Bayou Breeze Offshore Wind Farm

Collegiate Wind Competition

Project Development Final Design Report

University of Wisconsin-Madison

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Executive Summary:

The developers at WiscWind LLC. are thrilled to present the Bayou Breeze Offshore Wind Farm, a 660MW wind farm spanning eight lease blocks located off the coast of Port Fourchon, Louisiana, with an average wind speed of 6.78 m/s. This report discusses the siting design process and triple bottom line feasibility of the proposed project along with the potential environmental and social impacts of the project with 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 while conforming to site constraints. The proposed layout is projected to have net annual energy production (AEP) of 1,683 GWh/year with a capacity factor of 29.12%. Capital and operating expenses were estimated, and a cash flow analysis was conducted along with the calculations of key financial metrics including a levelized cost of energy (LCOE) of $91/kWh. Revenue for the project will be generated through a power purchase agreement (PPA) of $97.5/MWh with a capacity credit from a utility buyer (Entergy) out of New Orleans, Louisiana, to help them diversify their generation portfolio. WiscWind LLC is prepared to pay $99,000,000 for these lease blocks.

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1.0 Site Selection and Characteristics

WiscWind is submitting this report as part of a bid for the Department of Energy lease blocks auction off the coast of Louisiana. To assess the potential of each block in the given lease area, various factors were taken into consideration. These factors include wind resource, bathymetry, conflicting use, port proximity, and environmental considerations. Every lease block was given a score of 0-10, with 10 being the most favorable to wind energy development, based on relevant data about each factor. Factors were given a weighting based on their importance to project development and the variability of the data across the lease area. Each block score was then multiplied by the factor weighting and combined into a final heat map, as shown in **Figure 1**. Details about each factor are as follows:

1.1 Site Selection Process

Wind Resource- The Global Wind Atlas[1] was used to assess both the wind speed and direction for the lease area. The wind direction was used to select the orientation of the chosen lease blocks. Although wind speeds changed very little over the lease area, wind resource was given a weight of 20% as it is the most important factor for power generation and the main source of revenue for the project.
Bathymetry- Bathymetry is a crucial factor as foundation construction costs increase significantly with depth. Across the lease area water depth varied between 17.9m and 166.1m.[2] Any lease block with a depth over 60m was given a score of zero as beyond this depth, fixed foundations become financially nonviable[3]. Because of these influences, this category was given a weight of 25%.
Conflicting Use- Many different sea activities occur in and around the lease area. These include oil and gas infrastructure, vessel traffic, fishing, already leased areas, military use, and viewsheds. The nearest military use area is located 15 miles from the Bayou Breeze Wind Farm. A subhierarchy weighting system was used to determine the overall factor score for these conflicts. Areas containing active oil or gas leases, as well as areas near shipping fairways were given scores of 0 as they were deemed infeasible for use. Conflicting use had the greatest variance out of all considered topics as well as can provide significant project development constraints and therefore was given a weight of 30%.
Port Proximity- Port Fourchon was chosen to locate all construction and operation activities because it was the only port within a reasonable distance that had the capability of supporting utility scale offshore wind farm development. The distance from the center of each lease block to the port was used as a metric for this factor as project cost increases the farther vessels need to travel to reach the sire. These distances ranged from 12.8 km to 101.5 km.[2] Based on these considerations, port proximity was given a weight of 25%.
Environmental Considerations- Across all possible lease areas, there were few environmental factors that would pose significant additional complications to offshore wind development. These included known hotspots for coral and other species. These locations were infrequent throughout the lease area and as a result, this category was left unweighted. Notwithstanding, these factors were used to eliminate specific lease blocks where they were present.

