Galveston Offshore Wind Farm

Collegiate Wind Competition

Project Development Design Report

University of Wisconsin–Madison

WiscWind

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Executive Summary:

The developers at WiscWind LLC. are pleased to present the Galveston Wind Farm, a 510MW wind energy system located off the coast of Galveston, Texas, with an average annual wind speed of 7.66 m/s. This report discusses the siting design process and triple bottom line feasibility of the proposed project along with potential environmental and social impacts of the project and any necessary mitigation efforts. Capital and operating expenses were estimated and a cash flow analysis was conducted along with the calculations of key financial metrics. The proposed layout was optimized to increase energy production and minimize project costs. The collection system was carefully designed to meet project needs and conform to site constructability constraints. The proposed layout is projected to have a net annual energy production (AEP) of 1656.61 GWh/year with a capacity factor of 36.08% at a levelized cost of energy (LCOE) of $91/MWh. Revenue for the project will be generated through a power purchase agreement (PPA) of $102/MWh with a capacity credit from a utility buyer (Clearview Energy) out of Dallas, Texas, as they have a company goal of creating 100% of their energy from renewable resources.

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1.0 Site Selection and Characteristics

1.1 Site Selection Process

In order to develop a system to accurately compare the possible lease blocks in the given CWC lease area, many different factors were taken into consideration. The most important factor that was considered was wind resource. High wind resource availability leads to a higher energy production. The other factors included bathymetry, conflicting use, port proximity, and environmental factors. Each block in the lease area was given a score of 0-5 for each factor. These scores were then multiplied by their weights and added into a final heat map, **Table 1**, that displayed the scores of each cell. The weights were produced in conjunction with industry professionals to confirm the values given to each factor. These factors are detailed below and the overall scores for each lease block are shown in **Table 1.**

Wind Resource– Wind resource for the lease area ranged from 7.57-7.71 m/s. These wind speeds provide adequate resource for a wind farm, but the variation makes little difference. Because of the relative uniformity across the lease area, this factor was given a weight of 0.2.

Bathymetry– Bathymetry is important for an offshore wind farm as fixed foundations are only viable in water depths of 60 meters or less.[1] The shallower the water, the smaller the foundation needed, and the more money that is saved. This was given a weight of 0.1 as the bathymetry was similar throughout the area.

Conflicting Use– Conflicting use was the most variable factor in the decision-making process. Use of the lease area included shipping lanes, fishing areas, active lease areas, sand resources, and existing oil and gas infrastructure. The areas with active leases or the heaviest ship traffic were given scores of 0 as these areas would be unfeasible for use. Due to the high variance of use, conflicting use was given the highest weight of 0.4.

Port Proximity– Three ports in the area were considered when evaluating port proximity. These were Port Arthur to the northeast, Freeport to the southwest, and Galveston to the northwest. Each port would be capable of serving as a staging area to assemble the wind turbines. The closer the lease area to the port, the less time and resources spent traveling between the shore and the wind farm. This factor was given a weight of 0.3 to account for the variation in distance to the ports.

Environmental Factors– Of all possible lease area, there were few environmental factors that would pose additional complications to the project. These included known habitat hotspots for coral and other species. These locations were infrequent throughout the lease area and therefore would be addressed on a block-by-block basis, thus they were unweighted.

Table 1. Total scores for all blocks in the CWC lease area.

0.00	0.00	3.70	3.38	3.49	3.72	3.76	3.44	3.09	2.39
0.00	0.00	0.00	0.00	3.56	3.70	3.54	3.32	2.91	2.70
0.00	3.42	3.28	3.39	3.22	3.19	3.16	2.78	3.01	2.84
3.82	3.76	3.47	3.69	3.52	2.59	2.58	2.87	2.96	2.67
3.88	3.74	3.21	3.42	3.24	2.98	2.68	2.45	2.49	2.49
3.67	3.49	3.00	3.40	3.39	2.95	2.98	2.89	2.34	1.94
3.63	3.62	2.98	3.06	2.63	2.67	2.65	2.67	2.45	2.21
3.67	3.30	2.97	2.99	2.89	2.47	2.19	2.07	2.00	1.86
3.35	3.06	2.59	2.79	2.61	2.24	2.07	2.23	1.99	1.77

1.2 Chosen Site Characteristics

From this process, the lease blocks of 28562 and 28561 were chosen as they had the highest combined score in an East-West orientation. This block orientation was chosen because it was most beneficial for the available wind resource. There was no required size for the wind farm, so the two lease blocks were chosen and then site optimization led to the best layout for the chosen area. The geology of these two blocks are mainly clay-sand bottoms that range from 15-18 meters in depth. Since the site is in the open water, the roughness was estimated to be 0.001. The chosen site also has an average wave height of 1 meter; however, it is exposed to extreme weather events such as hurricanes.

1.2.1 Wind Resource Assessment

To assess the wind resource at this site, data was acquired through the NREL Wind Toolkit database[2] for all stations in the chosen lease blocks. This data consisted of wind speed and direction recorded in five minutes intervals over the course of six years starting in 2007 at a height of 100m. From analyzing this data, the prevailing wind direction was found to be out of the S-SE directions and blew the least frequently from the W-NW directions. A wind rose was constructed from the data and can be found in **Figure 1**.

