CU BOULDER WIND TEAM

2022 - 2023

PROJECT DEVELOPMENT FINAL REPORT

Prepared for Collegiate Wind Competition 2023
Stampede Wind Energy

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1. EXECUTIVE SUMMARY

The CU Wind Team, hereafter referred to as Stampede Wind Energy (SWE), presents a project development report for a 380 MW offshore wind farm in the Gulf of Mexico, south of Louisiana. Development of offshore wind in the Gulf has immense energy-producing potential. Recent estimations show that the Gulf could generate 510,000 MW of offshore wind energy per year; two times the current energy needs of all five states bordering the Gulf [1]. SWE has done extensive research to assess the potential ecological, economic, and social impacts of the construction and commission of the project presented in this report. Considering site characteristics and market conditions, SWE has developed a thorough wind farm plan that abides by all environmental constraints and is financially optimal. Layout optimizations and turbine selection iterations produced a relatively high-capacity factor for the Gulf at 32.8% and a competitive LCOE at $84/MWh. This wind farm will generate 995 GWh annually. Overall, SWE proposes a $30 million bid for 30,000 acres of land 66 km from the shore.

2. SITE DESCRIPTION

2.1 Site Resource

After reviewing wind resource data at 100 m above sea level across the given leasing blocks, SWE found that average wind speed varies between 6.91 and 7.01 m/s in the southeasterly direction [2]. This wind data is reanalysis data from the MERRA-2 public data source [3]. Due to consistent wind speeds across all given leasing blocks, SWE has determined that wind resources will not be the most significant factor in the selection of leasing areas. However, one primary concern in developing a wind farm in the Gulf of Mexico is the high frequency and intensity of hurricanes. In the historical record, eight Category 3 or greater hurricanes have gone through the leasing area [4].

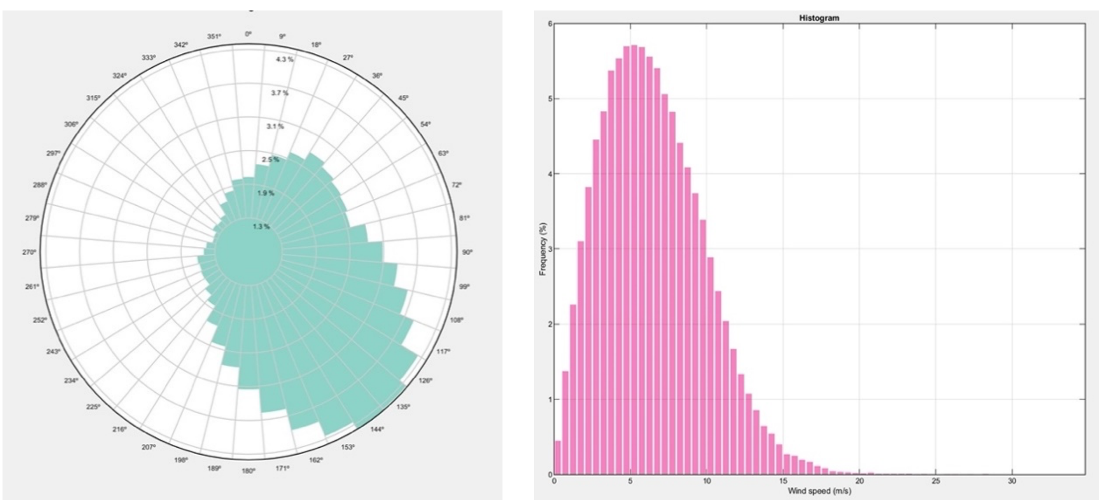

Figure 1. Wind Rose and Frequency Histogram for Leasing Blocks

The frequency histogram of the wind speed, *Figure 1*, has a shape parameter, of 2.15, which suggests a wider range of wind speeds on the lower side. The max extreme wind speed is 30.67 m/s, which occurred during Hurricane Katrina in 2005. The scale parameter is 8.49 m/s, proportional to the mean wind speed. Wind direction is another major contributing factor to the layout.

Over the leasing area, water depths range from 17 m to 46 m, with an average depth of 29 m [5]. The seabed gradient is low over most leasing blocks in contrast to the southeastern section, where the gradient steepens [5]. The seabed sediment consists mainly of sandy silt [2]. The average significant wave height is 0.7 m [6]. Understanding these parameters is necessary for foundation selection and optimizing turbine layout.