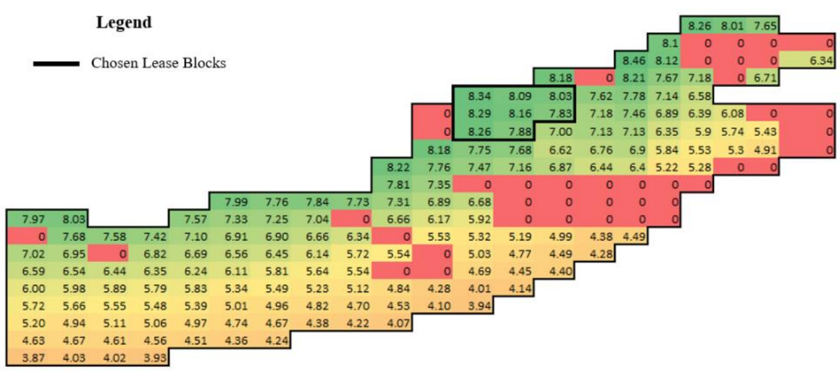

Figure 1. Total scores of all CWC lease blocks.

1.2 Chosen Site Characteristics

From the site selection process, lease blocks ST45, ST46, ST47, ST56, ST57, ST58, ST64, ST65 were chosen for the siting of the Bayou Breeze Offshore Wind Farm. The total area of these blocks is 186.5 km^2. The roughness coefficient at the site was estimated at 0.1 since it is in open water which was relatively uniform across the lease area[4]. The bathymetry of the lease blocks contains relatively flat sea floor surfaces with a minimum water depth varied from 17.9m-22.5m.[5] The average wave height and period for any given month ranged from 3.85m to 4.78m and .49s to .96s respectively.[5] Waves at this height and period impose relatively minimal loading to the turbine structure compared with other forces.

1.2.1 Wind Resource Assessment

To assess the wind resource at the Bayou Breeze Offshore Wind Farm, data was acquired from Vortex [5] for a central location relative to all chosen lease blocks at the hub height of the chosen wind turbine model. This data was generated by an ERA5 atmospheric reanalysis method at 1-hour intervals over the course of 12 years starting in December 2011 and ending in November 2022. **Table 1** breaks down the percent time that wind blows from each direction. The prevailing wind direction was from the SE and wind blew the least frequently from the NW directions. The average annual wind speed at the site is 6.78 m/s. Wind speed values were binned by their frequencies into 1 m/s intervals and fitted with a Weibull curve. The wind speed distribution and Weibull curve along with the accompanying wind rose can be found in **Figure 2**.

Table 1. Average wind direction as a percent time.

Direction	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
%T	4.80%	6.03%	6.92%	7.02%	7.89%	8.48%	10.94%	9.70%	8.71%	6.10%	5.21%	4.71%	4.55%	3.12%	2.59%	3.23%

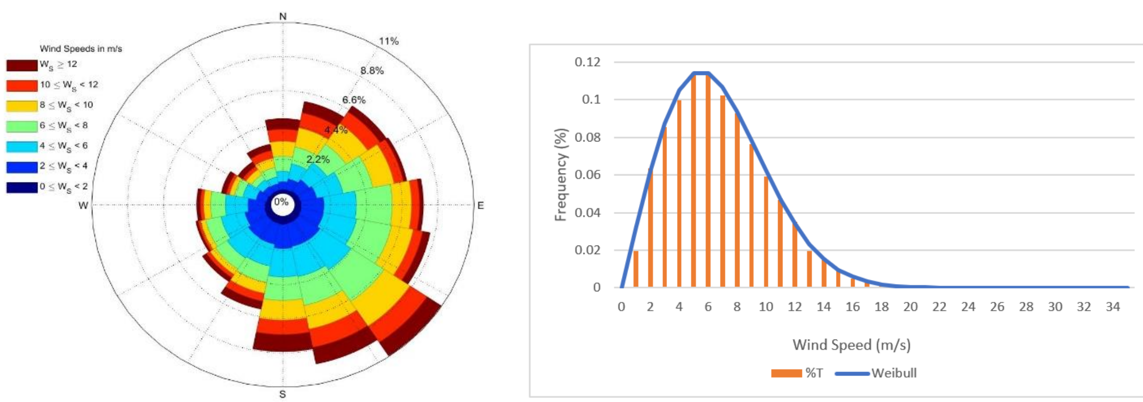

Figure 2. Wind rose (left) and wind speed distribution (right).

