle: Facts. *WWF* https://www.worldwildlife.org/species/leatherback-turtle (2022).
5. Fisheries, N. O. A. A. Leatherback Turtle: Overview. *NOAA* https://www.fisheries.noaa.gov/species/leatherback-turtle (2022).
6. Fisheries, N. O. A. A. Green Turtle: Overview. *NOAA* (2022).
7. National Geographic. Kemp's Ridley Sea Turtle. *Animals*.
8. Fisheries, N. O. A. A. Kemp's Ridley Turtle: Overview. *NOAA* (2022).
9. Sea Turtle Conservancy. Information About Sea Turtles: Green Sea Turtle.
10. Fisheries, N. O. A. A. Blue Whale: Overview. *NOAA* (2022).
11. Fisheries, N. O. A. A. Fin Whale: Overview. *NOAA* (2022).
12. Fisheries, N. O. A. A. Sei Whale: Overview. *NOAA* (2022).
13. Fisheries, N. O. A. A. Sperm Whale: Overview. *NOAA* (2022).
14. Department of Geospatial Science, R. U. Coral Reefs. *Biomes of the World* (2015).
15. Wildlife Management Areas, R. and C. A. | L. D. of W. and Fisheries. Wildlife Management Areas, Refuges, and Conservation Areas.
16. Restore the Mississippi River Delta. Explaining the Gulf of Mexico Dead Zone. https://mississippiriverdelta.org/learning/explaining-the-gulf-of-mexico-dead-zone/ (2023).
17. Port Fourchon. Our Environment. https://portfourchon.com/our-environment/.
18. BTNEP. *Background and Problem Addressed: Fourchon Maritime Forest Ridge and Marsh Restoration*. www.BTNEP.org (2016).
19. Offshore Wind Synthesis of Environmental Effects Research, U. *UNDERWATER NOISE EFFECTS ON MARINE LIFE ASSOCIATED WITH OFFSHORE WIND FARMS MAIN TAKEAWAYS*.
20. Field, P. & Gilbert, R. *Potential Impacts to Marine Mammals and Sea Turtles from Offshore Wind Research Framework Workshop*. (2018).
21. Technical University of Denmark (DTU). Global Wind Atlas 3.0. *Energy Sector Management Assistance Program (ESMAP* https://globalwindatlas.info.
22. National Renewable Energy Laboratory. Wind Toolkit Data. *NREL* https://developer.nrel.gov/docs/wind/wind-toolkit/wtk-download/.
23. Global Modeling and Assimilation Office. hourly wind data, version 5.12.4. *GMAO*.
24. Windographer. *Version 5*.
25. Vestas. V236-15.0 MW. (2021).
26. Bortolotti, P. & Zahle, F. IEA-22-280-RWT. https://github.com/IEAWindTask37/IEA-22-280-RWT.

27. Richard, C. Plans for 1GW-plus offshore wind farm with 20MW turbines. *Wind Power Monthly* https://www.windpowermonthly.com/article/1715905/plans-1gw-plus-offshore-wind-farm-20mw-turbines (2021).
28. International Electrotechnical Commission. Wind energy generation systems - Part 3-1: Design requirements for fixed offshore wind turbines. https://webstore.iec.ch/publication/29360.
29. NOAA. Saffir-Simpson Hurricane Wind Scale. https://www.nhc.noaa.gov/aboutsshws.php.
30. Musial, W. *et al. Offshore Wind in the US Gulf of Mexico: Regional Economic Modeling and Site-Specific Analyses*. https://www.flickr.com/photos/boemgov/ (2020).
31. Keystone Engineering Inc. IBGS, the 'Twisted Jacket'. *issuu* https://issuu.com/keystoneengineering/docs/ibgs_brochure (2013).
32. Prysmian Group. *66 kV Submarine Cable Systems FOR OFFSHORE WIND*.
33. for Business Enterprise, D. & Reform, R. *Review of Cabling Techniques and Environmental Effects Applicable to the Offshore Wind Farm Industry*. (2008).