Direction	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
%T	4.37%	6.10%	5.54%	4.65%	5.18%	7.71%	12.20%	16.53%	12.63%	8.51%	4.78%	2.40%	1.77%	1.61%	2.27%	3.75%

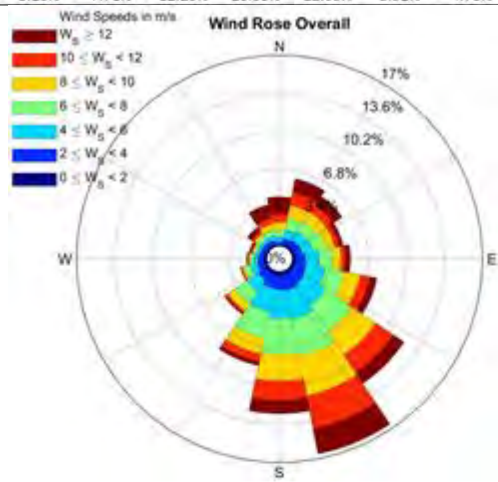

Figure 1. Average wind rose for lease blocks 28562 and 28561

To match the hub height of the selected turbine model, the raw data was vertically extrapolated to a height of 150m. The average annual wind speed across all 8 data sites at this height was found to be 7.66 m/s. Wind speed values were binned by their frequencies into 1 m/s intervals and fitted with a Weibull curve. These distributions in wind speeds across all stations were tested for statistical significance using the 2-Sample Kolmogorov-Smirnov Test and no significant differences were found. Thus, the individual Weibull curves were then averaged across all data locations to produce a final Weibull curve shown in **Figure 2**.

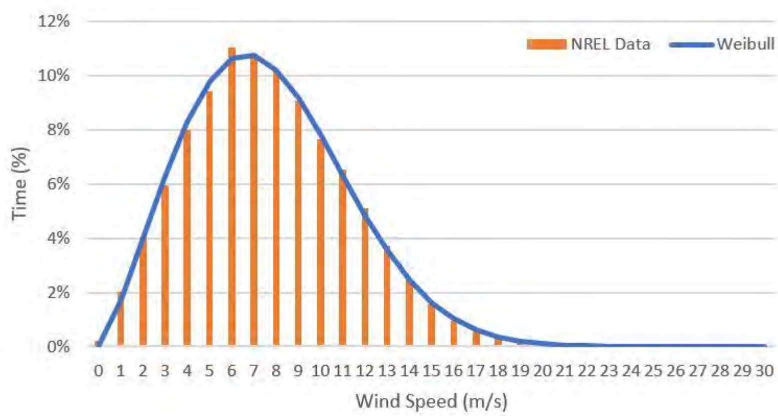

Figure 2. The distribution of wind speeds for lease blocks 28562 and 28561.

Based on the interannual variability, the P95 wind speed was calculated to be 7.22 m/s. The data were also analyzed for diurnal and seasonal patterns. The average wind speed from all data locations was calculated across all hours of the day and all months of the year. These diurnal and yearly profiles are shown in **Figures 3&4**. From this analysis, the wind speed was found to vary from 6.5 m/s at 1:00 pm to 8 m/s at midnight. Additionally, over the course of a year, the wind speed varied from 9 m/s in December to 5.5 m/s in August.

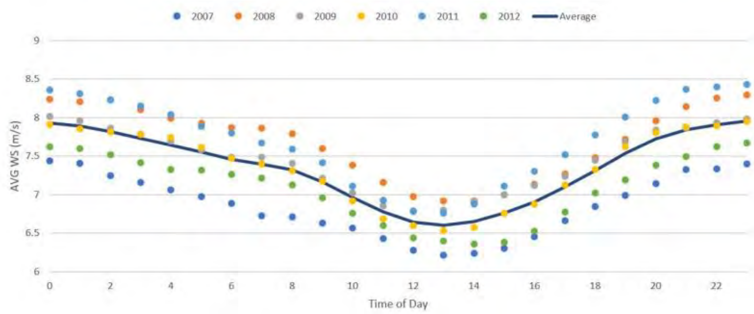

Figure 3. The diurnal variation of wind speed for lease blocks 28562 and 28561.

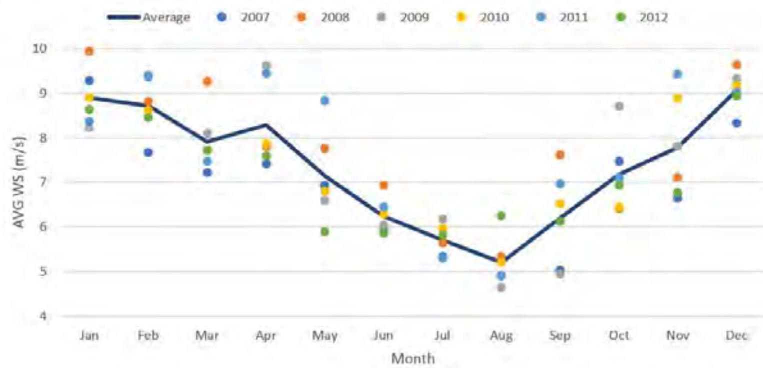

Figure 4. The monthly variation of wind speed for lease blocks 28562 and 28561.

2.0 Site Layout

The site layout details attributes about the proposed wind farm related to the turbines, electrical infrastructure, and ports/vessels needed to support its development. All these components support how the wind farm is constructed and operated as well as how the power is transmitted to the existing grid. Additionally, by combining the site layout and the wind resource assessment, the wind farms energy production can be estimated.

