Techsan Wind Team Project Development Report

Texas Tech University

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Executive Summary

This is the final development report for TWTs project located approximately 20.5km from the coast of southeast Louisiana. The report outlines the selection of appropriate lease blocks, presents wind resource analysis, outlines the rationale for turbine and foundation selection, and the grid interconnection requirements. Further, logistical, environmental concerns, site activity issues, and economic factors are presented that need to be considered during the development planning phase. Various development considerations at the site location are outlined below.

1.0 SITE DESCRIPTION

1.1 Site Characteristics

Upon reviewing the offshore Port Fourchon, Louisiana auction lease block, the Techsan Wind Team chose the following lease blocks: 35, 36, and 39 (Figure 1). Considerations for this selection included the wind resource, proximity to the shoreline, and bathymetry of the area. The average wind speed at 100m above the entire project area is approximately 6.6m/s, from the south south-east. While considering oil and gas pipelines and platforms, as well as other obstructions, this placement is the most economically feasible as it takes up fewer lease blocks, allows for efficient energy transmission, and is the closest to the shore, 20.5km, to allow a decrease in construction and maintenance costs. The bathymetry of this section of the Gulf of Mexico comprises of depths of approximately 80m at the deepest. The seafloor consists of sand and mud closest to the shore where the chosen blocks are, and exclusively mud further out. Bathymetry, wind resources, and layout are essential factors when determining the price of the project constructions. Other factors include temperature, humidity, precipitation, and wind speeds during construction.

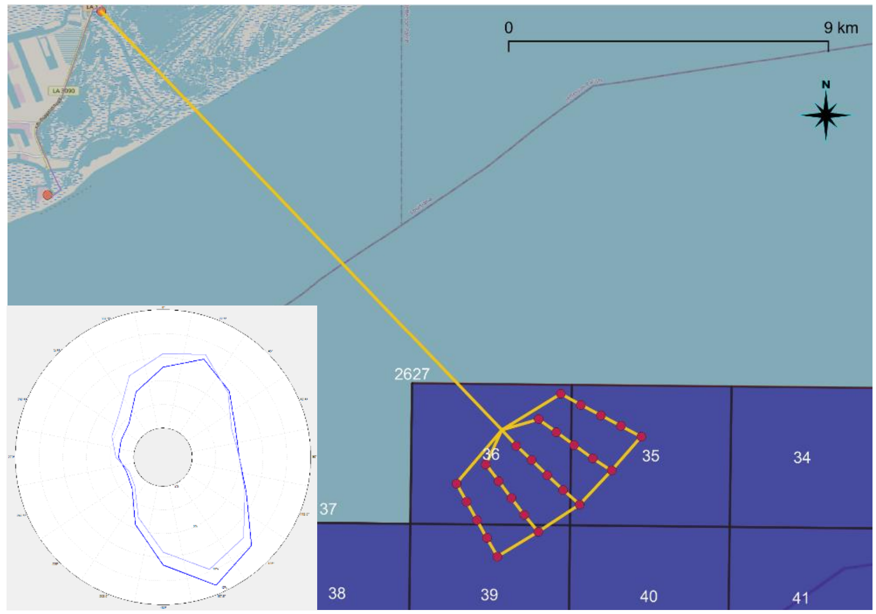

Figure 1 - Site Layout with Wind Energy Rose Overlay, predominately from 157.5 degrees.

1.2 Site Layout

Utilizing Wind Atlas Analysis and Application Program (WAsP), a wind sitting software, and the selected Siemens-SWT-4.0-130 turbine, TWT tested six different project formations to find the most effective array. Formation Zeta is the formation TWT team has selected to use because of its efficiency in energy collection and generation. A 2014 BOEM Offshore Wind Farm workshop highlighted that radial designs have been used to great effect in European offshore wind projects (Baring-Gould, 2014). The radial layout optimizes the cable connections and substation location to effectively gather and transport the energy to shore compared to standard grid layouts. TWT's Zeta Wind Formation is comprised of 5 rows aligned to the incoming wind direction to reduce overall project wake loss (Figure 2). The predominate wind direction is between angles 135 and 157.5 degrees. The multi-ring layout was devised to divide the power generated in a faulted

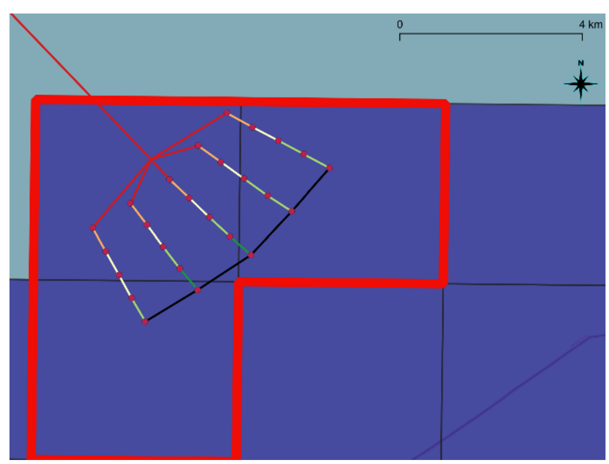

Figure 2 - Formation Zeta, Turbines and Collection System

string among the rest of the rows, precluding the capacity upgrade requirement (Lumbreras, 2019). This contingency exists if there is a fault in the line or row that would stop the flow of energy to shore. Combining the radial design with the multi-ring contingency allows for effective collection and redundancy.

The industry standard for ocean surface roughness length is 0.001m, however, an increase in wind speed increases this roughness exceeding the industry standard. Taking the percentage of annual wind intensity and multiplying it by a wind speed/wave height roughness, the new average ocean roughness is estimated to be 0.0046m. The adjustment to the roughness calculation changes the predicted 0.5% lower AEP compared to an estimate that uses the industry standard roughness length of 0.001m.

1.3 Site Activity

The coast of Louisiana has a flurry of activity between Port Fourchon and the Port of New Orleans. The lease area, given its proximity to Port Fourchon, sees heavy ship traffic year-round. Based on research of this traffic, it has been determined that the chosen lease blocks 35, 36, and 39, will see relatively minimal traffic. Conflicts with passing ships can be mitigated by designing the project in a way that they can pass through or around the project without issue. Because the total height of the turbine will be taller than 499 feet, the FAA will need to be notified and the permit, Off Airport Construction, will need to be acquired. The FAA also requires adequate lighting for structures over 200 feet to alert aircraft in the surrounding area as per the permit Advisory Circular (AC) 70/7460-1M, Obstruction Marking and Lighting.

Interference with radar systems must be considered when developing a project. Wind turbines can interfere with Doppler radars, microwave corridors, and airport radars, so it is important to know where these systems operate and how to develop around them if necessary. To conduct due diligence, TWT analyzed multiple maps of radar area use and determined that there is no conflict.