2.2 Site Obstructions

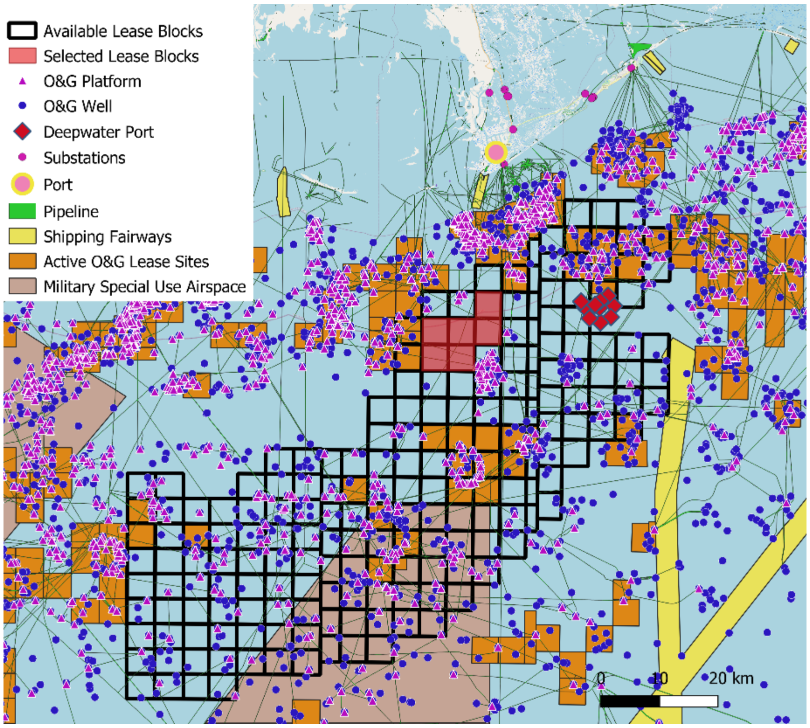

Figure 2. Obstructions Map for Leasing Blocks

To determine viable leasing blocks, SWE considered various marine hazards and obstructions in the leasing area using GIS layers provided by Marine Cadastre National Viewer presented in *Figure 2* [7]. The layers were then overlaid with available leasing sites to find sites that are the freest of already present obstacles. With the high density of oil and gas (O&G) operations in the Gulf of Mexico, some of the most prevalent obstructions relate to O&G. SWE immediately eliminated several leasing blocks because they are active O&G lease sites. Other possible sites were eliminated due to the high densities of drilling platforms that would significantly impede turbine layout. Oil wells also prevent wind farm development since they remove portions of the ocean floor necessary for foundations to be built upon. SWE must also build turbines at least 500 feet from O&G pipelines [8]. Additionally, SWE considered shipping fairways, but there were no lanes that existed in the available leasing blocks. A few deep-water ports need to be avoided, but SWE also considered using these ports as stations for maintenance crews. Military special-use airspace also intersects through the southwest portion of the available leasing blocks [7].

2.3 Site Selection

SWE initially prioritized minimizing transmission line length and transport distances when selecting leasing blocks. Blocks 35 and 36 were originally selected due to their proximity to land and being relatively clear from obstructions. However, after consulting with advisors working in the offshore wind industry and observing existing European projects, SWE sought to lease at least five continuous leasing blocks to allow for 300-1,000 MW of power generation, a range that recent United States offshore wind farms have strived towards [9]. At least five leasing blocks are needed to fit the number of turbines necessary in generating this much power. After iterating between multiple sets of leasing blocks, SWE found maximum financial optimization with minimal environmental impacts by utilizing 30,000 acres in leasing blocks 45, 56, 57, 58, 65, 64, and 63 (See *Figure 2*). The six selected leasing blocks are configured at an angle that will maximize the average number of turbines per row based on the predominant wind direction. The site is located 23 km from the nearest port with a relatively obstruction-free route to the port. The selected leasing blocks only contain five O&G pipelines that SWE must design around.

2.4 Environmental Considerations

A priority for SWE is to minimize the impact on the local ecosystem. Thus, SWE has sited the wind farm concerning important environmental considerations. Data for sensitive habitat areas and historic tropical hurricane tracks were found through the BOEM/NOAA Marine Cadastre program and mapped using QGIS in *Figure 3* [7].

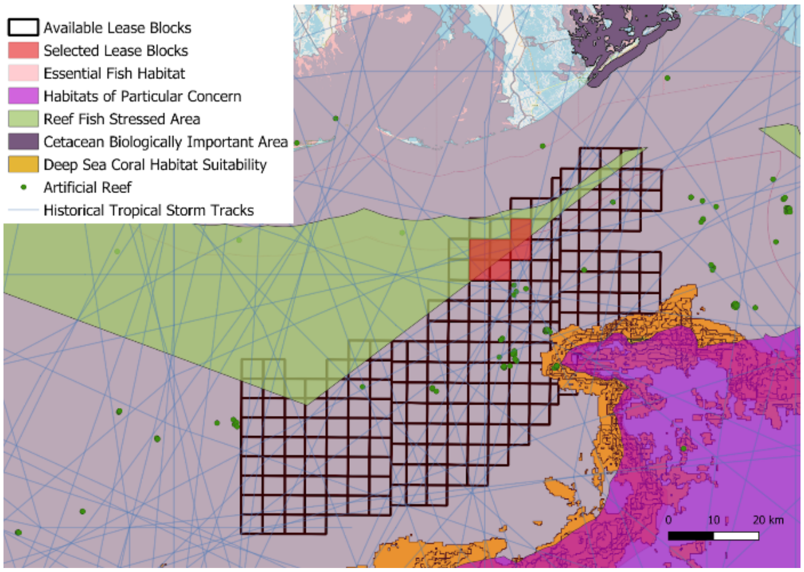

Figure 3: Map of Environmental Considerations

All available lease blocks are in essential fish habitats (EFH). NOAA designates this under the Magnuson-Stevens Act (MSA), an area necessary for sustainable fisheries. The lease blocks SWE has chosen for development are outside of habitat areas of particular concern (HAPCs), cetacean biologically important areas (BIA), and potential habitats for deep-sea coral.

More than half of the site is located within a reef fish-stressed area designated by NOAA Fisheries, with the use of certain fishing gear in this area being restricted [10]. Development in this area must not further exacerbate fishery conditions. Tropical storms have passed through all leasing blocks in the past. These storms are a critical consideration as the intensity and frequency of these storms will vary in the future due to climate change [4]. Damaged equipment poses risks to surrounding habitats from buckling and crashing which is discussed later in this report.