Based on the interannual variability, the expected lowest average annual wind speed over the projects design life time was calculated to be 6.35 m/s. The data were also analyzed for diurnal and seasonal patterns. The data was also analyzed for diurnal and seasonal patterns. The average wind speed for each hour of the day and all months of the year was calculated. The diurnal and yearly variation are shown in **Figure 3**. From this analysis, average hourly wind speeds varied from 6.41 m/s around 6:00 pm to 7.33 m/s around 1:00 am. Over the course of a year average monthly wind speed varied from 8.55 m/s in February to 4.46 m/s in July.

Month of the year	Hour of the Day: 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Jan	8.88	8.92	8.92	8.85	8.72	8.54	8.51	8.53	8.49	8.40	8.28	8.19	8.08	8.00	7.98	7.95	7.90	7.79	7.89	8.14	8.41	8.65	8.80	8.85
Feb	9.04	9.08	9.10	8.99	8.84	8.65	8.55	8.59	8.63	8.62	8.58	8.49	8.39	8.27	8.21	8.15	8.03	7.83	7.81	7.99	8.25	8.51	8.74	8.93
Mar	8.72	8.75	8.70	8.56	8.36	8.07	7.93	7.88	7.87	7.83	7.76	7.67	7.58	7.52	7.46	7.39	7.29	7.18	7.29	7.59	7.92	8.21	8.45	8.59
Apr	8.76	8.72	8.62	8.42	8.15	7.82	7.60	7.54	7.61	7.70	7.68	7.59	7.51	7.46	7.45	7.37	7.35	7.32	7.44	7.66	7.98	8.28	8.55	8.68
May	7.08	7.11	7.03	6.83	6.58	6.22	6.10	6.04	5.97	5.91	5.88	5.88	5.85	5.91	6.06	6.12	6.12	6.00	6.11	6.33	6.55	6.75	6.88	6.94
Jun	6.08	6.15	6.12	5.97	5.81	5.51	5.22	5.12	5.11	5.09	5.04	5.01	5.01	5.05	5.16	5.27	5.35	5.24	5.08	5.15	5.31	5.49	5.66	5.88
Jul	4.89	5.00	5.06	5.03	4.91	4.60	4.28	4.13	4.06	4.02	3.96	3.90	3.92	3.98	4.12	4.29	4.41	4.36	4.20	4.24	4.39	4.53	4.66	4.78
Aug	5.31	5.40	5.41	5.35	5.21	4.89	4.63	4.59	4.60	4.60	4.52	4.47	4.46	4.56	4.72	4.83	4.88	4.71	4.50	4.53	4.72	4.93	5.11	5.24
Sep	5.89	5.82	5.70	5.57	5.48	5.29	5.15	5.13	5.21	5.27	5.29	5.30	5.30	5.32	5.38	5.45	5.50	5.35	5.24	5.36	5.57	5.72	5.82	5.88
Oct	7.28	7.25	7.18	7.09	7.00	6.77	6.67	6.65	6.69	6.67	6.66	6.62	6.57	6.57	6.64	6.67	6.68	6.62	6.67	6.84	7.00	7.13	7.25	7.32
Nov	7.79	7.80	7.81	7.78	7.74	7.59	7.54	7.59	7.62	7.57	7.50	7.35	7.19	7.08	7.06	7.06	7.09	7.07	7.19	7.38	7.57	7.69	7.76	7.78
Dec	8.39	8.31	8.26	8.29	8.27	8.14	8.08	8.06	8.08	8.07	8.04	7.98	7.92	7.86	7.82	7.77	7.77	7.75	7.79	7.94	8.11	8.29	8.43	8.48

Figure 3. Wind speeds of a typical year.