There are multiple ocean floor obstructions to be aware of in the area, though none are major concerns. These obstructions are oil field debris that pose minimal risk to construction, operations, or maintenance if they are avoided properly. According to the Coast Survey's Automated Wreck and Obstruction Information System (AWOIS) and Electronic Navigational Charts (ENC), there are shipwrecks and other debris such as trawl nets and rigging within the lease blocks that may pose a threat to the installation of foundations. Near the turbines placed there are also other reported obstructions found using the AWOIS system. These obstructions are not a threat to construction; however, they will be examined before beginning construction.

The Louisiana Department of Wildlife Fisheries has a research station located on Grand Isle. The Grand Isle Fisheries Research Lab is responsible for sampling, tagging, and other research projects regarding data about the marine wildlife within the area. There are thirty-one species of fish in the area that are managed under the Fishery Management Plan for Reef Fish including grouper, snapper, mackerels, tuna, and other species. Grand Isle is a popular fishing spot in Louisiana, with year-round fishing. Some of the most popular fish caught in the area are the Black Drum, Red Drum, Sheepshead, Spotted Seatrout, and Tarpon. There are broad fishing areas off the coast of Louisiana, some of which are within the project lease areas. Following European offshore wind industry development, positive interactions between fishing/trawling companies and the offshore wind industry can be expected. Further, as explained below (Section 3.1), twisted jacket foundations are proposed for this project that are known to increase marine biodiversity likely resulting in a small increase in the quantity of marine life farmed.

Considerations for archaeological and historical interests, as well as those of areas governed by Native Americans must be made. TWT utilized data from the Native Land Information System to ensure the proposed project did not overlap with any areas that may be considered native land, as that would entail addressing issues with the local native-government body. The National Register of Historical Places was consulted to ensure no conflicts with any historical or archeological sites of interest. Historical shipwrecks were also researched, and it was determined that none existed within the chosen area.

1.4 Wind Resource and Surface Conditions

Several wind speed databases were explored before the most complete database options were selected. The initial data source examined, LOPL1, has an anemometer at a height of 57.9m located in the lease block area provided by the National Oceanic and Atmospheric Administration's (NOAA) National Data Buoy Center (NDBC) (NDBC, 1996). However, the available data was time-stamped inconsistently, making it difficult to work with. Therefore, Modern-Era Retrospective analysis for Research and Applications (MERRA-2) satellite data was explored that measured at 50m height, and finally, ERA5 data at 100m which included complete years dating back to 1979. Owing to the availability of two different measurement heights, a shear exponent of 0.11 was calculated. These two databases also significantly increased the amount of quality data for analysis. MERRA-2 and ERA5 data were analyzed by *Windographer*, the chosen wind analysis software, to formulate the wind rose, vertical shear profile, monthly mean wind speed averages, and diurnal wind speed averages. *Windographer* was chosen because of the ease of data cleaning and user interface.

After analyzing the MERR-2 and ERA5 data with *Windographer*, the average wind speed at 100m in the anticipated lease block area was found to be 6.6m/s, with a predominant wind direction from the south-southeast direction. These wind speeds are lower than the preferred wind speeds for an offshore development. Turbulence intensity is below 16%, considered "low turbulence" by IEC 61400.

Another concern for the area is the frequency at which hurricanes could occur, bringing high wind gusts and potential damage to the site. High wind gusts from severe weather are not automatic deal breakers for potential wind development sites. However, this, coupled with low wind speeds at this site, prevents available offshore wind turbines from performing optimally.

2.0 Technical Analysis

2.1 Turbine Selection

There are three crucial factors to consider when deciding on a wind turbine for a site: net annual energy production (NAEP), net capacity factor (NCP), and cost.

The wind turbine selected is the Siemens-SWT-4.0-130. This model has a 4 MW asynchronous generator, a rotor diameter of 130m, and will have a 100m hub height. The cut-in wind speed is 2.5m/s, the rated wind speed is 12m/s, and the cut-out speed is 25m/s (Figure 2). This turbine is classed as IEC IB. Class II, III, or IV offshore turbines are not commercially available, though they would be a preferred option. Although it is not typhoon-class, IEC IB is rated for a 70 m/s gust and hurricane impacts could be mitigated by employing appropriate emergency procedures.

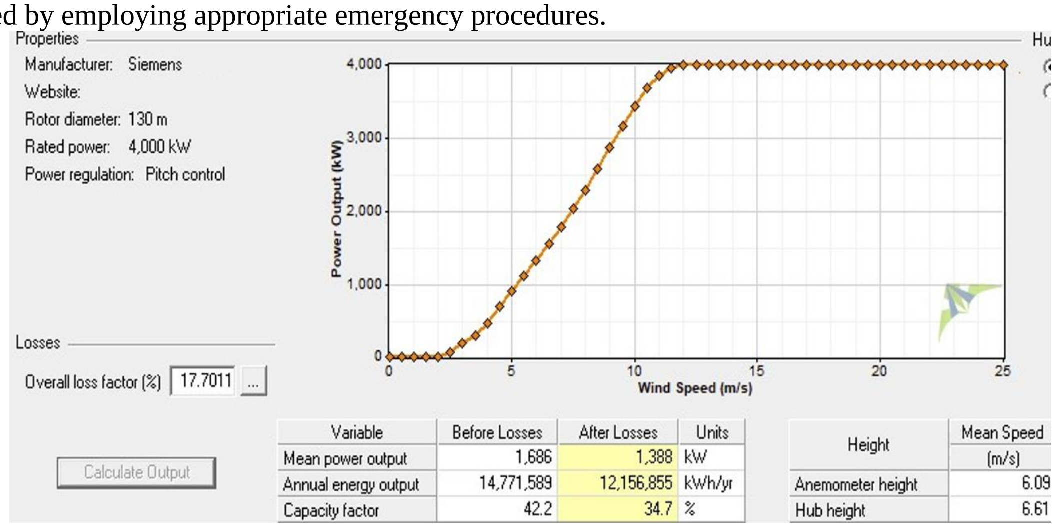

Figure 3 - Windogrpaher Calculations and Power Curve for Siemens SWT-4.0-130 (P50)

Calculations done in *Windographer* can be used to estimate the P50 performance of an individual wind turbine within the site. These estimations, including losses, electrical and mechanical, of 17%, show that the Siemens-SWT-4.0-130 would have a Net Annual Energy Production (NAEP) of 12,157 MWh/yr, and a Net Capacity Factor (NCP) of 34.7%.