Observation of density data for endangered species such as the Kemp's Ridley, Leatherback, and Loggerhead Turtles suggests that habitat densities for these turtles are the lowest around the planned project's site [11]. Data concerning avian collision sensitivity and marine mammal sound sensitivity is only available for the Atlantic Outer Continental Shelf. Habitat and density data for endangered avian, finfish, marine mammal, benthic, and other marine species in the Gulf of Mexico were additionally not found to be publicly available or easily accessible. These datasets are critical in preventing the take and harassment of sensitive species and the disturbance of important migratory paths from development activities. The aforementioned information illustrates the need for on-site surveying during the pre-construction phase of the project following the BOEM Survey Guidelines for Renewable Energy Development [12]. Surveying the site will then help determine if any adjustments need to be made to environmental impacts mitigation strategies which is discussed in *Section 4.1.*

The project must additionally comply with all relevant environmental regulations. An Incidental Take Permit will be secured from the Fish Wildlife Service to comply with the Migratory Bird Treaty Act (MBTA) and Bald and Golden Eagle Protection Act (BGEPA) for any incidental avian take that occurs during the project's lifespan. Surveying and a Biological Assessment will be prepared to comply with the Endangered Species Act (ESA). An Essential Fish Habitat Assessment must be conducted to comply with the MSA – ensuring that development doesn't adversely impact fishery health. In addition, an Incidental Harassment Authorization must be secured to comply with the Marine Mammal Protection Act (MMPA). The project also must adhere to the National Environmental Policy Act (NEPA) for BOEM to approve the project's siting, following the development of an Environmental Impact Statement (EIS) and public review. This includes preparing a range of alternatives, ensuring impacts to fishing and marine trust resources are fully considered, as well as community outreach [13].

2.5 Environmental Impacts and Mitigation Strategies

A review of literature that included research papers, EISs for offshore wind farm (OWF) projects, and BOEM guidelines for OWF development identified potential adverse environmental impacts from the construction and operation of the SWE farm. Mitigation strategies to address these environmental impacts have been drafted and compiled into action alternatives, similar to an EIS. SWE compared these strategies by taking cost, immediate ecological impact, onshore community impact, fishing community impact, and climate change mitigation effort into account. Final selections have been made for mitigation strategies based on these impact areas.

One of the major environmental impact areas is disturbance to marine wildlife during the project's construction phase. These disturbances are primarily from installing the foundation and laying transmission cables due to noise and soil disturbances. A slow start of construction could startle wildlife away from the site, but they will quickly return after construction completes [14]. Operational noise of the wind farm could also pose a negligible risk of displacement to marine mammals and other wildlife [15]. Electromagnetic fields generated by transmission cables can disturb seafloor dwellers and electro/magneto-sensitive fish [16]. Cables will be buried at a depth of at least 2 meters, satisfying industry standards, to dampen these effects [17]. Constructing and operating within a Reef Fish Stressed Area is also important. Some aspects could be ultimately beneficial to this habitat, with turbine foundations and scour protection providing additional habitat with the formation of artificial reefs - bolstering stressed fishery health.

The wind farm has the potential for avian take and the disturbance of migratory flight paths [16]. Surveying with technology such as Identiflight can be used to identify endangered species during the surveying process. This technology can also be used during the operational life of the farm, allowing for real-time curtailment while minimizing power generation losses [18]. Painting one blade black on each turbine has also been shown to decrease avian take [19]. Automatic shutoff of all non-essential lights and the use of Aircraft Detection Lighting Systems on turbines will also reduce avian attraction to the site and disturbance to marine wildlife [17]. Some of the previously mentioned mitigation strategies may change as the extent of habitat sensitivity and impact is assessed with on-site surveying. Visual and audio nuisance from the farm to onshore communities has also been found to be negligible, with the site approximately 60km from shore [16].

3. SYSTEM SELECTION AND OPTIMIZATION

3.1 Turbine Make Selection

As mentioned in *Section 2.3*, most upcoming offshore wind projects in the United States range from 300 to 1,000 MW of nameplate power capacity [9]. As advocates for the transition to clean energy, SWE aims to develop a wind farm within this power range to displace fossil-fuel electricity production and encourage further renewable energy sources in the area. To meet this large capacity within the limited area of the selected leasing blocks, SWE initially sought to use most powerful offshore wind turbines on the market.

Current offshore wind turbines reach up to 15 MW of nameplate power rating, and SWE investigated the feasibility of several of these models in the proposed wind farm. Financial models computed by the System Advisory Model (SAM) revealed that the high capital costs of 15 MW turbines and significant capacity factor losses from the relatively low wind speeds in the region resulted in a project with a negative net present value. Despite not making profit, SWE considered moving forth with this financially by discovering potential tax incentives. However, extensive research combined with numerous iterations between wake and financial models proved that this proposed wind farm would never come to fruition with such a high degree of financial risk. SWE recognized the need to downsize the turbine power rating in the wind farm to increase capacity factor in low-wind periods and reduce capital costs.

SWE tested offshore wind turbine models ranging from 7 to 10 MW in the wake and financial software programs and showed drastic improvement for economic feasibility. Smaller, 7 MW, turbines yielded higher capacity factors but were less beneficial for the project's net present value and total clean power generated. Through these iterations, SWE concluded that 10 MW turbines were the best suitors to meet SWE's financial and sustainability goals.

Selecting the specific make and model of the 10 MW turbine in the wind farm required careful consideration of several factors such as cost, specifications, and lifespan. Industry leaders in turbine manufacturing and sale do not make critical specifications, such as power curves or cost, of their turbines publicly available. SWE recognized during the early phases of the wind farm development that this lack of private data would be a challenge to run real wake and financial models. To curb significant inaccuracies in these models that would result from interpolating private specifications, build similarity of the respective available metrics to NREL's IEA 10 MW reference turbine was a priority in selection. The required turbine data and specifications for the reference turbine to run power generation simulations were available for SWE's use, and any differences between the selected and reference turbine were considered negligible. Furthermore, the price per turbine of private models is not stated by manufacturers as it can vary by project, so an assumption of $1.3 million/MW of nameplate rating was consistent for all candidates [20]. Thus, any 10 MW turbine would be assumed to cost roughly $13 million per turbine. Lastly, all applicable candidates had an identical expected turbine lifespan of 25 years [21] [22]. SWE assumed that the more similar the dimensions of the selected private model to the NREL IEA 10 MW [23], the more accurate our financial and layout models would be. Thus, our main determinant in selecting the turbine model was the closeness to the reference turbine. *Table 1* shows two industry leading manufacturers, Siemens Gamesa [21] and Vestas [22], and the dimensions of their respective 10 MW models. The SG 10.0-193 DD™ is more similar to the NREL IEA 10 MW in terms of rotor diameter and power density than the V164-10.0 MW™. The proximity of the available specifications to the reference turbine utilized in wake models will increase SWE's confidence in the wind farm's financial and power projections.