2.0 Site Layout

2.1 Turbines and Foundation

For the Bayou Breeze Offshore Wind Farm, 44 Vestas V236 15-MW turbines were selected. This resulted in a nameplate capacity of 660 MW. These turbines are installed at a hub height of 150 m with a 236 m rotor diameter. These models will be available in 2024,[6] with prototypes already in operation. Since the V236 specifications are not publicly available, the IEA 15 MW turbine[7], was used as a reference turbine to design the wind farm since no data for the V236 could be obtained.

The turbines are oriented primarily in a Southwest to Northeast direction as this was the direction perpendicular to the primary wind direction. The turbines are spaced at 8 rotor diameters (1,888 m) within and between rows. To support the turbines, a jacket foundational structure was chosen. The ideal parameters for a jacket foundation are a water depth less than 60 meters as foundational costs become prohibitive in water depths greater than 60m. The max water depth across the lease blocks is 22.5 meters, which is less than the max depth for the jacket foundations. Stiff clays or medium-to-dense sands are also ideal, as other foundation types pose issues when driving piles.[3] Furthermore, the seafloor sediments in the chosen lease blocks consists mainly of mud and sandy mud according to the National Oceanic Atmospheric Administration[8]. If a geotechnical investigation reveals softer soils, the jacket foundation's piles can be extended to maintain structural integrity.

2.2 Collection System, Transmission, and Interconnection

Electricity generated by the turbines is carried through a total of 148.54 km of cabling at 69 kV to the offshore substation. The turbines were connected in circuits of four to the substation where the voltage of the lines is stepped up by transformers to 138 kV. The offshore collection system including cabling and the offshore substation are shown in **Figure 4.** One export cable at 138 kV, 61.69 km in length, runs from the offshore substation in a straight line run towards Chauvin. When it crosses the Bayou Terrobonne, it enters the Bush Canal and follows the Bayou Petit Gaillou where it makes landfall and connects to the onshore substation in Chauvin. This export cable route is shown in **Figure 5.** This substation was chosen based on its proximity to the wind farm, existing capacity, and area for expansion. The transmission line connected to the substation is owned by Entergy Louisiana Inc and rated at 230 kV.[9]

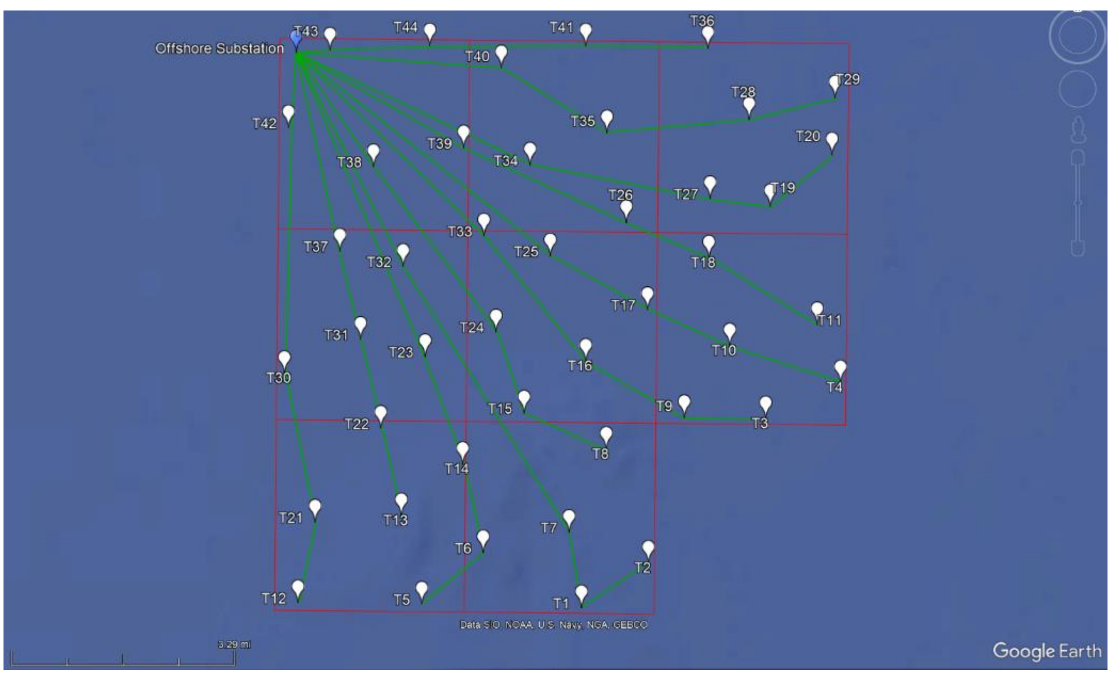

Figure 4. Site Layout, collection array cabling, and offshore substation.