Alternative turbines were analyzed to find the turbine that best fits the project, specifically the GE Halide 6-150, Vestas V164-10MW, and Siemens Gamesa Siemens-SWT-6.0-154. These turbines' large rotor diameter makes up for the low 6.6 m/s wind speeds by catching more wind and have larger generators than the Siemens SWT-4.0-130 that was chosen for this project. Though the two models by Siemens Gamesa are not a direct comparison, in part because of the differing hub heights due to blade and generator size differences, a clear indication was given that the smaller 4.0MW model will perform better than the larger 6.0MW model.

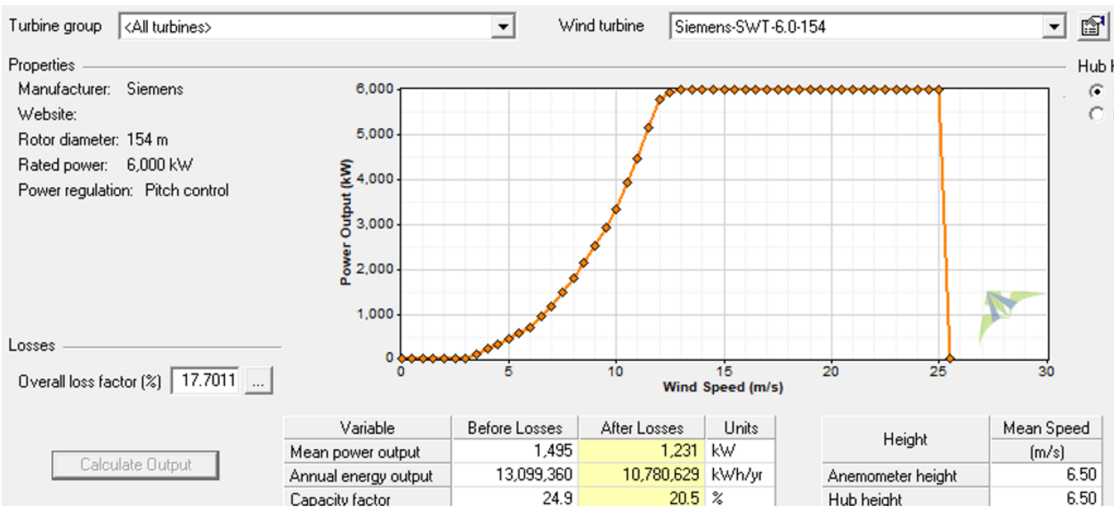

Figure 4 - Windogrpaher Calculations and Power Curve for Siemens SWT-6.0-154 (P50)

The team's initial thinking was that a larger turbine would automatically be better for this site. However, upon further technical and financial analysis, it was discovered that this was not the case. The increase in upfront cost for the larger turbines, towers, and blades is significant, and is not compensated for by an increase in expected production. Therefore, the smaller, and less expensive turbine, the Siemens SWT-4.0-130, was more appropriate for this project.

2.2 Production Estimation

To estimate the annual energy production (AEP) for this project TWT utilized two industry standard programs. WAsP was used to calculate the most likely (P50) and realistic scenario, and System Advisory Model (SAM) was used to calculate a less likely (P90) worst case scenario. To perform these differing calculations only the capacity factor is manipulated, and all other variables remain static.

WAsP performs a P50 calculation, meaning that 50% of the time the project will produce more or less than estimated AEP. This is also the expected value. This calculation accounted for the use of the site-specific surface roughness calculated by TWT instead of an industry standard value. Using a capacity factor of 40 %, WAsP estimated that the annual energy production of the project will be 365,068 MWh.

SAM performed a (P90) calculation; this means that there is a 90% chance that the estimate given by SAM will be exceeded. Using a capacity factor of 20%, it is estimated that the project will produce 174,031 MWh. Due to the risk posed by this project TWT has decided to financially operate within the constraints provided by this P90 estimate.

2.3 Foundation

For the project, three types of foundations were researched: floating, monopile, and jacket. The team analyzed factors such as water depth, soil type, cost, endurance, and environmental impact to determine the foundation that would best fit the needs of the turbine model.

A floating foundation would likely be the most expensive and complex to develop since it is in the early stages of development. The Floating foundation will not be available in time for the project, however, it may be relevant in a future build-out scenario. This type of foundation is the least compatible with the water depth of the Gulf of Mexico.

The 15–20m Gulf depth limits the options to monopile or jacket-based designs. Monopile foundations are common in similar depths in the North Sea, however, they do not perform well in loose soils like the kind found in the chosen lease blocks. A monopile foundation is also more prone to endurance failures in hurricane-liable areas like the Gulf. These drawbacks in both floating and monopile foundation types contributed to the choice of an Inward Battered Guide Structure, or "twisted jacket" substructure for the foundation.

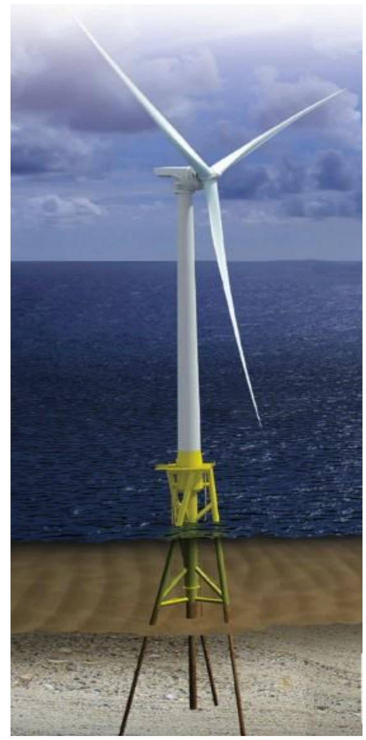

Figure 5 - Twisted Jacket Foundation - Keystone Engineering.

A Louisiana-based company, Keystone Engineering, already exists that produces twisted jacket offshore foundations and has experience from producing Block Island's traditional jacket foundations (Tristan Baurick, 2021). When compared to traditional jacket foundations (Ocean Conservancy, 2013), twisted jackets entail lower costs, as much as 20% lower than traditional jacket foundations, and higher endurance against dynamic loads like hurricanes. Twisted jacket foundations are much cheaper than traditional jacket foundations because fewer building materials are required, and they can be installed almost entirely above ground.

TWT focused on addressing the issue of endurance against the frequent hurricanes in the Gulf of Mexico to improve on the 2022 Techsan project. A twisted jacket foundation is more likely to effectively withstand hurricanes than a traditional jacket foundation and has been used for years in the oil and gas industry and survived multiple hurricanes. In May 2014, the Department of Energy selected the jacket design to serve as the fixed bottom foundation for three offshore wind projects through funding grants (EERE, 2017). According to the research, this type of foundation also satisfies the requirements of the lease area's soil, bathymetry, and depth. This is because twisted jacket designs distribute the weight of the foundation and turbine more effectively on soft soils while being a lighter-weight option. To avoid scouring degradation to the foundation, concrete mattresses or rocks could be offloaded atop a small surrounding area of the foundation. Twisted jacket designs also support deeper depths of up to 100m, the most extreme depth in the potential lease blocks.