Turbine Make and Model	Power Rating (MW)	Rotor Diameter (m)	Hub Height (m)	Power Density (W/m^2)
NREL IEA 10MW	10	198	119	325
V164-10.0 MW™	10	164	Site Specific	473
SG 10.0-193 DD™	10	193	Site Specific	342

Table 1. Turbine Candidate List with Dimensions

SWE is confident in selecting the Siemens Gamesa's SG 10.0-193 DD™ turbine as they are a proven industry leader in the offshore wind market and several international projects have succeeded with their turbines [24].

3.2 Foundation Selection

The foundation used in the SWE offshore wind farm is significant for structural purposes and can also significantly alter the local marine environmental impact. After doing a trade study of the ecological effects of standard offshore turbine foundations, the twisted jacket foundation had the overall lowest impact based on factors such as habitat loss, artificial reef effect, wake effect, and acoustic effect [25]. This is mainly attributed to the relatively small footprint and volume, with a larger surface area compared to other foundation types. Jacket foundations are already widely used in the Gulf of Mexico for the oil and gas industry, which will allow for the use of labor, vessels, and manufacturing that is already equipped for jacket foundations, decreasing costs. After analyzing specific jacket style foundations, the IBGS twisted jacket was chosen. Compared to conventional jacket designs, there is a 20% reduction in manufacturing costs and a 40% reduction in transportation costs for the twisted jacket [26]. The twisted jacket produces fewer acoustic disturbances than conventional jackets since the pile driver is never submerged [25]. Keystone Engineering designs these foundations, a company leveraging their O&G experience to support wind energy projects, including the Block Island Wind Farm [27]. Using IBGS twisted jacket foundation will also further stimulate the local economy, as Keystone Engineering is a Louisiana-based firm. Furthermore, twisted jacket foundations that use piles are ideal for the soft soil conditions within the leasing area. With water depths in the selected leasing area averaging around 20 m, the maximum allowable depth for jacket foundations of 60 m is easily within the range [25]. With hurricanes being a concern for turbine foundations, it is worth noting that the twisted jacket design withstood a direct hit from Hurricane Katrina in 2005 [25].

3.3 Layout Optimization

The wind farm layout significantly impacts energy production, directly related to profit generation. SWE had four main goals that were taken into consideration when iterating through layouts. The first goal is to maximize the capacity factor. Assuming a constant capital and installation cost per rated capacity, an increase in capacity factor leads to a significant increase in profit margins [28]. The leading cause for a decreased capacity factor based on the layout is wake losses. A wake loss occurs when a turbine uses the energy in the wind to spin its blade, causing the turbine behind to experience lower wind speeds. A typical wake effect is 6.7%, with a range of 3-15% [28]. Decreases in wake losses can be achieved through increasing spacing and changing grid angles. Typical downwind spacing is 6D-10D, and typical crosswind spacing is 3D-6D, where D represents turbine rotor diameter [28]. The second goal is to maximize the use of the leasing blocks. By increasing the number of turbines and thus the total capacity per area, revenues increase, and the use of the leasing blocks' area is maximized. This goal conflicts with the previous goal since the reduction in wake losses is achieved through increasing spacing between turbines. The third goal is to minimize the installation costs, in which the main element for consideration is the collection and transmission system. These costs are reduced by minimizing the total length of cable required, which can be achieved by decreasing spacing and limiting stranded turbines (two or fewer turbines on a single row). The fourth goal is to meet regulatory requirements. The primary consideration is the avoidance of the buffer zones for undersea pipelines, with five crossing through the site.

SWE optimized the layout in Furow by placing turbines in a grid and varying the following variables: downwind spacing, crosswind spacing, and grid angle. There were five variations in spacing which were 4Dx10D, 5Dx10D, 6Dx10D, 6Dx11D, and 5Dx11D. Then for each of these variations there were 24 iterations of angles between 0-90 degrees with smaller increments perpendicular to the predominant wind direction. To achieve goal three, wind turbines that were stranded were removed from the grid. To meet regulatory requirements, a buffer zone of 500 ft was placed around the pipelines that ran through the site, as this is the recommended minimum buffer without contacting the owner of the pipelines [29]. The following dependent variables were recorded for 120 iterations: total capacity, wake losses, capacity factor, and total energy production using the Bastahnkah-Porté-Agel wake model [30]. Using a weighted score that considered wake losses and total capacity, the top five layouts were reviewed to find which had the least amount of transmission cable needed for the chosen collection system. The final layout consisted of 38 turbines with a spacing of 6Dx10D at an angle of 68° (*Figure 4*).