Figure 5. Export cable route from offshore substation to point of interconnection and export cable landfall in Chauvin, Louisiana.

2.3 Port Infrastructure

Port Fourchon 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 have to travel 16 nautical miles. Wharf 630 in the port was selected because its characteristics are conducive to component staging as well as other port operations. It was calculated that for the proposed 44 turbines, a direct area of 30 acres would be required for their components. A port plan map showing these staging areas and other wharf amenities are given in **Figure 6**. The depth of the channel is important for giving needed vessels access to the port. The average import vessel requires a water depth of 32 feet[10] 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 wharf provides 1,580 feet which is more than the required 500 feet.[10] To determine if the ground has enough strength to support port activities and heavy lift operations, additional geotechnical testing would be required. For wind farm operations and maintenance, a facility and proper port amenities were designed along with a UW-Madison civil and geological engineering capstone team. These amenities include service roads and parking, vessel docking, and a helipad and hanger.

Figure 6. Wharf 630 layout

2.4 Vessels

Throughout the wind farm's lifespan, various specialized vessels will be required for the development, construction, maintenance, and decommissioning of the offshore wind farm. These vessels must comply with the Jones Act of 1920, which limits access to U.S. ports to vessels that are built, owned, and operated by United States citizens or permanent residents. Due to this limitation, combined with the specialized activities, some vessels will have to be imported, making them non-Jones Act-compliant. Imported vessels will not be able to dock at Port Fourchon but will be supplied using a feeder barge system with Jones Act-compliant feeder support vessels.

Imported vessels include the Fastnet Pelican, Fugro Excalibur, Van Oord Aeolus, and Isaac Newton. The Fastnet Pelican[11] is a survey support vessel that will collect environmental, geophysical, and hydrologic data. The Fugro Excalibur[12] is a foundation installation vessel that will be used to install the wind farm's underwater infrastructure. The underwater cable will be laid by the Isaac Newton, which will be provided by the Dutch company Jan De Nul[13]. The Van Oord Aeolus[14] will be used as a wind turbine installation vessel, using its 1,600-ton crane to install the turbine towers. Crew support vessels and service operations vessels will be used to transport maintenance crews to and from the offshore wind farm. These vessels will be furnished through the retrofitting of existing Jones Act-compliant maintenance transport vessels and commercial liftboats[15].

2.5 Net Annual Energy Production

To estimate energy production of the proposed wind farm, the same wind data obtained from Vortex[5] was analyzed using excel. The average annual Weibull distribution was multiplied times the IEA 15MW power curve to yield a gross annual energy production (AEP) of 2,053 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. The Vortex[5] data was also imported into the wind farm modeling software program Furow[16] To asses wake loss. This yielded an AEP very similar to the excel assessment and a wake loss of 9.23%. Electrical losses occur during the transmission process as heat is generated from this electrical movement. These electrical losses ranged from 1-5%[17] and a geospatial relationship between water depth and distance from cable land fall[17] was used to calculate electrical losses at a value of 2.8%. 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%[17] was used for these availability losses. Other losses account for a value of 2%.[17] 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 1,683.463 GWh/year, which yields a capacity factor of 29.12%.

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 hurricanes, birds, benthic changes, noise, and sediment.