2.1 Turbines

For this site, 34 Vestas V236-15MW turbines have been chosen, resulting in a total installed capacity of 510 MW. These turbines have a hub height of 150 m, a rotor diameter of 236 m, and will be available starting in 2024.[3] Because the V236's data is highly proprietary; the IEA 15 MW turbine,[4] whose power and thrust curves are shown in **Figure 5**, was used as a reference to model the proposed wind farm. This reference turbine can most accurately reflect how the V236 turbine would influence project development. The turbines are spaced in two East-West rows within the lease blocks, each containing 17 turbines. Within each row the turbines are spaced at 2.3 rotor diameters apart (555 m) with rows themselves being 17.7 rotor diameters apart (4240 m). To support the turbines, a monopile foundational structure was chosen. Because of the loose sand/clay sediments in the area and shallow water depths, the monopile foundation was the most cost-effective choice.

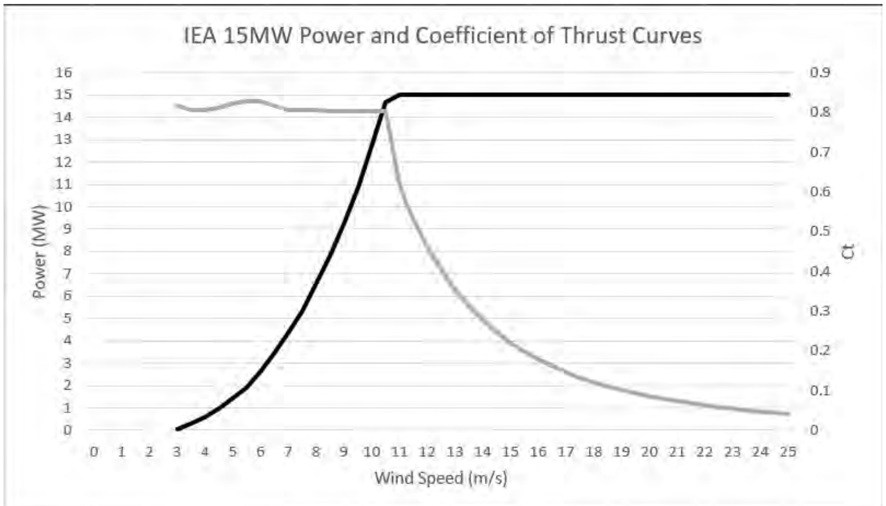

Figure 5. The power and thrust curves of the IEA 15-MW turbine.

2.2 Collection System, Transmission, and Interconnection

The electricity generated at the turbines is carried through a total of 19.76 miles of cabling at 69 kV to the offshore substations located at each row. The turbines were connected in circuits of four with one turbine being directly connected to the offshore substation where the voltage is stepped up by transformers from 69kV to 138kV. The locations and routes of the array cabling and offshore substations within the wind farm are shown in **Figure 6**. Two export cables at 138 kV, totaling 54.2 miles in length, run from the offshore substations, make landfall in Galveston, and connect into the Moody Reit substation as shown in **Figures 7&8**. This substation was chosen based on its proximity to the wind farm, space for expansion, and ease of access to the station. At the onshore substation, only a switch gear and breakers will need to be installed as the voltage in the export cables match the voltage on the existing transmission line.

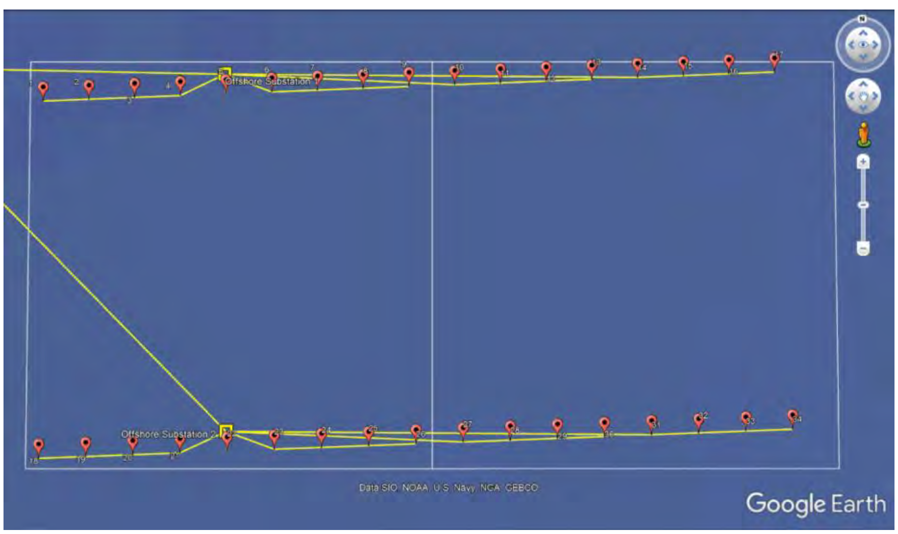

Figure 6. Wind farm turbine layout, array cabling, and offshore substations.

Figure 7. The export cable routes from the offshore substations to the point of interconnection.

Figure 8. The export cable landfall and point of interconnection in Galveston, Texas.

2.2 Port Infrastructure

The Port of Galveston was chosen as the base of operations for both construction and operation activities for this project. To reach the proposed wind farm from this port, vessels would have to travel 27.6 nautical miles. Three wharfs totaling an area of 32.5 acres were selected which will allow for the needed component staging and movement. It was calculated that for the 34 turbines in the proposed layout, a direct area of 23.4 acres would be required for their components. These staging areas are mapped out onto selected wharfs and are shown in **Figure 9**. The depth of the channel is important for giving vessels access to the port. The average import vessel requires a water depth of 32 feet[5] and the channel from the port to the ocean has depths greater than this value. The port's quayside also needs to be long enough to accommodate the vessels for component delivery and transfer. The selected wharfs provide a total of 2,560 feet available to these vessels, which is more than the required 500 feet.[5] To determine if the ground has enough strength to support port activities, additional geotechnical testing would be required. However, this site has been used for smaller wind turbine component delivery in the past making it likely that it could support the larger components of the proposed wind farm. For wind farm operation and maintenance, the building on the middle wharf will serve as an office space for which the wind farm will be controlled. Additionally, this building can be used as storage space for wind farm components.