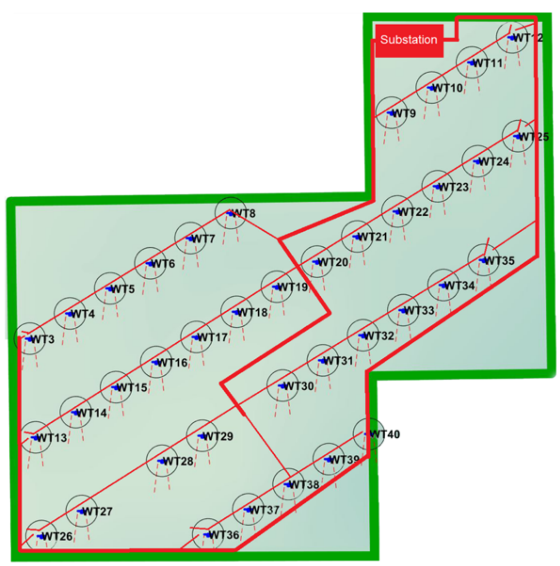

Figure 4. Final Layout

3.4 Transmission

When building a wind farm, an important factor is sending the power generated back to shore and interconnecting with the rest of the power grid. The power transmission needs to be efficient and minimize the total losses caused by transmitting power over long distances. The main concern is resistive losses caused by the length of cabling, which can be remedied by stepping up the transmission line voltage, which will in turn reduce the amount of current flowing through the lines [31]. SWE also considered the type of transmission line being used to send the power to shore; High Voltage Alternating Current (HVAC) and High Voltage Direct Current (HVDC). HVAC is more cost-effective to step up the voltage since it only needs an appropriate transformer, whereas HVDC needs expensive, specialized equipment to convert the generated power to increase the voltage [31]. However, due to the rapid alternating currents in HVAC, the transmission line has losses associated with the capacitance and inductance. HVDC does not have this issue since the current isn't changing at high frequencies and is suitable for long-distance transmission given a high enough voltage.

Another aspect of the transmission plan involves the collection system of the wind farm. The collection system is how all the power generated from the individual wind turbines are combined and sent to the high-voltage hub to be transmitted back to the onshore substation. SWE analyzed different types of collection system layouts that trade off reliability and cost effectiveness as a result of how many and how long these interconnections need to be. Simpler collection systems send all the generated power to the hub, offshore substation, where the voltage is then stepped up and transmitted to the rest of the grid. A more complex collection system implements disconnects in rows of turbines and alternative paths for power to flow in case a fault occurs in a turbine, which will shut down the affected part of the wind farm and allow the rest to continue operating, thus creating a more reliable wind farm. SWE decided to go with a single return, single hub collection system which provides the best combination of a reliable and cost-effective collection system by creating an alternative path to the hub and minimizing the total amount of cable needed to interconnect the wind turbines.

SWE decided to transmit the power using HVAC since the wind farm cabling would consist of 66 km of cabling. This is less than 75 km that has been determined to be the economic break-even distance for HVAC and HVDC, with an estimated annual power loss of around 4% [31]. SWE plans to step up the voltage to 320kV at an onsite substation and send it to the Chauvin substation on shore, which will step down the voltage and feed into the power grid's 260kV export line. We chose the Chauvin substation over ones closer to the site because of its relatively high voltage export line which will allow SWE to transmit the power we generated. However, it would have been more desirable to have a substation with a 320kV line. Ideally, we would want to upgrade the carrying capacity of the export transmission line to safely transmit our power the wind farm starts generating power.

4. OVERALL TIMELINE

4.1 Site Assessment Campaign

Offshore wind project success depends on a sound wind resource assessment campaign. In the United States, there is currently a scarcity of high quality wind measurements taken at or near hub heights, especially in the Gulf of Mexico [25][26]. MetOcean data includes water movement, wind conditions (wind speed, wind shear, and turbulence), wave height, temperature, precipitation, icing, and physical ocean parameters (temperature, salinity, sea ice, etc.). SWE will collect this data over two years since it directly influences the design of the wind turbine structure and layout [32].

Since SWE selects a site with no existing platforms, floating Light Detection and Ranging (LiDAR) buoys will be deployed to record this necessary data. Utilizing the Carbon Trust Offshore Wind Accelerator roadmap for the commercial acceptance of floating LiDAR technology, floating LiDARs will be deployed in three phases: baseline, pre-commercial, and commercial to calibrate the LiDARs properly

[28]. Floating LiDARs are ideal for this project because they are relatively low cost, and require less deployment time compared to the erection of multiple meteorological towers [32]. SWE has selected to use a P-U-V (pressure and horizontal and axial velocity terms) system since this will provide accurate directional wave spectral information and is relatively inexpensive and easy to install [32]. The measurements will be coupled using an Acoustic Doppler Current Profiler (ADCP) mounted on the ocean floor and measures wave surface elevation. The combination of these devices will also measure current.

SWE will complete surveys to assess the location's feasibility and to determine construction and installation procedures. Environmental surveys are needed to assess the specific ecology of the sites. For environmental surveys, vessels equipped with sensors or autonomous underwater vehicles are required; both are readily available from the extensive O&G infrastructure in the area. Required geophysical surveys will determine "installation procedures, cable routes, and jack-up operations" can be conducted using small vessels [33]. Geotechnical surveys, necessary to assess soil properties to aid in foundation selection, can be completed with vessels dedicated to geotechnical surveys [33].

4.2 Community Outreach Plan

An intentional and transparent community outreach plan is essential to keeping our wind farm construction and operation on schedule. During the site selection process, a community outreach task force selected by SWE will conduct meetings and outreach events in the local communities. Community outreach events aim to educate citizens and local entities about the benefits of renewable energy and allow them to ask questions and express their views on the wind farm's potential impacts. As a part of the community outreach plan, SWE will host monthly town hall meetings to allow an open space for community members to express concerns about the project. Most of these meetings will address the economic implications of the wind farm, as well as noise pollution and other physical impacts on the community.

A timeline for the overall pre-construction phase for the proposed wind farm can be seen in *Figure 5*. It is expected to take 3.5 years and conclude in 2026.