2.4 Grid Connectivity

Regarding Grid Connectivity, TWT selected the closest lease blocks to the shore to reduce the amount of cabling used to connect the project to shore, minimize electrical losses, and optimize for cost. For this, the offshore project substation is located 17.5km East-Southeast of the Port of Fourchon within block 36 of the Louisiana lease block. To the Northeast of this site is the only other point of interconnect in the vicinity but it is over 19km away and does not feed into an adequate grid system. This makes the northern most lease blocks the most desirable as they are the closest to the shore and connect to an economic substation. Each turbine is placed five rotor diameters apart within rows, then placed into a shallow radial design for effective offshore wind gathering. These placements, between rows, are about 0.65km between each other and will increase cabling based on the economic ampacity of the previously added turbines. Between columns, the turbines will be placed eight times the rotor diameter of the turbines apart at 1.03km.

The collection system was designed using the wind industry's average of 0.55 economic carrying capacity (ECC). Losses that occur when above 55% total amp capacity are too high to be financially viable, so cables must be chosen with a maximum ampacity, nearly double that of which the cable will carry. The cabling between these distances' ranges from the Underground 34.5 kV lines, 4/0 AA, 500 MCM AA, 750 MCM AA, and 1000 MCM AA. The cables, just before entering the substation, are a pair of twinned 750 MCM AA cables and the final ocean-to-shore cable is the 1000 MCM AA.

The point of connection onshore is a 230kV substation located north of Port Fourchon. This substation was located using a shapefile obtained from the Energy Information Agency, however key information such as wire type and transmission voltage was unavailable. To obtain this information TWT performed a visual inspection online of the outgoing transmission lines, particularly counting the number of insulating disks present between the line and its supporting tower. Research into these disks reveals that multiple factors contribute to the kV capacity indicated on the line by each disk. Spacing, material choice, local climate, and local regulations can all affect this determination. Generally, each disk could insulate 11-15kV based on these factors. Since the line has 17 insulating disks, it was estimated that the line has 230kVcapacity. Since other transmission lines in the area run at 115kV, or 230kV, TWT has determined that this substation operates at 230kV.

2.5 Novel Considerations

Hydrogen production, battery storage, and blade recycling are huge potential changes coming to the wind energy industry in the coming decade, and as such deserve attention in this report.

On site hydrogen production is a way to transform electricity that would otherwise be sold for an unacceptable price, into hydrogen that can be sold for profit, or to avoid curtailments. This process uses electrolysis to split fresh water into hydrogen to be stored, and oxygen to be released into the atmosphere.

Though TWT did consider this, two issues arose during research that dissuaded the team from this option. First, water used for the process will have to be desalinated though an energy intensive process. While progress has been made in performing electrolysis on salt water (Jiaxin Guo, 2023), these improvements are not in line with TWTs timeline. The second issue has to do with the price of energy. Since TWT is signing a Power Purchase agreement, to be expanded later, the project will not need to produce hydrogen to offset costs when the price of electricity is low. Battery storage systems are used for arbitrage opportunities as well, however TWT decided against their use for the same reasons. This prevents increasing the overall project cost without any meaningful benefit.

Turbine blade recycling is a hot button issue. At present, retired blades end up in yards where they are cut, stacked, and stored indefinitely. This clearly poses an issue, as this kind of waste is bad for both the environment, and how average people view the wind industry. Currently there are multiple blade manufacturers and third-party companies looking to solve this issue with promising results. As it is likely that by the end of the lifetime of this project there will be commercial scale solutions to recycling blades, when the time for decommissioning comes, TWT will commit to recycling the used blades.

TWT also considered using a derated turbine for this project. This is the process of taking an existing turbine and replacing the generator with one of a smaller capacity, which would yield a higher capacity factor and a potentially higher AEP. TWT Decided against this due to the uncertainty of a custom turbine, an increase in turbine cost per MW, and an increase in insurance costs.

2.6 Decommissioning Plan and Future Build-out Scenario

While lease agreements in the early days of wind energy did not require a decommissioning plan, contracts have since evolved that now require funds be set aside throughout the life of the project. This ensures a complete decommissioning process can take place at the end of the project's lifetime, to return the affected area to its original state, or to ensure that repowering may occur. Using the Cape Wind project's decommissioning plan from 2014 as a guide, it is estimated that the cost of decommissioning per turbine would range from $700,000 to $1.2 million, with $1 million being the estimated true value. This puts the total cost of decommissioning at an estimated range of $17.5 million to $30 million, with $25 million being the estimated true total cost value.

As for a future build out scenario, it is expected that offshore wind turbine technology will have improved exponentially in the next two decades, with floating foundations expected to have a Technology Readiness Level (TRL) of nine, meaning it is fully commercially available. Compounded by this, it is expected that a wider selection of turbine choices will be available, with those rated for low wind speeds available. Along with this, the data analysis aspect of wind energy, from data acquisition to turbine layout and wake effect awareness, will all be improved, allowing for greater efficiency and optimization. With this in mind, a future build-out scenario could include repowering the current layout with more appropriate turbines that have been described in Section 2.1 after the conclusion of the turbine lifetime. In addition, turbines with floating foundations could be placed further from shore so that slightly better wind speeds could be taken advantage of, and obstruction and environmental issues could be avoided.

3.0 Flaws and Environmental Analysis

3.1 Risks, Fatal Flaws, and Mitigation Strategies

A nearby air force base controls a large swath of airspace in the 80–100m zone in the Northern section of the potential lease blocks for training, including the lease blocks for the intended project. If an agreement cannot be reached to allow the project to coexist in this zone, the project would have to be moved to the Southern portion of the potential lease blocks, significantly increasing costs, and potentially ending the project.

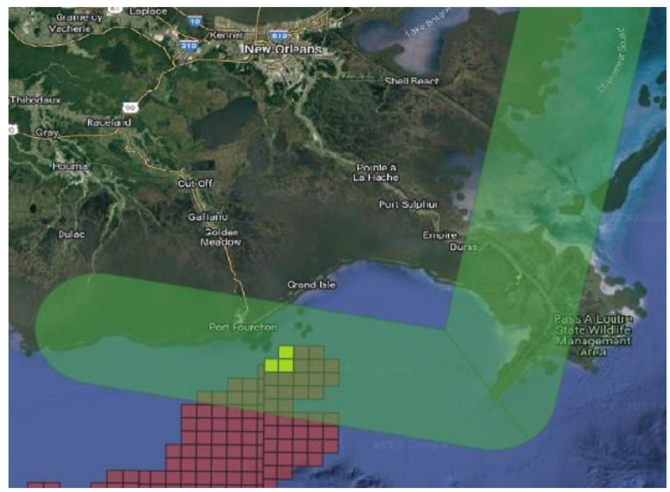

Figure 6 - USAF Path Conflict (green), Chosen Lease blocks (Yellow).