Figure 9. Layout of turbine components within the Port of Galveston.

2.3 Vessels

Over the wind farm's lifecycle, various types of vessels are needed for development and maintenance. These vessels must comply with the Jones act which requires goods shipped between U.S. ports to be transported on ships that are built, owned, and operated by United States citizens or permanent residents. However, due to the lack of Jones Act compliant vessels these ships must be acquired through other processes. The necessary vessels must be imported or built by repurposing regular boats.

Imported vessels include the Fugro Proteus,[6] Furgo Excaliber,[7] Ulstein LX109 CLV[8], and the Van Oord Aeolus[9]. The Fugro Proteus is a survey vessel that will obtain environmental, geophysical, and hydrological data. Furgo will also provide their ship, Furgo Excalibur, which is a foundation installation vessel. A Feeder Support Vessel (FSV) like the Ulstein LX109 CLV will be used for cable laying. Lastly, the Van Oord Aeolus is a wind turbine instillation vessel (WTIV) with a crane that can lift 1,600 tonnes.

Boats will have to be repurposed to create Service Operations Vessels (SOV) and Crew Transfer Vessels (CTV). The CTV's will be used to transport service teams to the wind turbine while the SOV's will provide turbine service and repair.

2.4 Net Annual Energy Production

To estimate energy production of the proposed wind farm, wind data was obtained from Vortex[10] and imported into a wind farm modeling software program named Furow.[11] This yielded a gross annual energy production (AEP) of 2024.95 GWh/year. However, some of the energy produced by the wind farm is lost due to a variety of sources. Wake loss is the reduction in energy production experienced by a turbine downwind of another. This occurs as the wind's energy is absorbed by the turbine, its speed is reduced and turbulence is increased. Using Furow, wake losses were estimated at 9.19% for the proposed site layout. Electrical losses are due to the conversion of the kinetic energy in the wind to mechanical energy and then to electrical power for transmission. The transmission process is also not perfectly efficient. Losses occur as electricity is transmitted over distance in addition to the heat generated from this electrical movement. These electrical losses ranged from 1-5%[12] and an average value of 3% was chosen. Availability losses are due to wind farm maintenance and occasional lack of energy demand as the turbines would have to be shut down in these situations. A value of 4%[12] was used for these availability losses. Other losses account for a value of 2%.[12] These losses include reductions in energy production due to turbine underperformance, environmental factors, and curtailment. Based on these losses, the net AEP for the proposed wind farm is 1,656.61 GWh/year which yields a capacity factor of 36.08%.

3.0 Environmental Impacts and Mitigation

Environmental impacts are an important concern for wind farm construction, especially for offshore farms that affect the ecosystem above and below water. This section will address the major environmental impacts of the wind farm in regard to birds, benthic changes, noise, sediment, and hurricanes.

Birds- Birds are perhaps the greatest environmental concern for the wind farm, especially as it is located in the Central Flyway that runs along the Texas Gulf coast.[13] This flyway is estimated to be travelled by 400 bird species, such as the American goldfinch and field sparrow.[13] The artificial reefs of offshore wind farms could potentially have an attractive effect on some of these migratory species, causing them to linger and disturb their natural migratory patterns.[14] Of even greater concern are the local bird species such as the royal tern, brown pelican, and black skimmer.[15] For migratory species, the energetic cost of avoiding an offshore wind farm is trivial, but for birds with nearby breeding colonies there are potential detrimental effects to their survival and reproductive success.[16] As the wind farm is 25 miles from shore, this reduces the energetic concerns and risk of collision, as it is on the outskirt of most local species' ranges.[15]

To reduce the frequency of bird collisions, the visual monitoring system Identiflight will be used, which acts as an automated curtailment system.[16] This camera system identifies and classifies flying objects, curtailing individual turbines to prevent potential collisions.[16] A study conducted at a wind farm in Wyoming found an 82% reduction in eagle fatalities when using Identiflight, showing the effectiveness of this emerging technology.[16] Through Identiflight, significant bird fatalities will be prevented while avoiding the drop in energy production that comes from blanket curtailment.

Benthic- The installed monopile structures can provide a number of benefits to the local benthic environment. These structures provide a habitat for the accumulation of shellfish, as seen at the Block Island Wind Farm off the coast of Block Island, Rhode Island.[17] This creates a habitat comparable to an artificial reef, increasing the local biodiversity and biomass.[15] The enhanced foraging opportunities and refuge areas would also attract invertebrate and fish species in the Gulf, such as blue crabs and red snapper.[14] The limitations to fishing in the area would further allow for the development and protection of this artificial reef.[16] These reefs provide the opportunity to support locally rare species, but can also serve to expand the dispersal pathways of invasive species, deemed the "steppingstone effect."[18] To account for this, seabed photography will be carried out during intermittent dives to observe the temporal changes to substrates and species. Grab samples will also be performed to allow for further biological analysis. Both of these have been performed at the Block Island Wind Farm in Rhode Island.[19]

Noise- A trade-off of using pile driving installation is the underwater noise and pressure waves produced by the process, which can result in mortality or injury to marine mammals, fish, or sea turtles.[14] The noise can also produce behavioral altercations in these species, such as startling, fleeing, and hiding.[14] These effects are temporary, with species returning to the area once pile driving has ceased.[14] Following installation, sound levels are unlikely to reach harmful levels or mask marine mammal calls.[20]