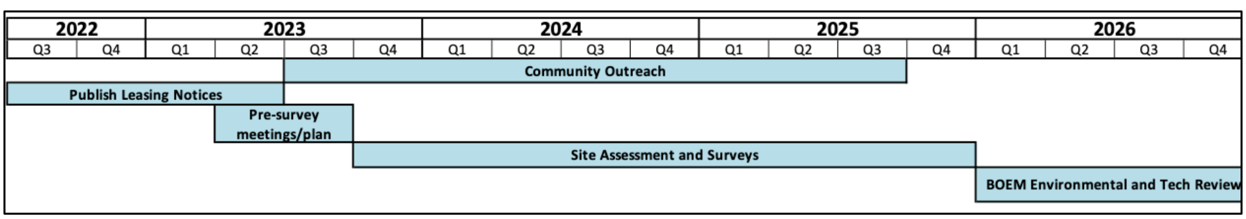

*Figure 5*1*: Pre-Construction Expected Timeline*

4.3 Construction and O&M

The first step in the construction of an offshore wind farm is selecting a port that meets the following criteria: heavy-duty wharfs made of iron or concrete that can withstand up to 3,000 tons, lay down areas for staging heavy and oversized components (must be longer than 100 yards to accommodate blade length), potential dredging capability to guarantee access to large vessels, and an overall ability to improve facilities where needed [34]. With these parameters in mind, the primary port selected for this project is Port Fourchon, the southernmost industrial port in Louisiana. Port Fourchon has been chosen because of its proximity to the selected build site and its existing facilities, which include 1,500 feet of steel bulkhead frontage that offer 24-hour heavy lifting capabilities, and 226,000 square feet of outside storage that could be used for staging [35].

The second phase of construction is procuring Jones Act compliant vessels. In short, the Jones Act mandates that any vessel carrying cargo, components, equipment, etc., from a U.S. port must be U.S. built, owned, and operated. With this federal policy in mind, the team has elected to move forward with the *Feederdock* wind turbine installation vessel (WTIV). The *Feederdock* is the first WTIV that can dock

Jones Act compliant articulated tug barges (ATBs), meaning the turbine components will be loaded onto the ATBs at the port and then transported out to the WTIV at the build site. German-based ONP Management and U.S.-Based Renewable Resources International is developing the vessel specifically for addressing the U.S. offshore wind market. It will have the capability to install turbines up to a power capacity of 25 MW in water depths up to 70 meters [36]. Construction for the *Feederdock* is scheduled to begin in 2023 and be completed in 2026, which aligns well with the pre-construction timeline. We are selecting the *Feederdock* over Dominion Energy's *Charybdis* vessel, another Jones Act compliant WTIV, because the *Charybdis* has already been contracted out for three major projects pending its completion in 2023 [36].

In addition to a WTIV, the wind farm's construction is also dependent on surveying vessels, cable laying vessels, and service and operation vehicles (SOVs). As stated in *Section 4.2*, surveying vessels are needed for the site's environmental, geophysical, and geotechnical assessments. Vessels with these surveying capabilities are readily available in the Gulf due to the extensive O&G infrastructure. For cable laying operations, the team has elected to work with Royal IHC, a Dutch-Based company specializing in cable laying for offshore energy [37]. Per an August 2020 U.S. Customs and Border Protection ruling, "the mere laying of cable by a foreign vessel in U.S. territorial waters is permissible" [38]. While this means that the Royal IHC vessel does not violate the Jones Act, it is possible that the high-voltage cabling will have to be transported to the vessel via a Jones Act compliant barge or SOV. Finally, for operations and maintenance, the team will rely on Jones Act compliant SOVs that are readily available in the Gulf for the transport of crew, engineers, technicians, small scale equipment, etc.

Construction on this wind farm off the southern coast of Louisiana will begin in 2027 following the completion of the pre-construction process and all BOEM reviews. Once started, the high-level construction schedule (*Figure 6*) will look similar to the one outlined by BOEM for the recent 800-megawatt Vineyard Wind Project.

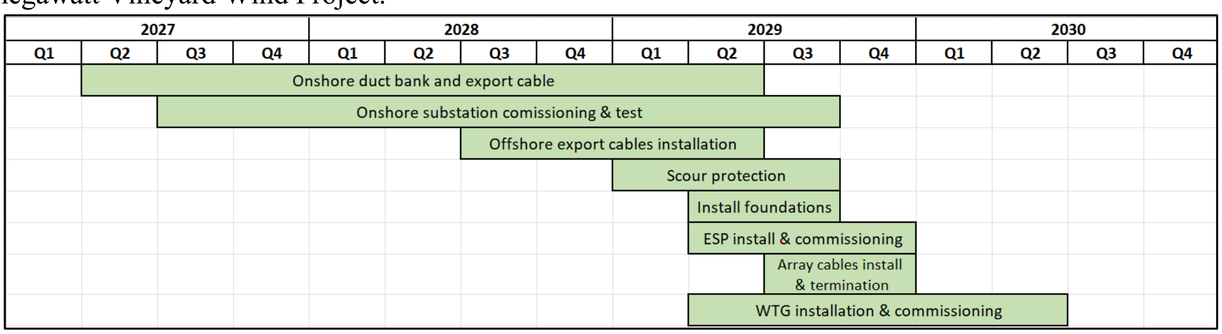

Figure 6: High-Level Construction Plan Modeled from Vineyard Wind Project [39]

4.4 Decommissioning

SWE is expecting the wind farm to run for 25-years due to the selected turbines' manufacturing specifications. Afterward, it will either be decommissioned or repowered. Before the commencement of the decommissioning process, a decommissioning application will be submitted to the Bureau of Safety and Environmental Enforcement (BSEE) to proceed with the end-of-life procedures [10].

To begin the decommissioning process, all components of the wind farm will be disconnected from the electricity grid. For turbine removal, lubricants such as motor oil, gear oil, and additional liquids will be removed from the nacelle and contained to minimize the risk of spillage into the ocean. The decommissioning will be the reverse of the installation process [40]. The blades, rotor, and nacelle will be removed together. The nacelle and rotor components can be disassembled onshore to remove any steel scraps that can be sold. Everything else that cannot be recycled or reused will be landfilled. Heavy-lift vessels or dynamic positioning vessels can aid in removing those components [40].

Some consideration will determine whether foundations or cables more than a meter below the ocean floor should be completely removed during decommissioning. Removing the cables that are more than a meter deep below the surface may cause further damage to the seabed and create additional decommissioning costs, making it a less favorable option [40]. As aforementioned, jacket foundations have in some cases been used as an artificial reef for marine species [40]. If the jacket foundations chosen by SWE are being used as artificial reefs at the end of the farm life, the team would request to not remove the foundations under section 285.909 of Title 30 in the Code of Federal Regulations (CFR) [10]. A portion of the capital cost will be allocated and saved for decommissioning. The recycled scrap metal can be sold and is included in the salvage value of the project.