Similarly, uninterrupted views of the ocean are often something that coastal communities would like to preserve. NIMBY-ism typically impedes renewable energy projects because they could be interpreted as being an eyesore to the landscape. However, since the turbines are 20.5km from shore, well past the horizon, they will not be visible to those onshore. Thus, the project should not be impacted for aesthetic reasons. The area where the turbines are located is also closest to an industrial area onshore and therefore will not be hindering typical coastal activities such as beachgoers.

Additionally, a recent memo released by NOAA, stating that the multiple whale deaths along the Atlantic coast are due to wind turbines, has caused a public debate on the environmental impact of offshore wind turbines. If these claims were proven to be true, offshore wind development could be significantly slowed or halted entirely, as multiple whale species exist in the area. To continue this project, TWT is assuming that offshore wind projects can safely advance through the development, construction, and O&M phases without being suspended due to the presence of whales.

TWT investigated mitigation strategies of European offshore wind projects for environmental concerns. The TWT found four mitigation strategies that will be utilized for this project. To address concerns for aerial species such as the piping plover or brown pelican, the base of the wind turbine and blade tips will be painted. Painting these portions can provide visual aid to birds and other aerial species to prevent strikes and collisions. To address marine life and marine habitats the choice of using twisted jacket foundations for the project and the implementation of scour protection systems, will be used as they help in the creation of artificial reefs. Artificial reefs are manmade reefs that utilize manmade objects like ships or foundations to provide areas for coral to latch onto. Artificial reefs have been found to increase biodiversity in areas and they can become habitats for multiple marine species. Twisted jacket foundations have been found to benefit in the start of artificial reefs, twisted jacket foundations provide a hard surface for species involved with the formation of corals to attach to. Scour protection systems are used to prevent erosion and changes in benthic habitats, these impact artificial reefs creation by introducing gravel, boulders, or synthetic fonds around the base of the foundations, these provide more hard surfaces to the project area for establishment of artificial reefs. The last mitigation strategy TWT will employ will center around the construction of the project is soft starts. Pile driving for the installation of foundations and dredging will introduce new sounds and sights in the marine environments in the project area, this can introduce new stress in the environment and the wildlife that live in it. To reduce environmental stress, construction must start off slowly and then ramp up as construction progresses, this will slowly introduce the new noises to the area so marine species will not be as startled and can slowly get used to the sounds and sights of construction.

Although the Gulf of Mexico is not generally known as a tectonically active area, with the intersection of the North American and Caribbean plates located just outside the gulf (USGS, 2023), it is pertinent to check for seismic activity. The most recent earthquake in the area surrounding the project happened 4 years ago, a magnitude 4.6 at a depth of 10km, approximately 120km away from the project area (Earthquake Track, 2023). The largest earthquake in the area was a magnitude 5.3, 5km deep, approximately 100km away. Neither of these quakes, nor any other, has affected the projected project area. Still, it is an important consideration to make as seismic activity can shift the soil around a foundation, and therefore tilt the foundation (Kaynia, 2019).

With an anticipated project lifetime of twenty-five years, it is statistically likely that a hurricane could impact the project. Though hurricanes of a lower category on the Saffir-Simpson scale of one or two occur more often at a rate of once every 3.3 years and tropical storms at a rate of once every 1.6 years, the wind speeds associated with these weather phenomena are lower than the rated survival speed of the selected turbine, at a wind speed maximum of 32.41 m/s for tropical storms and a wind speed maximum of 48.87 m/s for category two hurricanes. These speeds are well within the IEC 61400-01 standard for offshore wind turbines of 70 m/s survival wind speeds. While the selected turbines for the project are not typhoon class, as a small percentage are, there is little that can be done to protect the turbines from higher-class hurricanes other than normal emergency operating procedures such as pitching the blades and yawing out of the wind.

Connecting a project to a grid requires a grid interconnection study to be conducted, currently there are over two terra-watts of energy projects in a queue waiting to clear this hurdle (Berkely Lab, 2023). TWTs project will enter this queue as well, with a timeline of approximately three years, there is no way around this process.

3.2 Critical Habitats and Wildlife Analysis

The designated lease block area for the project is located off the coast of Louisiana within the Gulf of Mexico. The Gulf of Mexico is home to many threatened and critically endangered plant and animal species (Love, 2013). There are twenty-eight different species of marine mammals known to occur in the Gulf of Mexico. All twenty-eight species are protected under the MMPA and six are also listed as endangered under the ESA. They are: The Sperm, Sei, Fin, Blue, Humpback and North Atlantic Right Whales. Of the six ESA-listed whales, only endangered sperm whales are considered to commonly occur. There is a resident population of female sperm whales in the Gulf of Mexico, and whales with calves are sighted frequently.

Kemp Ridley’s Sea turtle is one of the species that can be found in the list of endangered and threatened species for the Gulf of Mexico and the chosen lease blocks, along with other turtle species (Threatened, 2022). Due to the Kemp Ridley’s Sea Turtle being found in the area, approval from BOEM will be needed per the Endangered Species Act and the Marine Mammal Protection Act of 1972. This will require a Habitat Conservation Plan (HCP). Under the BOEM Renewable Energy Program Regulations

(30 CFR 585), Subpart H: once notified of the existence of endangered or threatened species in the vicinity of the lease, BOEM will consult with appropriate State and Federal Fish and Wildlife agencies to identify whether, and under what conditions, the project may proceed (Bureau of Ocean Energy Management, 2014).

The available lease area is considered a critical habitat for the Loggerhead Sea Turtle. This means federal agencies consult with NOAA Fisheries to ensure actions they fund, authorize, or undertake are not likely to destroy or adversely modify the critical habitat. Whales, including Rice's Whale and others, along with coral species like the Lobed Star species, Smalltooth Sawfish, Whitetip Shark, Giant Manta Ray, and the Piping Plover, an avian species, all live in the area. The Migratory Bird Treaty Act will also need to be followed as the Piping Plover migrates between Louisiana and Mexico (ERegulations, 2022).

3.3 Green House Gas Reduction Estimate

For this analysis, TWT will be using the emissions generated from burning coal to calculate the emissions avoided by this wind project. Though Louisiana is primarily powered by natural gas, and thus the natural choice for this calculation, as renewable energy enters the grid, coal powerplants will be the first to close as shown in the next-door ERCOT grid.