Noise reduction technologies will be used to mitigate the effects of underwater sound during the pile driving process. A big bubble curtain and/or isolation casings will be used to meet this goal. A big bubble curtain uses bubbles rising from a nozzle pipe on the sea floor to reduce noise by 15 dB by reflecting, scattering, and absorbing sound waves.[21] This mitigation technique has been used in >700 pile driving procedures and can be prepared in advance to reduce time delays.[21] Isolation casings are another option that have seen use in 450 installations, using a shell-in-shell system around the pile to reduce noise. The casings feature a double wall, with an air-filled interspace and bubble curtain that reduce noise by 13–16 dB.[21] Both these methods are acceptable at the water depths of the selected lease blocks.[21] One or both of these technologies will be used to reduce installation noise to an acceptable level.

Passive acoustic monitoring (PAM) will also be used to monitor the underwater soundscape, tracking behavioral and distributional changes of species in response to offshore wind activities.[22] A real-time PAM system will allow for the rapid detection of species, and subsequent noise reduction and vessel movement will be performed accordingly.[22] A PAM system will be used during the installation and operation of the wind farm, taking special care to adjust procedures according to the local species like the Kemp's Ridley Sea Turtle and Atlantic Bottlenose Dolphin.[15]

Sediment- Within the selected lease blocks there are no sensitive corals, reefs, or habitat hotspots of concern.[15] The installation of the monopile and scour protection may disturb up to 7% of the offshore wind farm site area, dropping significantly to <1% post-installation.[14] The impact of this footprint is minimal compared to the vastness of the ocean, especially compared to the effects of fishing or warming of the oceans.[23] A temporary increase in sediment suspension may result from site installation activities, releasing potential contaminants such as arsenic, heavy metals, organotin, or PCBs.[14] These effects would be short-term and localized.[24] The installation of turbines using pile driving will result in less extensive sediment disturbance than other methods such as reverse-circulation drilling.[14] Standard water quality sampling will be used to monitor temperature, chemical composition, acidity, and dissolved oxygen to document potential changes.[24]

Once installed, the turbine foundation structures create an accelerated water movement around themselves, known as a wake effect.[14] This typically results in scour, the loss of soft sediment around the structure, and can persist for 200 m down-current.[14] This can be prevented through a scour protection system.[25] The common low-cost choice of dumped riprap will be used, which places stones around the monopile structures to weigh down and protect the soft sediment.[25] This will maintain the local sediments of sand and mud and avoid the potential downstream effects of their spread.[15]

Hurricanes- Blanket curtailment will still be used in response to dangerous weather. Hurricanes are a significant concern for offshore wind farms in the Gulf of Mexico. The hurricane track density was uniform within the CWC lease area at 0.330-0.361.[27] The turbines selected are rated at IEC Class 1B, which have been constructed to sustain winds of 70 m/s, those equivalent to a Category 4 hurricane. While Category 4+ hurricanes pose a significant threat, there have only been three occurrences within the radius of maximum wind of the site area since 1842 and none within the last 80 years.[28] In the case of a hurricane or extreme winds, the turbines would lock and feather their blades to reduce the surface area pointing into the wind.[29] This would minimize storm damage and allow turbines to resume energy production once wind speeds return to normal.

4.0 Social Impacts and Mitigation

Public perception and acceptance are both imperative to the success of offshore wind farms. This section will address the social concerns and impacts of the wind farm on vessel traffic, fisheries, radars, and tourism. It will also address the process of decommissioning at the end of the wind farm's lifespan.

Vessel Traffic- The primary social concern is how the wind farm will affect vessel traffic. This was considered heavily in the siting matrix by taking special care to avoid zones of high traffic. However, wind turbines can still obstruct views and obscure smaller vessels such as recreational fishing boats. The wind farm has been constructed with a considerable buffer zone on major traffic lanes, but it is impossible to fully ameliorate this concern.

Fisheries- Another social concern is the effects of the wind farm on fisheries. A qualitative survey of the Block Island Wind Farm interviewed 25 fishers who frequented the area, both commercially and recreationally. Some of the popular themes during the interviews were the navigational concerns of running into the turbines, additional fish species in the area, and little to no impact on fisheries.[30] An approach will be used that was conducted at the Block Island Wind Farm, employing a local fisher to act as a liaison, facilitating the planning process and implementing community feedback. This process was deemed "critical" by Block Island community members and helped to effectively meet their needs.[29]

Radars- There is concern of the wind farm causing radar and microwave interference. A number of radio-communicative services have proven to be sensitive to the presence of wind turbines such as maritime, air traffic control, and weather radars.[29] The effects on radar systems can be mitigated through advanced signal processing to identify signal cluttering effects and remove them.[29] The wind farm's presence within transmission systems will be actively considered and turbines will be positioned accordingly to minimize their impact.

Tourism- Offshore wind farm proposals are often met with concerns that the project will affect tourism and recreation.[28] Research investigating these concerns has shown that offshore wind farms do not negatively influence tourism and may even serve as a minor attraction.[28] As the wind farm is in the range of 25-48 turbines and being constructed 25 miles from shore, tourism impacts and viewsheds will not be a significant concern. Studies have shown that wind farms of this size and distance from shore are far past the range for being a major focus of visual attention (10 mi) or noticeable to casual observers (18 mi).[31]

Site Restoration- If there is no opportunity for repowering, the wind farm will be decommissioned. The turbines will be removed and the foundations will be cut below the seabed depth. The scour protection will be left in place to preserve any marine life. The array cables will be removed while the export cables may be left in place. The ends will be buried so they are not exposed after decommissioning. The cables onshore will be abandoned in place while some electrical components deemed useful may be reused. All cable ends will be buried to limit exposure after decommissioning. The material from the offshore wind turbines will first be considered for reuse, and then disposal by industry best practices.