Hurricanes- Hurricanes are a significant financial and operational concern for offshore wind farms in the Gulf of Mexico. Within the chosen lease blocks, the hurricane track density is consistent at 0.28-0.32 tracks per 50 square km[18]. There have been eight instances of Category 4+ hurricanes since 1856 within the radius of maximum wind, with the most recent being Hurricane Ida in 2021[18]. The Vestas V236 15-MW turbines selected are rated IEC Class S and have a cut-out speed of 108 km/h, which is equivalent to a Category 2 hurricane[19]. Additionally, the IEA 15-MW reference turbine, which is rated IEC Class 1B, can withstand winds of 252 km/h, equivalent to a Category 4 hurricane[20].

In a hurricane, the turbine tower is vulnerable to strong winds, but its foundation is also susceptible to the large, powerful waves that are generated. In response to dangerous weather, blanket curtailment will be implemented. The turbines will lock and feather their blades to reduce the surface area pointing into the wind. This minimizes storm damage and allows turbines to resume energy production once wind speeds return to normal. Other preventative measures include adding backup power so that even when grid power is lost, the turbines can rapidly yaw to point directly into the wind. There is a 30% probability that hurricanes will destroy more than 10% of a wind farm off the coast of Louisiana over a 20-year lifespan[21]. However, with backup power to track wind direction, this risk decreases to a 10-15% chance, and will be an addition strongly considered for this wind farm.

Birds- Birds are a significant environmental concern for the wind farm, especially as it is located in the Mississippi Flyway that crosses the Gulf of Mexico[22]. This flyway is estimated to be traveled by more than 325 bird species, such as the seaside sparrow and piping plover[22]. The artificial reefs of the wind farm could potentially have an attractive effect on some of these species, causing them to linger and disturb their natural migratory patterns[23]. Of even greater concern are the local bird species such as the royal tern, brown pelican, and black skimmer[24]. 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[25]. As the wind farm is 12 miles from nesting grounds, this reduces the energetic concerns and risk of collision, as it is in the outer half of most local species' ranges[24].

A bird detection system such as IdentiFlight, which curtails individual turbines when birds are detected nearby to reduce collisions and fatalities[26], will be implemented. It is an effective solution from both an impact and cost perspective, with a study conducted at a wind farm in Wyoming finding an 82% reduction in eagle fatalities when using Identiflight[27]. Through Identiflight, significant bird fatalities will be prevented while avoiding the drop in energy production that comes from blanket curtailment. Additional protective measures may be considered, such as painting the rotor blades black to reduce their motion smear, which has shown a 70% reduction in bird fatalities[28].

Benthic- The choice of jacket structures ameliorates damage to the local benthic environment, causing roughly one-tenth the habitat loss of a monopile installation[23]. The structures are also expected to cause positive benthic changes in the form of artificial reefs, a phenomenon observed at the Block Island Wind Farm[29]. Turbine foundations in the ocean are biomass hotspots, and the initial settlement of mussels can evolve into a diverse ecological system resembling a coral reef. The greater surface area of the jacket structure compared to other substructures also serves to exponentiate this reef effect[29]. Gulf species of higher trophic levels, including red snappers, gray snappers, and cobia fish[24] are attracted to these structures for food availability and shelter.

These reefs provide the opportunity to support locally rare hard-bottomed species, but can also serve to expand the dispersal pathways of invasive species, known as the "stepping stone effect[30]." 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 collected to allow for further biological analysis[31]. Additionally, plans can be made to consult with the Louisiana Artificial Reef Program to maintain and monitor the ecosystems that develop on the turbines.

Noise- The jacket structures will require pile driving installation, creating underwater noise and pressure waves which can result in mortality or injury to marine mammals, fish, or sea turtles[23]. The noise can also produce behavioral altercations in these species, such as startling, fleeing, and hiding[23]. These effects are temporary, with species returning to the area once pile driving has ceased[23]. Following installation, sound levels are unlikely to reach harmful levels or mask marine mammal calls[32].