To generate 1 MWh of electricity requires burning 1,100 pounds of coal. This in turn produces 2,100 pounds of Carbon Dioxide, 3.9 pounds of Sulfur Dioxide, and 1.6 pounds of nitrogen oxide (DOE, 2016). Of note is that the Carbon Dioxide emissions from coal are greater than the amount of coal originally input, this is due to the burned carbon reacting with the oxygen in the surrounding air. Coal also leaves behind solid waste in the form of coal ash, thorium, uranium, and mercury (Freeing Energy, 2020). Emissions and pollution due to the extraction of coal, while massively impactful, are outside of the scope of this analysis.

With an estimated AEP of 365,068 MWh per year, TWT can calculate an emission saving of 381,520 tons of Carbon Dioxide, 709 tons of Sulfur dioxide, and 291 tons of nitrogen oxide. A considerable reduction in the face of climate change.

3.4 Permitting

The designated lease block area for the project is located off the coast of Louisiana within the Gulf of Mexico. The chosen area lies approximately 20.5km from the shore of Louisiana; therefore, it lies outside of the state's legal boundary which is three nautical miles, meaning no state permits are required and federal agency permits will be acquired. Federal governing agencies that permits are going to be acquired from are the Bureau of Ocean Energy Management (BOEM), the National Oceanic and Atmospheric Administration (NOAA), the United States Fish and Wildlife Service (USFWS), the United States Army Corp of Engineers (USACE), the U.S. Coast Guard, the Department of Defense (DoD), the Federal Aviation Administration (FAA), and the Environmental Protection Agency (EPA).

The lease area falls within areas of endangered species, approval from the BOEM will be needed in accordance with the Endangered Species Act and the Marine Mammal Protection Act of 1972. This requires a Habitat Conservation Plan (HCP). Under the BOEM Renewable Energy Program Regulations (30 CFR 585), Subpart H: once notified of the existence of endangered or threatened species in the vicinity of the lease, BOEM will consult with appropriate State and Federal Fish and Wildlife agencies in the vicinity of the lease, BOEM will consult with appropriate State and Federal Fish and Wildlife agencies to identify whether, and under what conditions, the project may proceed.

Commercial lease of submerged lands for a renewable energy development permit will need to be acquired; the lease is subject to the Act and regulations promulgated pursuant to the Act, including but not limited to, offshore renewable energy and alternate use regulations at 30 CFR Part 585 as well as other applicable statues and regulations in existence on the effective date of the lease. The lease is also subject to those statutes enacted (including amendments to the Act or other statutes) and regulations promulgated thereafter, except to the extent that they explicitly conflict with an express provision of the lease. Site Assessment Plan (SAP) approval will be needed which will be acquired from (BOEM). Submissions of any required consistency certification and necessary data and information pursuant to 15 CFR part 930, subpart D or E, to the applicable State Coastal Zone Management Act (CZMA) agency or agencies and BOEM. Approval from the U.S. Department of Homeland Security, U.S. Coast Guard (USCG) under 14 U.S.C 81, the USCG is authorized to establish aids to navigation. To obtain approval to establish a private aid to navigation (PATON) a CG-2554 must be submitted. A PATON is a buoy, light, or day beacon owned and maintained by any individual or organization other than USCG. These aids are designed to allow the organizations to mark privately owned marine obstructions or other similar hazards to navigation. A meteorological tower and/or buoy in the wind energy area, regardless of height, would be considered a PATON and this would be required to have lighting and marking for navigational purposes. A consultation with the U.S. Department of Defense (DOD) pertaining to the siting of the plan. Rivers and Harbors Appropriation Act of 1899 (33 USC 401 et seq.), Section 10 (33 USC 403) delegates to the USACE the authority to review and regulate certain structures and work that are in or that affect navigable waters of the United States. The Outer Continental Shelf Lands Act (OCSLA) extends the jurisdiction of the USAC, under section 10, to the seaward limit of Federal jurisdiction.

Incidental Take Permits will need to be approved as there is a possibility that any one of the endangered species could be killed or harmed during the construction, operations, or maintenance phase of the project. One way to mitigate any damage or harm caused by the project is by donating to foundations located within Louisiana that support the restoration and protection of the Gulf of Mexico. The Gulf Restoration Network is an organization that protects and restores natural resources in the area while educating local citizens on problems and solutions that impact the Gulf of Mexico.

Federal Governing Agency	Permitting Requirement
Bureau of Ocean Energy Management (BOEM)	Commercial lease of submerged lands for renewable energy development Site Assessment Plan (SAP) approval Construction and Operations Plan (COP) approval Facility and Design Report (FDR) approval Fabrication and Installation Report (FIR) approval
National Oceanic and Atmospheric Administration (NOAA) Fisheries, United States Fish and Wildlife Service (USFWS)	Consultations for: Magnuson-Stevens Fishery Conservation and Management Act, Marine Mammal Protection Act, National Historic Preservation, Endangered Species Act Authorization for incidental take or harassment under: Marine Mammal Protection Act, Endangered Species Act, Migratory Bird Treaty Act, the Bald and Golden Eagle Protection Act, and the Magnuson-Stevens Fishery Conservation and Management Act
United States Army Corp of Engineers (USACE)	Permit for subsea cables under the Clean Water Act
U.S. Coast Guard	Navigational Lighting Permit
Department of Defense (DoD), Federal Aviation Administration (FAA)	Consultations pertaining to siting
Environmental Protection Agency (EPA)	Air quality and pollution prevention permits

Figure 7. Chart showing common permits and respective governing agencies.

4.0 FINANCIAL ANALYSIS

The team used multiple methods of analysis, including industry tools like System Advisor Model (SAM), as well as multiple proprietary models for financial analysis. A variety of factors informed this analysis, including capital expenditures (CAPEX), operational expenditures (OPEX), taxation, depreciation, information from wind development software, as well as financial and site assumptions. This information was used to find a breakeven Net Present Value (NPV) at 20 years, the Internal Rate of Return (IRR), Real Levelized Cost of Energy (RLCOE), and the Debt Service Coverage Ratio (DSCR). To preface, all project costs are estimates from the NREL tool SAM, which, after reading the source code, has been determined to be a very comprehensive cost analyzer, including the cost of dredging, dredging vessel, transmission lines, and foundation costs among numerous others. SAM is a (P90) financial analysis model, meaning this analysis was performed in a worst-case scenario wind wise, which is favorable for this project due to the outsized risk it presents. In the continued iterative design of the project, the team continually updated the design and layout of the project to determine the best possible design. In contrast to the preliminary report by TWT, the current design has many changes and alterations that help to create a more optimized project.

4.1 Market Conditions

This development takes place in the SERC grid, off the coast of Louisiana. Understanding the market in which the electricity would be sold is vital in informing TWT's decisions. Average electricity prices in Louisiana are 8.82 ¢/KWh (EIA, 2021), the 7th cheapest in the country (EIA, 2021) due in part to plentiful natural gas reserves. Louisiana is one of the few remaining states that does not have a Renewable Portfolio Standard, meaning that there is no inherent goal by the government of the State of Louisiana to reduce natural gas dependence and incentivize renewable energy in any way.