5.0 Legal

Prior to wind farm development, a risk investigation must be completed and numerous legal requirements must be met. These procedures involve identifying the BOEM leasing process and their requirements, the permitting and approval, and risk/fatal flaws.

5.1 Lease Process and Requirements (BOEM)

The overall lease process is a long process that includes many site investigations and needed approvals. To initiate the lease process, area with adequate wind resources is identified in the area of the potential wind farm. Once a site is chosen, the leasing notices must be published and the land acquired by auction. Once the lease is won, the SAP is assembled and presented to the BOEM for approval. The next step is to conduct multiple assessments such as geotechnical and wind surveys to develop a COP, which will also be approved by the BOEM. BOEM will conduct their own environmental reviews and then the design and installation plans will be submitted. Following these steps, the wind farm can begin installation.

As part of the lease process, a site assessment plan (SAP) would be submitted to the BOEM prior to the installation of the wind farm. This plan would include the detailing of a geological and geotechnical investigation of the site. These investigations will give details related to the seabed characteristics which will lead to the development of appropriate foundations. The SAP will also include the steps to assess the metocean data. This would include meteorological data such as wind speed/direction, turbulence, and air temperature/pressure/density as well as ocean data such as current speed/direction and wave height/period.

Additionally, a construction and operations plan will be developed to describe the activities, both onshore and offshore, related to the construction, operation, and decommissioning of the project. The plan will display how the project will meet all the requirements set forth in 30 CFR 585.621. These requirements are listed under 30 CFR 585.626 and describes surveys needed which include geological and geotechnical, shallow hazards, biological, and archaeological surveys as well as an overall site investigation. This section also details considerations for the lifecycle of the site including construction concept, waste generated, operating procedures, decommissioning procedures, as well as important contact information. Additional requirements are also listed under 30 CFR 585.627 which describes certifications for the National Environmental Policy Act (NEPA) such as water quality, hazard information, biological resources including the species within it, and sensitive habitats. An oil spill response plan and safety management system will also be described.

5.2 Permitting and Approval

In the process of building a wind farm numerous permits and authorizations must be obtained before construction can began. These permits must be acquired from various government agencies on a federal, state, and local level. These agencies were contacted to provide input on the permits that would be required for the development of the proposed wind farm. The content of these permits cover land use, environmental protection, legal responsibilities, and more.

Federal- On the federal level numerous permits will be required. As the BOEM manages energy development on the Outer Continental Shelf, they must approve the Site Assessment Plan (SAP) and Constructions and Operations Plan (COP) before development can begin. As part of the of their reviewal and approval process, BOEM will provide consultation on Section 106 of the National Historic Preservation Act, Section 7 of the Endangered Species Act, and The Magnuson–Stevens Fishery Conservation and Management Act.

There are also federal permits that have to be acquired outside of BOEM's authority. The Environmental Protection Agency (EPA) requires all offshore wind energy projects to meet the standards set forth by Section 328 of the Clean Air Act. This monitors the air pollution created by all Outer Continental Shelf projects. Also, to make sure no turbines impede on navigable air space form 7460-1 must be filled out and approved by the Federal Aviation Administration (FAA). Additionally, The US Coast Guard must be consulted on two sperate permits. One of which, is the Private Aid to Navigation (PATON) authorization which marks the privately owned area that the wind farm will reside in. The other is the Local Notice to Mariners which simply lets vessels know where potential obstructions will be located during wind farm construction. Furthermore, the National Marine Fisheries Service will have to provide a letter of authorization stating that the project will have negligible impacts on marine mammal species in that area.

State- When it comes to state permits the US Army Corps of Engineers (USACE) is the main regulatory agency. Through this agency a Regional and Programmatic General permit must be acquired. This permit signifies compliance with Section 10 of the Rivers and Harbors Act which checks that the project does not obstruct any navigable waterways. Section 408 of the Rivers and Harbor Act, which mandates that any use or alteration of a Civil Works project by another party, is subject to the approval of USACE. For the proposed wind farm, the export cable will pass near the Galveston Seawall. The final permit provided by the USACE is obtained under Section 404 of the Clean Water Act which authorizes any discharge of dredged or fill material into US waters. During this approval process, the application will be released to other Texas agencies for review. These agencies include the Texas Park and Wildlife department and the Texas Commission of Environmental Quality. They provide threatened/endangered species and environmental protection consultations respectively. The only permit that is not obtained through the USACE application process is provided by the Texas General Land Office. They grant permission to cross state waters boundaries.

Local- At the local level, three permits will need to be obtained from the City of Galveston. These permits will cover construction activities associated with the onshore cable route and substation. A building permit that covers all construction projects in Galveston must be acquired. On top of this, a Beachfront Construction and Dune Protection permit will grant permission to build in beach areas. Furthermore, a Right of Way Construction permit is needed to shut down roads allowing work to occur without threat of oncoming traffic.

5.3 Risk and Fatal Flaws

In the process of building a wind farm, many different risks are encountered. These risks are similar to those experienced by onshore wind farms and span all phases of wind farm development. These risks are related to the development, legal, and financial aspects of the project. In addition to project risks, several fatal flaws for this project have been identified. These fatal flaws would pose significant setbacks to the development of the proposed wind farm if not addressed and properly mitigated. These fatal flaws include the aspects of the project related to the onshore substation, existing transmission line, port, and vessels.