5. FINANCIAL ANALYSIS

5.1 Financial Metrics

SWE determined an important factor for designing and operating a profitable wind farm is the calculated net present value (NPV). A positive NPV is essential for the project developer and investor to consider taking on the project. Consequently, the internal rate of return (IRR), a metric directly related from the NPV, is regarded as the highest priority. If the IRR is not above the discount rate, then the NPV is negative, and there is no financial benefit from the project. For an offshore wind farm, an IRR should at least be between 5-6% for an investor to consider the project [41]. For this analysis, the nominal discount rate was set equal to the weighted average cost of capital (WACC), as the developer expects to earn back initial capital costs.

The next essential factor is the power purchase agreement (PPA), which dictates the price SWE sells electricity to the off-taker. A PPA price needs to stay within the market value of electricity. The selected utility company that SWE will sell electricity to is Entergy. *Figure 7* shows the trend of electricity prices in Louisiana, created from data accessed from the Energy Information Administration [42][43]. It is important to note that Louisiana has lower electricity prices than the national average. SWE has done extensive market research to sell electricity at a profitable price compared to O&G prices. In 2030, when SWE is expected to begin operation, the market price of electricity is expected to be 8.74 ¢/kwh [43].

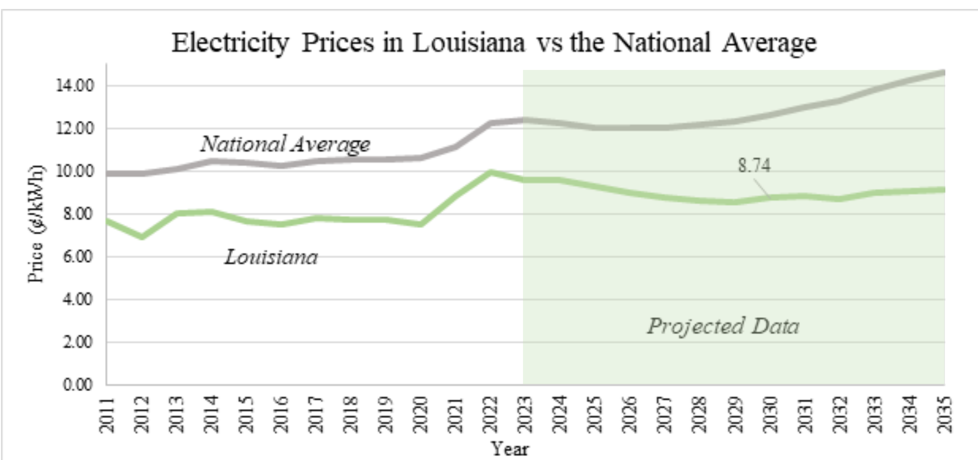

Figure 7: Electricity Prices in Louisiana Compared to the National Average

The levelized cost of energy (LCOE) is another important financial metric that is used to compare the project's cost efficiency [44]. The U.S. Department of Energy (DOE) estimated a global LCOE for offshore wind farms between \$61-\$116/MWh, so it is desirable to stay within that range [45].

5.2 Incentives

The Inflation Reduction Act (IRA) of 2022 extends the tax credits previously available for renewable energy and makes tax credits transferrable [46]. With this new legislation, the Production Tax Credit (PTC) and Investment Tax Credit (ITC) are available incentives for SWE. NREL's System Advisory Model (SAM) *Version 2022.11.21* was used to evaluate various financing scenarios [25]. SWE concluded that the ITC would be more lucrative compared to the PTC, so SWE elects to claim the ITC. To do this, SWE must "satisfy apprenticeship and prevailing wage requirements" which the developers have the intention of fulfilling [47].

5.3 Financing Plan

The challenge in the United States with many renewable energy projects is the need for a large amount of capital to bring the project off the ground. With offshore wind, there are three ways to finance a project, referred to as the "capital stack": sponsor equity, tax equity, and debt capital [48]. SWE utilized SAM to evaluate various financing scenarios and ultimately decide the best financing option for the wind farm. SAM has an evaluation for three scenarios under a Power Purchase Agreement (PPA):

- Partnership flip with debt - utilizing all three resources of the capital stack
- Partnership flip without debt - utilizing sponsor and tax equity
- Single Owner - utilizing debt capital only

SWE evaluated several variables for the three financing options, including the use of the most recent PTC, ITC, and various equity shares. Through a series of iterations, SWE found that a single owner with debt financing scenario combined with utilization of the ITC would be the most cost-effective for the wind farm. Other scenarios either demanded a higher PPA unreasonable for market conditions or terminated with a negative net present value (NPV).

5.4 Financial Assumptions

SAM is a valuable resource for its comprehensive analysis, although many variables must be considered for an accurate financial model. Many of the SAM input values SWE decided to keep at default, considering the project's scope and after consulting the information tabs SAM provides. This section details some of the most critical values that were researched for the financial analysis.

Energy losses are site-specific with the turbine used and are difficult to predict. Wake losses were taken from the Furow analysis as 5.5%. The remaining losses (availability, electrical, performance, environmental, and curtailments) were assumed to be 6.0%, 2.1%, 2.5%, 2.6%, and 0%, respectively [28].

Balance of system costs are evaluated in SAM based on the chosen construction, bathymetry, distance to landfall, and electrical connections. SWE utilized EIS and QGIS to obtain the most accurate site location information. SAM also considers the maximum water depth and distance of transmission lines. Many financial parameters were chosen based on past NREL Cost of Wind Energy Reports [49]. Based on the lifespan of the SG 10.0-193 DD™ and NREL reports, SWE chose an analysis period of 25 years. Operations and maintenance costs were assumed to be $111/kW-yr [49]. The analysis was conducted with an inflation rate of 2.5% and a nominal discount rate of 5.29%, which was chosen to be equal to the estimated weighted average cost of capital (WACC) estimated by NREL. Additionally, a 5-year MACRS depreciation schedule was utilized [49].