Noise reduction technologies will be used to mitigate the effects of underwater sound during the pile driving process. A big bubble curtain 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[33]. This mitigation technique has been used in >700 pile driving procedures and can be prepared in advance to reduce time delays[33]. 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[33]. Both these methods are acceptable at the water depths of the selected lease blocks[33] and will be used to reduce installation noise to an acceptable level. Additional mitigation efforts will include ramping up the pile-driving process to allow species time to move away and carrying out these processes in periods of reduced animal abundance.

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[34]. A PAM system will be used during the installation and operation of the wind farm, taking special care to adjust procedures to local species protected under the Marine Mammal Protection Act[35] such as the West Indian Manatee and Atlantic Bottlenose Dolphin[24].

Sediment- Within the selected lease blocks there are no sensitive corals, reefs, or habitat hotspots of concern[24]. The installation of the jacket structures and scour protection may disturb up to 7% of the offshore wind farm site area, dropping significantly to less than 1% post-installation[23]. 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[36]. A temporary increase in sediment suspension may result from site installation activities, releasing potential contaminants such as arsenic, heavy metals, organotin, or PCBs[23]. These effects would be short-term and localized[37]. The installation of turbines using pile driving will result in less extensive sediment disturbance than other methods such as reverse-circulation drilling[23]. Standard water quality sampling will be used to monitor temperature, chemical composition, acidity, and dissolved oxygen to document potential changes[37].

Once installed, the turbine foundation structures create an accelerated water movement around themselves, known as a wake effect, which can persist for up to 200-m down-current[23]. This typically results in scour, the loss of soft sediment around the structure, and can be prevented through a scour protection system[38]. The common low-cost choice of dumped riprap will be used, which places stones around the foundation structures to weigh down soft sediment and avoid the potential downstream effects of their spread[38].

4.0 Social Impacts and Mitigation

The team considered multiple environmental and social impacts during installation, operation, and decommissioning and developed plans to mitigate these impacts.

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 alleviate this concern.

Fisheries- The construction and operation of offshore wind farms is an understandable concern for the fishing industry. 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, new fish species in the area, and little to no impact on fisheries[39]. Additionally, a local fisher was employed 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[30]. A similar system will be implemented in Fourchon to respond to the needs of the local community. Furthermore, commercial fishing practices will not be significantly disrupted by the presence of Bayou Breeze Offshore Wind Farm, as the chosen lease blocks are not heavily trafficked.

Tourism- Offshore wind farm proposals are often met with concerns about the project affecting tourism and recreation. However, research has shown that offshore wind farms do not negatively influence tourism and may even serve as a minor attraction[41]. At 10 miles away, wind turbines are no longer a major focus of visual attention and at 18 miles they stop being noticeable to casual observers[42]. This wind farm is 23 miles from populated areas, so tourism impacts and viewsheds will not be a significant concern.

Nonetheless, the area surrounding Port Fourchon is scattered with nature preserves such as the Nature Conservancy of Grand Isle and East Timbalier Island National Wildlife Refuge[43]. These contain critical bird habitats that draw in crowds of nature enthusiasts, namely during the Grand Isle Migratory

Bird Festival, which occurs every year during spring migration.[44] Bird fatalities from turbines are likely a major concern within this crowd, and a new offshore wind farm nearby may not be favorable despite the mitigation measures mentioned in section 3.0. A representative from the wind farm will travel to the bird festival each year to converse with birders and answer any questions they may have. In addition, since the Fourchon Port Commission works closely with nature conservationist programs to preserve the area's wildlife[45], a percentage of profit from the wind farm could be contributed to these efforts.

Military- Although the Bayou Breeze Wind Farm is located 15 miles from designated U.S. Military Special Use Airspace[46], there are no problems expected to result from this proximity. Any drills or tests carried out by the U.S. Armed Forces will remain within the designated airspace. U.S. Naval exercises, such as the GOMEX (Gulf of Mexico Exercises) occur yearly within the Gulf of Mexico[47], but are not in close proximity to the wind farm site.

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.[48] The effects on radar systems can be mitigated through advanced signal processing to identify signal cluttering effects and remove them.[48] The wind farm's presence within transmission systems will be actively considered and mitigation efforts carried out as necessary.