Risks:

Preconstruction Energy Estimate- Associated with the projected annual energy production (AEP) based on available data such as site wind condition, layout, turbine selection, loss estimation, and more.

Construction- These risks are higher than onshore. Everything is based off ships which are not as readily available as onshore equipment such as cranes. Means of installation are less of a system as there haven't

been a lot of farms yet. Also, construction can potentially impact the environment. Construction must also be scheduled with hurricanes and inclement weather in mind, which are less of a worry onshore.
Project Development- The uncertainties of a project reaching commercial operation and energy generation such as site control difficulties, lack of transmission access, and unfavorable market dynamics. The access of ports also plays a factor as space is needed throughout the construction process. Public backlash regarding the placement of the site can also be problematic as Galveston is a tourist dependent area.
Regulatory- Policies toward wind energy are always changing. Texas is not always favorable towards wind energy and the PTC expired resulting in less financial incentives. Being offshore in federal waters means both state and federal agencies are involved.
Market/Selling Price- Uncertainties in sources of revenue due to unknown selling price. While a fixed-price PPA agreement can reduce the negative exposure of market variability, it prevents investors benefitting from potential upsides of increasing market price. However, the ability to finance a project is generally dependent on securing a long-term PPA.
Technology/Energy Production- Associated with the reduced energy production and the diminished electricity sales volume and thus revenue. Some of these factors including curtailment (operation from hurricanes and environmental species impacts), technology reliability, unexpected operations, and maintenance (O&M) events, and extreme weather events are already factored into the loss calculation applied to gross energy production. O&M maintenance would be harder as the wind farm is both harder to access and hard to service.
Fatal Flaws:
Onshore Substation Land Use- The substation is adjacent to the Scholes International Airport. An expansion of the substation would be needed which would be needed from the airport. FAA regulations or the airport's unwillingness to release the land would require other substations to be considered as alternative points of interconnection.
Existing Transmission Line Capacity- The current line capacity might not be enough to handle the additional power of the proposed wind farm. A transmission study would need to be conducted to determine if this is the case. If found to be true, alternative grid connection points away from this transmission line would need to be considered.
Port/Wharf Availability- The Port of Galveston may not have the proposed area available to be leased. If this were true, a smaller port area could be used for staged component delivery to the wind farm. Other ports would need to be considered if no wharfs are available.
Vessel Availability- There are only seven vessels capable of installing the V236. As multiple projects are underway, these ships could be substantially delayed. Site construction can be initially planned to accommodate for the lack of ships to ensure there will be availability when needed.

6.0 Optimization Process

The Galveston Offshore Wind Farm optimization process occurred in two major steps: turbine placement, and then electrical transmission. This process justifies decisions made to both reduce costs and maximization energy production thus yielding an optimal layout. Consideration was also given to various project constraints that effect turbine locations and electrical components.

6.1 Turbine Locations

Originally, lease blocks 28562 and 28561 were chosen for which to construct turbines. This 1x2, East-West orientation was expanded North and South to encompass the lease blocks that scored well in the preliminary site selection evaluations. This direction was chosen because the wind is primarily resolved in these directions and the shipping fairway to the East as well as lack of available lease blocks to the West posed significant challenges. This new 8 block combination included one row above and two rows below the originally chosen lease blocks.

Using the wind farm modeling tool Furow[11], the energy density of these lease blocks was analyzed by creating different layout configurations with varying inter-row and intra-row spacing. To determine the final number of lease blocks and turbine spacing, a wake loss of 10%[32] was used as a constraint to limit the size of any given layout. This constraint was used because each additional turbine has a reduced energy potential as the wake effects caused by this turbine increase. Also, the cost savings of this additional turbine decrease as the initial number of turbines increases. Therefore, the marginal addition of a turbine becomes economically inefficient once a large enough sized wind farm has been achieved. From this layout variation, a pattern emerged that the wake loss could most easily be kept under the 10% threshold when it had a large vertical spacing and small horizontal spacing. The energy density for each block and layout combination was calculated from the gross energy output, wake loss percentage, and lease block area. The layout that had the highest energy density consisted of a 1x2 lease block with 2 rows at maximum North-South spacing and 18 turbines each. As a final consideration in Furow, the rows were varied by different angles which yielded negligible changes in wake loss and energy production relative to the amount the spacing reduction that would have to occur to accommodate the change in angle. Therefore, the layout was kept oriented due East/West.

Upon optimization of the spacing and orientation considerations, the layout was imported into Google Earth. The turbine locations were adjusted by using a 120m buffer to prevent overhanging outside of the lease blocks or into the shipping fairway. With these adjustments turbine spacing would decrease causing the wake losses to increase and therefore, one turbine was removed from each row. This allowed the turbines to be respaced in the row at a larger distance and keep the wake losses under the identified 10% threshold.

6.2 Collection System

Once the turbine locations were finalized, optimization of the collection system was conducted. Based on a variety of factors like cable pricing, thicknesses, installation, and vessel traffic; the substations, inter-array cabling and export cable were all optimized in unison. The overall distance of cables in the inner array was significantly reduced when the number of offshore substations was increased from one to two, and the substations were placed at each row. This placement was not only cost efficient, but also allowed vessels, specifically fishing boats, in the area easier navigation through the wind farm After qualitative analyses of the COPs for other wind projects in the U.S with larger turbines, it was determined that four turbines could be connected in circuit. Having each substation localized to the turbine rows, reduces the lengths of the cables in circuit and thus the overall cost and power loss. The export cable routes were optimized by calculating the best place to cross the shipping fairway located to the Northeast of the site. This was done by finding the most optimal locations to cross the fairway for the export cable segment between the point of interconnection and the fairway as well as the point of interconnection and the substations. The relationship of how the cable lengths of these two segments changed was determined as the crossing point along the fairway was varied. The solver function in Excel was used to calculate the exact crossing location at which the total cable lengths would be a minimum. The export cable route was also adjusted to account for oil and gas infrastructure as well as shipwrecks.