Inflation of raw goods, materials, and labor is important to factor into the project, especially as prices have recently risen and are projected to continue to rise. To analyze inflation TWT can look at the producer price inflation (PPI) to understand how the cost of goods related to production will increase during construction and through the lifetime of the project. Since the emergence of the world from the COVID-19 pandemic, monthly PPI has consistently hit its highest levels, over 1% monthly, since 2010. Though the economy is now showing signs that PPI will stabilize, to combat this instability TWT suggests buying materials and commencing construction before PPI has a chance to increase once again.

This project presents an outsized risk relative to similarly priced renewable developments due to the low 6.6m/s wind speed, the uncertainty that comes with being a first mover, and the inherent risk of developing offshore.

4.2 Capital Expenditures

Due to the inability to reasonably acquire live prices of physical units, coupled with the variability of raw materials both in time and the market, mathematical approximations were used in financial calculations for portions of this report. Components of Capital Expenditures (CAPEX) such as turbine, substation, cabling, and substructure unit costs were approximated utilizing formulas and reasonable information. These units have variable costs associated with site-specific features such as water depth, distance to shore, capacity, and unit design. This approach increases CAPEX accuracy influenced by environmental aspects and design decisions of the project. SAM has been unitized to aid in estimating these costs as well as organizing information. These are the costs predicted for TWTs 100MW project of twenty-five turbines, in the designed layout.

The chosen turbine rating is 4MW, assuming a $1442.41/kW turbine cost, the total cost of all turbines is estimated to be $144,241,000. This rate aligns with the research TWT has conducted.

The balance of systems (BOS) capital costs for the project, which includes costs such as electrical infrastructure, foundations, and other costs but excludes turbines is $357/kW or $35,700,000 total. With a sales tax of 5.0%, the total estimated capital cost of the project is $179,941,000.00 or $1,799.41/kW.

As for the total balance of the system's costs, now including installations, legal compliance fees, and numerous miscellaneous charges, SAM estimates the cost to be $805,062,968 or $8,051/kW, this cost includes the previous BOS capital costs.

Added all together this brings the total installed cost of TWTs project to $949,303,968, this price contains the necessary and appropriate contingencies. The DOE estimates that 70% of an offshore wind project total cost is in installation and construction, this project lines up closely with that estimate.

TWT will be depreciating these assets using the 5-year Modified Accelerated Cost Recovery System (MACRS) offered to wind energy developments by the federal government. This system works by reducing the time it takes to depreciate the project to just 5 years as follows: 20%, 32%, 19.2%, 11.52%, 11.52%, and in the 5th year 5.76% (IRS, 2022). This accelerated system is beneficial as it allows the project to deduct a greater amount of value from the depreciated assets in the first 5 years of the project's lifespan, which is when this advantage is most needed.

Port Fourchon will be used as the main connection between the Gulf of Mexico and construction and operations and maintenance personnel. The port has the capacity to handle a wind project but will need to be further developed with O&M buildings and reinforced concrete due to the heavy load of turbine components. There are also port lease blocks available that can be used as a staging area for the construction of the project that will need to be leased. According to Figure 8, days 150 through days 250 would be the optimal time to construct the project as this is the time when the wind speeds are lowest. This means cranes will be able to operate more consistently, as too high wind speeds obligate cranes to cease operations. These times correspond to approximately the end of May to the beginning of September.

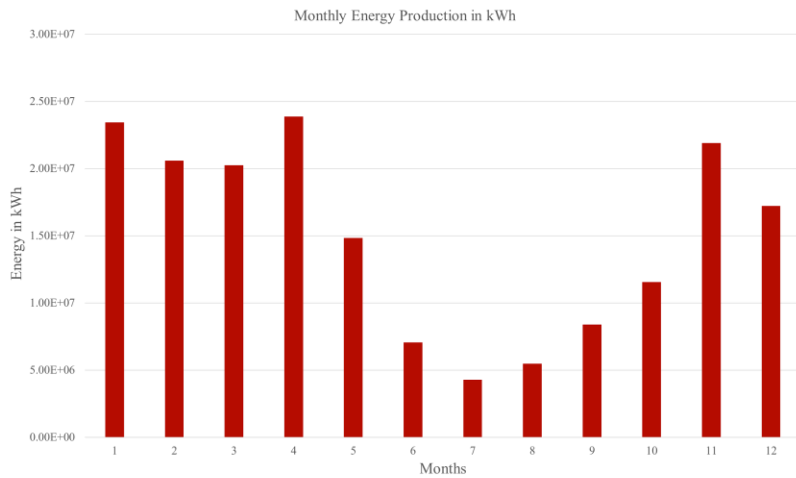

Figure 8. Monthly energy production in kWh.

4.3 Annual Operating Costs

Operations and maintenance costs include the cost for maintaining and repairing turbines, blades, towers, and foundations, and routine inspections and testing, and labor. These costs will be higher than similar wind energy projects onshore, this is due to the "first mover" effect. As the United States wind industry is not yet experienced with offshore operations, all operations will be more costly and time-consuming.

Using SAM, TWT was able to input financial, site, and project assumptions to reach an annual operation cost of 43$/kW-yr. As of 2018, typical onshore O&M costs were 40$/kW-yr (OSTI, 2019) and will continue to fall as the industry expands and components become more reliable.

Insurance is also a considerable annual operating cost. When determining the project insurance rate, it is also necessary to account for other factors that could increase the rate, such as the risk of hurricanes. Since a major hurricane of at least a category three on the Saffir-Simpson scale occurs once every fourteen years, using a Bernoulli trials calculation, it can be estimated that the probability of a hurricane striking the project is 33% over a period of 20 years. It will be necessary to increase the capital dedicated to insurance so that the project can be adequately protected. Since there is, as of yet, no physical means of protecting a wind turbine, other than emergency operating procedures like pitching the blades and yawing out of the wind, insurance is essentially the only way to protect a turbine.

TWT is interested in leasing out the Port Fourchon Waterfront Property WBL-0, the monthly base rent price for this lease area is $309 per acre, the WBL-0 lease area in total is 142.567 acres, overall cost per year would be $528,638.44.