34. Port Nola. Port Nola: Capabilities.
35. American Clean Energy. ACP Offshore Wind Port Infrastructure Needs.
36. BOEM. Survey Guidelines For Renewable Energy Development. *Bureau of Ocean Energy Management* https://www.boem.gov/renewable-energy/survey-guidelines-renewable-energy-development.
37. 4C Offshore. Offshore Survey Vessel Database.
38. United States Coast Guard U.S. Department of Homeland Security. Offshore Wind Support Vessels. https://www.dco.uscg.mil/OCSNCOE/Renewable-Energy/Support-Vessels/ (2022).
39. Memija, A. US and German Firms Unveil Jones Act-Compliant Offshore Wind Farm Installation Solution. *offshoreWIND.biz* https://www.offshorewind.biz/2022/09/27/us-and-german-firms-unveil-jones-act-compliant-offshore-wind-farm-installation-solution/ (2022).
40. Barnes, J. Purpose-built vessels for offshore wind development needed. *WorkBoat* (2021).
41. Hutchins, D. The Risks and Opportunities of Offshore Wind Energy. *Global Risk Intel* https://www.globalriskintel.com/insights/risks-and-opportunities-offshore-wind-energy (2020).
42. Risktec. De-risking offshore wind power. (2011).
43. Baeßler, Dr.-Ing. M. & Babutzka, M. Sc. M. How wind turbines remain stable in rough seas. *BAM* https://www.bam.de/Content/EN/Standard-Articles/Topics/Energy/article-LeBeWind.html.
44. PMI. Challenges in the Installation and Repair of Offshore Wind Turbines. https://pmiind.com/challenges-installation-repair-offshore-wind-turbines/ (2016).
45. Nelson, D. R. What happens when a wind turbine gets hit by lightning? *as* https://en.as.com/latest_news/what-happens-when-a-wind-turbine-gets-hit-by-lightning-n/ (2022).
46. NOAA. Historical Hurricane Tracks. Preprint at (2023).

47. Office of Energy Efficiency & Renewable Energy. How Do Wind Turbines Survive Severe Storms?
48. PBS North Carolina. Explore science & nature. *PBS*.
49. Baltic, S. Hardening the Energy Coast. *GlobalSpec* (2016).
50. Karyotakis, A. *On the Optimisation of Operation and Maintenance Strategies for Offshore Wind Farms*. (2011).
51. Southeastern Wind Coalition. *Potential Military Interaction Issues*.
52. Ottinger, P. S., Bars Adjunct Professor of Law, T. & Hebert Law Center, P. M. *IS THERE A FUTURE FOR WIND ENERGY IN THE BAYOU STATE? Symposium on 'Disruptive Technologies' Journal of Energy Law and Resources*. (2018).
53. NREL. Limitations of JEDI Models. https://www.nrel.gov/analysis/jedi/limitations.html (2023).
54. NREL. System Advisor Model (SAM).
55. van der Tempel, J., Zaaijer, M. & Subroto, H. *The effects of Scour on the design of Offshore Wind Turbines*. (2004).
56. Musial, W. *et al. Offshore Wind Market Report: 2022 Edition*. (2022).
57. Radowitz, B. 'Great step forward' | Vestas 15MW offshore wind giant produces first power. https://www.rechargenews.com/wind/great-step-forward-vestas-15mw-offshore-wind-giant-produces-first-power/2-1-1381575 (2022).
58. Vestas. Wind Turbine Manufacturing in North America.
59. Crowle, A. P. & Thies, P. R. Floating offshore wind turbines port requirements for construction. *Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment* **236**, 1047–1056 (2022).
60. ONP Management. FEEDERDOCK: Game-Changing, Jones Act Compliant Offshore Wind Installation Solution. https://www.onp-management.com/onp/reference-and-press/2022-feederdock/ (2022).
61. Bank of America. Sustainable Finance. https://about.bankofamerica.com/en/making-an-impact/sustainable-finance (2023).