7.0 Financial Analysis

7.1 Market Conditions, Power Purchase Agreement, and Revenue

The electricity generated at Galveston Offshore Wind Farm will be sold wholesale to Clearview Energy at the rate of 102 $/MWh. This price was estimated based off current market conditions and trends.[33] Clearview is committed to achieving 100% of their energy from green sources.[34] They also partner with many community initiatives such as Arbor Day Foundation, climate research, and wind energy research from many different universities and partners.[35] The PPA would have a 2% escalation factor to offset turbine component degradation. With the estimated net annual energy production of the wind farm at 1656.61 GWh/year, the project is expected to generate $168,974,383 annually and $3,379,487,654 over the project lifetime.

7.2 Initial Capital Costs, Annual Operating Expenses, and Taxes

The initial capital costs and annual operating expenses for the Galveston Offshore Wind Farm were estimated using the assumptions from NREL's Cost of Wind Energy Review 2019 and 2020 reports.

Economies of scale were applied to these values to adjust them for the proposed wind project's site and development characteristics. The capital costs were estimated at $1,652,400,000 while the annual operating expenses were estimated at $47,940,000/year. A 2% escalation factor was applied to account for inflation. The only applicable corporate tax in Texas is the franchise tax. This is based off yearly revenues at a rate of .375%. These payments were estimated totaling $13,314,363 over the 20-year life of the project.

7.3 Incentives

One of the main financial incentives used in this project was the Investment Tax Credit.[36] This is a one-time credit that is applied at the start of the project. This credit applies to the CapEx costs associated with this project. The rate applied to the capital costs is 30% and then converting the tax credit to cash at an 80% rate would give the project a total ITC savings value of $251,042,000. Another financial incentive used was the 5-year Modified Accelerated Cost Recovery System (MACRS).[37] This is an incentive for an accelerated depreciation of assets compared to other methods such as straight-line depreciation or sum of years digits depreciation. By employing MACRS, it allowed the wind farm to recoup an additional $184,373,535 over the first 5 years of the project.

7.4 Financing Plan

The project will be financed through debt-equity with the ratio of 80:20. The interest rate for the 20-year loan is assumed to be 8%. This will lead to a total cost of $1,342,320,000 and $335,580,000 in debt and investor equity respectively.

7.5 Financial Analysis

The twenty-year cash flow diagram is shown in **Figure 10** and represents the annual gains and losses of project components. Using a discount rate of 8%, the Net Present Value (NPV) was calculated to be $12,004,926. This value implies that the project is worth pursuing as it is projected to bring in profits to developers and investors barring any setbacks. The Internal Rate of Return (IRR) for this project is projected to be at 10.831%. The Levelized Cost of Energy (LCOE) is an economic measure to compare the price competitiveness between various sources of energy generation and calculated by dividing the lifetime costs of the project by its energy production. The LCOE of Galveston Offshore Wind Farm is projected to be $.091/kWh.

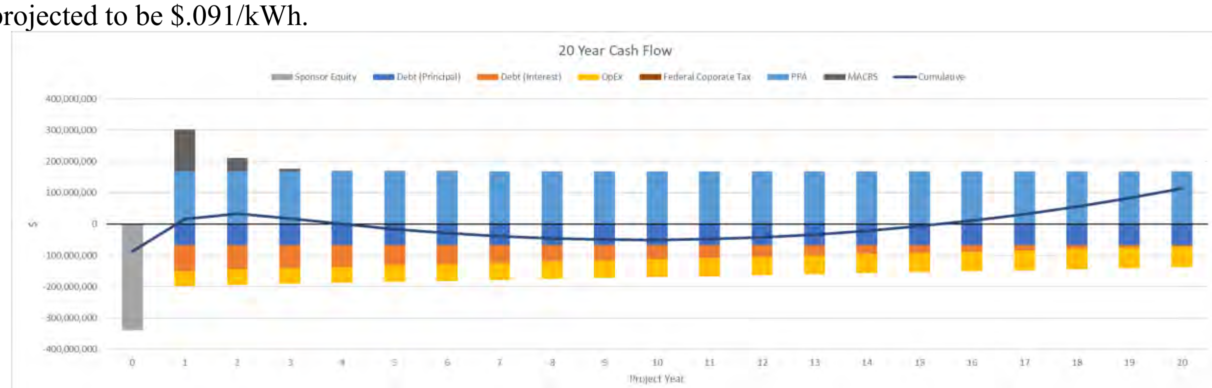

Figure 10. 20-year cash flow diagram for the proposed wind farm.

8.0 Conclusion

The goal of this report was to detail the proposal of a wind farm off the coast of Galveston, Texas which would be attractive to investors and to include a thorough financial analysis. Rigorous research was conducted, turbine models and annual energy productions were compared, and site layout was designed. Rigorous research was conducted, turbine models and annual energy productions were compared, and site layout was designed. Environmental and social impacts along with legal factors were also factored in. Based off these factors, WiscWind LLC. is prepared to pay $40,800,000 for the two selected lease blocks.

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