4.4 Incentives

One of the many incentives offered for wind energy projects is the Production Tax Credit (PTC), which at this time is 2.6 cents per Kilowatt-hour (EERE, 2022) and is available for ten years after the beginning of operation. In the event of a potential repowering situation, the PTC can be earned again, meaning that if the project installs new generators it can continue to be earned for another ten years. While the PTC is more favorable to projects that have a lower initial capital cost, which this project is not necessarily a lower cost, it is also not favorable to projects that have frequent curtailments. This project is not expected to be curtailed often, but because of the low wind speeds it is expected to be producing well below maximum capacity at most times. Due to this, the PTC is not an attractive choice as it could be for projects based in higher wind speeds. Since the project is based offshore; it will have higher costs in general compared to onshore projects. The Investment Tax Credit (ITC) is another incentive, which is a dollar-for-dollar amount for 30% of installed costs and decreases to 26% in 2033 and 22% in 2034. However, due to American-made requirements in the regulations, along with location requirements, this project is not eligible for the ITC.

Renewable Energy Certificates (RECs) are a market-based incentive that is used to represent the non-power, environmental, and social benefits of renewable energy (ERA, 2023). One REC is given per Megawatt-hour (1MWh) of electricity generated. As with most wind energy developments, the project will be in debt initially after construction and the beginning of operations. This means that nonrefundable tax credits, such as RECs, cannot be used until the project is cash flow positive, and the loan is paid in full. Until that time comes, there is an alternative use to RECs that can be used to increase revenue for the project. REC arbitrage allows for generated RECs to be sold to third parties, who buy RECs to substantiate carbon footprint reduction claims (EPA, 2023). REC arbitrage will be an important revenue source for this project.

The PTC along with REC arbitrage incentives will allow TWT to generate revenue outside of the normal Power Purchase Agreement (PPA). However, as the project lies in a low wind-speed area, these incentives are not as beneficial as they otherwise would be in a higher wind-speed area.

4.5 Pro Forma

This project poses a greater investment risk than that of traditional energy ventures. While standard renewable energy projects include political risk, they also contain development risk, competition in the market, and regulatory uncertainty (Feldman, 2020). The TWT project would be a “first of a kind” project as it would be one of the first offshore wind energy projects in the United States, the first in the Gulf of Mexico, and the first to connect with SERC (Levitt, 2011). This brings inherent uncertainty financially to the project and its continued development. Offshore development is inherently more cost prohibitive than traditional onshore turbines, and the challenges are compounded by the lack of infrastructure and support in the project region.

To reach an NPV of 0$ in 20 years, the breakeven PPA price is 13.3 ¢/kWh with an escalation of 2.5% every year, which is standard within the industry. Due to inflation, the escalation rate could be even higher year-over-year. There is a large delta between the PPA price and the average price of electricity in Louisiana of 8.82 ¢/kW.

Internal rate of return (IRR) is used to estimate the profitability of a project and to understand the return associated with the risk of an investment. After all, this project’s main goal is to generate renewable energy such that it generates monetary returns for its shareholders. Using the breakeven PPA price, SAM has estimated that the IRR at the end of the project is 10.34%.

The DSCR describes the ratio of debt to equity over a project. The DSCR TWT has decided on is 50%, this value was decided upon from research and talks with industry professionals. In order to reach a

50-50 equity-debt split, TWT will be using an equity partner. By compensating equity partners at 6¢ of the PTC earned, a partnership with a non-profit organization can be used to bring in a large company that will bring the remaining money for the project. The sale of RECs can be used to further encourage this partnership.

RLCOE measures the lifetime cost of a project divided by energy production. The RLCOE for this project is 11.76¢/kWh. LCOE for new offshore wind projects (IRENA, 2021) has declined 13% in 2021, to just 7.5¢/kWh. TWTs project lands above this mark due to the lower production compared to the global offshore projects this average cost is drawn from.

After making changes to the debt percentage and insurance rate, the PPA was increased from approximately 0.83¢/kWh to 0.97¢/kWh to eventually 13.3¢/kWh. This represents the stark changes that can come from having more accurate information to better match that of real-world expectations for risk.

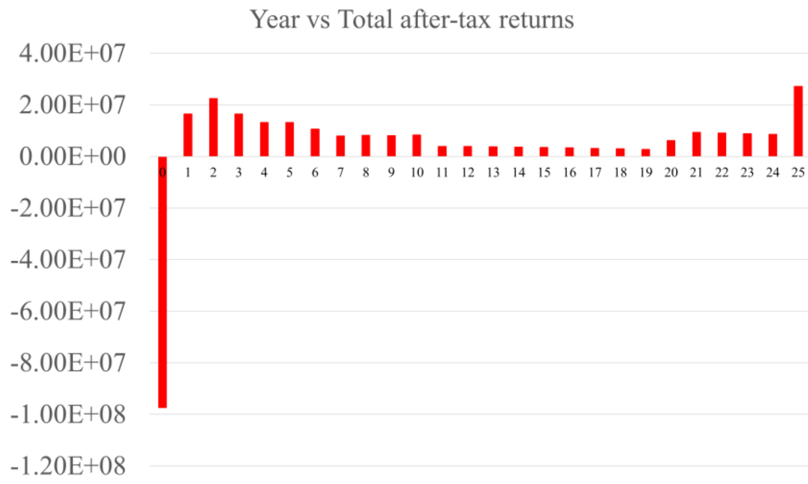

Figure 9 - Cashflow though Project Lifetime. (Millions USD)

4.6 Auction Bid

Since there aren't any substantial offshore wind projects in the United States, the method for determining the auction bid price for the desired lease blocks was based upon the limited available data. The California lease blocks were used as basis to determine lease price for this project. The California lease blocks that were recently sold for the purposes of offshore wind energy were severely undersold, mainly due to the fact that the ocean floor is so deep that floating foundations would be required. Because floating foundations are so expensive and this would be a large hurdle to overcome, developers were less willing to spend a high price for the lease blocks. While the project area depth is not an issue, the low wind speeds are a significant issue. A compounding factor is that because the project is not eligible for the ITC, this would mean that TWT is even less willing to pay a high price per lease block. Finding the average of the California lease blocks auction bid prices, it was found that an acre of the lease block cost $2,489.82. Using this price per acre and considering that TWT is using three lease blocks at 15,000 acres per lease block, TWT's estimated bid price is $37,347,150.00, with a maximum bid price of $46,000,000 for the three blocks.

CONCLUSION

A preliminary assessment of a site 20.5km southeast of the Louisiana coast was conducted. Based on available wind speed measurements, a wind resource assessment was accomplished. The Siemens-SWT-4.0-130 turbine was decided upon for the project, and initial analysis shows an AEP of 365,068 MWh/yr is estimated for a 100MW nameplate capacity project at a capacity factor of 40%. A twisted jacket foundation is proposed for the turbine. Further, environmental, logistical, and site activity issues to be considered are summarized in the report. Based upon the financial analysis, it has been determined by TWT that it would be more financially responsible for a developer to spend the estimated cost of this offshore project on an onshore project that would produce more energy at a cheaper rate. This would also resolve many of the complications that come with the challenge of developing offshore projects.

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