62. JPMorgan Chase & Co. Sustainable Development Target. https://www.jpmorganchase.com/impact/sustainability/es-commitments#:~:text=JPMorgan%20Chase%20set%20the%20Sustainable,and%20contribute%20to%20sustainable%20development. (2023).
63. Santander. *Climate Finance Report Climate Finance Report Climate Finance Report*. www.santander.comwww.santander.com (2021).
64. Groom, N. Vineyard Wind secures $2.3 bln loan, allowing construction to start. *Reuters* (2021).
65. YCharts. 10 Year Treasury Rate (I:10YTCMR)2. https://ycharts.com/indicators/10_year_treasury_rate (2023).
66. Congressional Research Service. *CRS INSIGHT Prepared for Members and Committees of Congress Offshore Wind Provisions in the Inflation Reduction Act Offshore Wind Leasing Provisions*. https://crsreports.congress.gov (2022).
67. McGuire Woods. Continuity Safe Harbor Extended for Offshore Wind, Renewable Energy Projects on Federal Land. (2021).

68. Watson, C. D. & Sherlock, M. F. Proposed Tax Preference for Domestic Content in Energy Infrastructure . *Congressional Research Service* (2022).
69. Richter, S. M. & Hampton LLP. Domestic Content Requirements of the Inflation Reduction Act: Basic Requirements, Qualification Analysis, and Lingering Questions. *JD Supra* https://www.jdsupra.com/legalnews/domestic-content-requirements-of-the-5954792/ (2023).
70. Watson, G. Combined Federal and State Corporate Income Tax Rates in 2022. (2022).
71. Louisiana Department of Revenue. General Sales & Use Tax.
72. YCharts. US Discount Rate (I:USDRND). (2023).
73. Muller, W. Louisiana lawmakers block attempt to pull tax breaks from solar, wind projects. *Louisiana Illuminator* https://lailluminator.com/2022/04/06/louisiana-lawmakers-block-attempt-to-pull-tax-breaks-from-solar-wind-projects/ (2022).
74. U.S. Energy Information Administration. State Electricity Profiles. *eia* https://www.eia.gov/electricity/state/louisiana/ (2022).
75. Entergy Louisiana, L. *ENTERGY LOUISIANA, LLC RESIDENTIAL AND FARM SERVICE RATE SCHEDULE SCHEDULE RS-L*. (2015).
76. Entergy. Entergy Green Select. https://renew.entergy.com/new-orleans/green-select/pricing#pricing-cards (2023).
77. 10/12 Industry Report Staff. Entergy, Edison Chouest launch shore power project at Port Fourchon. https://www.1012industryreport.com/energy/entergy-edison-chouest-launch-shore-power-project-at-port-fourchon/ (2020).
78. Freese, D. Entergy Louisiana, ECO Launch Shore Power Project to Reduce Emissions for Gulf Coast. *Entergy* https://www.entergynewsroom.com/news/entergy-louisiana-eco-launch-shore-power-project-reduce-emissions-for-gulf-coast-1729408408/ (2020).
79. Richard, D. Plugging into Entergy's Shore Power Program (T&D World Magazine). *Entergy* https://www.entergynewsroom.com/article/plugging-into-entergy-s-shore-power-program-t-d-world-magazine/ (2021).
80. Entergy. Entergy Commits to Achieving Net-Zero Carbon Emissions by 2050. https://www.entergynewsroom.com/news/achieving-net-zero-carbon-emissions-by-2050/ (2020).
81. Fasting, G. *Onshore Power Supply for Cruise Vessels-Assessment of opportunities and limitations for connecting cruise vessels to shore power*. (2018).
82. Solute. Furow.
83. U.S. Department of the Interior. Biden-Harris Administration Sets Offshore Energy Records with $4.37 Billion in Winning Bids for Wind Sale. https://www.doi.gov/pressreleases/biden-harris-administration-sets-offshore-energy-records-437-billion-winning-bids-wind (2022).