Federal income tax rates were taken to be 21%. State tax rates in Louisiana were found to be 7.50% for income tax and 4.45% for sales tax [50][51]. A 2.5% PPA escalation rate was chosen to keep up with inflation and as a competitive basis with Vineyard Wind LLC's PPA [52].

Finally, SWE researched insurance and decommissioning rates to find a cost per unit that could be manipulated in SAM. Insurance rates were assumed to be $10,000 per turbine, then appropriately calculated in SAM to be 0.02% of total costs annually [53]. Decommissioning rates were assumed as $40,000 per MW, and calculated in SAM to reflect that number as a percent of total returns for various scenarios [54].

5.5 Financial Models

SWE evaluated each finance scenario SAM provides under a PPA and found a single owner to be the most cost-effective. Initially, it was found that the net capital cost for the wind farm would be about $2.2 billion. *Table 2* shows a summary of the "break-even" scenario, which found the PPA price that would be necessary to equate the IRR to the WACC.

"Break-Even" Financial Model	
Metric	**Value**
PPA price in year 1	9.69 ¢/kWh
IRR	5.29%
NPV	$0
LCOE	$95/MWh
Net capital cost	$2.21 billion
Bid price	N/A

Table 2. Financial Model Based on a "Break-Even" Analysis

Unfortunately, given the market conditions in Louisiana, this is unfeasible. SWE will not find an off-taker to buy the electricity at a higher price than it can be sold for. Because SWE needs more deep industry contacts to negotiate costs, it will rely on cost projections to make the project profitable.

Offshore wind is still a relatively new technology in the United States, unlike Europe, which has been building offshore wind farms for decades. Offshore wind capital costs in Europe have decreased by 55% in the last ten years and are projected to drop an additional 28% in the next 12 to 15 years [55][56]. Reduction in costs is driven by increased project scale and turbine sizes and valuable years in operation improving technology. The U.S. only has two operating wind farms off the east coast but has 180 projects in the making [57]. With offshore wind growth, the U.S. can expect to see similar trends as Europe. Certain improvements can already be seen with the cost reduction in twisted jacket foundations, which are not yet an input into SAM [58]. NREL estimates a 22% decrease in capital expenditures for fixed-bottom offshore wind from 2018 to 2030 [49]. Given these metrics, SWE created another financial model in SAM with a 20% reduction only to the balance of system (BOS) costs, resulting in an overall cost reduction of 15.4%. *Figure 8* shows the breakdown of capital costs and that the BOS accounts for around 77% of the total.

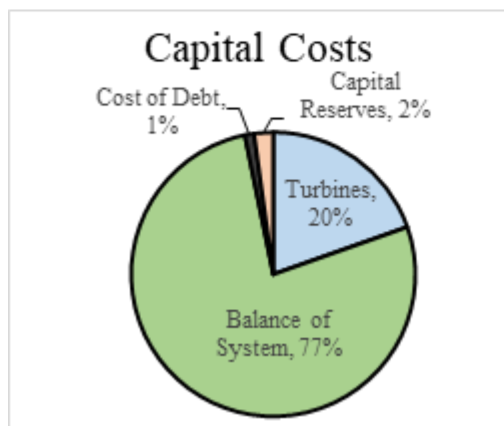

Figure 8: Breakdown of Capital Costs

With an assumed reduction in capital costs, SWE was able to produce a cost model with a high enough NPV to make a bid with a competitive PPA price below market value. *Table 3* shows a summary of the final financial model including a bid price of $30 million, to be discussed further in *Section 6*.

Final Financial Model	
Metric	**Value**
PPA price in year 1	8.70 ¢/kWh
IRR	5.47%
NPV	$11.1 million
LCOE	$84/MWh
Net capital cost	$1.84 billion
Bid price	$30 million

Table 3. Final Financial Model Including Bid Price

5.6 Risk Analysis

The financial success of the SWE wind farm relies heavily on the presumption that capital costs will decrease by at least 20% throughout the next seven years. This analysis was also conducted with a 2.5% inflation rate, a traditionally fair assumption over a long period of time [59]. However, given today's abnormally high inflation rates, this could potentially lead to higher costs than SWE is expecting.

Beyond this, political and weather risks are significant factors that SWE must consider when developing the wind farm. Fluctuations in federal and Louisiana policies may lead to significant construction delays or undesirable financial risk. SWE is taking advantage of tax incentives, and if the next presidential party were to remove these from legislation, the wind farm would likely be financially impossible. Weather can have significant impacts to our revenue and the longevity of the wind farm as well. The Gulf of Mexico is prone to hurricanes annually from June to November and is expected to increase in strength due to climate change trends [4]. The SWE wind farm is insured against damages as discussed in the following section.

5.7 Insurance

SWE will purchase the appropriate insurance to cover any liabilities throughout the duration of construction and operation. Construction insurance will cover any accidents that affect either employees or assets during the construction phase. Operations insurance covers any damage to the turbines, employees and other materials during maintenance, normal operations and inclement weather. Insurance cost used for financial analysis was estimated to be 0.02% of the annual project cost [60].

6. BID PRICE

SWE is proposing an overall bid of $30,000,000 for the selected lease blocks. This bid was decided based on our determined NPV and comparing it to recent bid prices in United States offshore wind auctions. This bid was worked into our financial analysis and is competitive against other proposed bids. SWE recognizes that this bid is low compared to bid prices in the East Coast but justifies this reduction with overall lower wind speeds and high hurricane impacts. Also, with no wind farms in the Gulf of Mexico currently, initial bid prices can be lowered as well to remain financially viable from funders and for the developers.

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