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. The material from the offshore wind turbines will first be considered for reuse, and then disposal by industry best practices.

5.0 Legal

5.1 Lease Process and Requirements (BOEM)

If successful in this lease block auction, a Site Assessment Plan (SAP) will be assembled and presented to the Bureau of Ocean Energy Management (BOEM) for approval prior to 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.

The data gathered under the SAP is used to develop a Construction and Operations Plan (COP), which will also need to be submitted to the BOEM. Additionally, the COP will be developed to describe the activities, both onshore and offshore, related to the construction, operation, and decommissioning of the project. After approval, the wind farm can begin installation.

5.2 Permitting and Approval

In the process of building an offshore wind farm, there are many permits and authorizations that must be filed prior to construction beginning. Permits must be obtained on a federal, state, and local level, and from various government agencies. Some of 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, among others.

Federal- As the BOEM manages energy development on the Outer Continental Shelf, they will review the SAP and COP. These plans must meet the requirements listed under 30 CFR 585.626, which describes the surveys needed. These include geological and geotechnical, shallow hazards, biological, and archaeological surveys as well as an overall site investigation. This section also details the 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.

As part of the of their approval process, BOEM will provide consultation with various other federal agencies under: Section 106 of the National Historic Preservation Act, Section 7 of the Endangered Species Act through the National Oceanic and Atmospheric Administration (NOAA), and The Magnuson–Stevens Fishery Conservation and Management Act through National Marine Fisheries Service (NMFS). Outside of what is covered by the BOEM, the NMFS will have to provide a letter of authorization stating that the project will have negligible impacts on marine mammal species in that area.

In addition to the BOEM, there are other governmental agencies that will regulate the construction of an offshore wind farm. 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 to monitor air pollution created by all outer continental shelf projects. The Federal Aviation Administration (FAA) will also need to approve form 7460-1 to ensure no turbines impede on navigable air space form 7460-1.

The US Coast Guard (USCG) must be consulted on multiple permits and aspects. The Private Aid to Navigation (PATON) authorization is one permit which marks the privately owned area that the wind farm will reside in. Another is the Local Notice to Mariners which makes vessels aware of where potential obstructions will be located during wind farm construction. In addition to this, the USCG will also need to inspect and regulate offshore wind support vessels under 46 CFR Subchapters "L" or "T".

State- With permitting on the state level, the US Army Core of Engineers (USACE) is the main regulatory agency, however the New Orleans District requires certain permits to be processed jointly with the Louisiana Department of Natural Resources (LDNR). A joint permit application process allows a simultaneous application for a Coastal Use Permit (CUP), the Department of the Army Permits under Section 10 of the Rivers and Harbors Act, and Section 404 of the Clean Water Act. The CUP regulates the use of coastal wetlands and development projects. The Department of the Army permit covers a Regional and Programmatic General permit which checks that the project does not obstruct any navigable waterways through the Section 10 of the Rivers and Harbors Act. Section 404 of the Clean Water Act authorizes any discharge of dredged or fill material into US waters. In addition to this, Section 408 of the Rivers and Harbor Act mandates that any use or alteration of a Civil Works project by another party is subject to the approval of USACE in the New Orleans District and must be filed outside of the joint application process.

In order for the joint permitting through USACE and LDNR to be approved, Section 401 of the Clean Water Act requires all federal licenses and permits to be certified through the Louisiana Department of Environmental Quality (LDEQ) through a Water Quality Certification. This is required for construction in navigable waters or wetlands and will determine if the construction will impact the site-specific water quality standards. Without Section 401, the prior permits cannot be issued. In addition to this, LDEQ also requires a Stormwater Construction General Permit (CGP) to cover pollutant discharges into state waters. Consultation is required at the state level to determine project impact on listed rare, threatened, and endangered species in compliance with Section 7 of the Endangered Species Act, but it completed during the joint permit preparation.

Other Louisiana agencies require permits associated with the construction. State of Louisiana Department of Transportation and Development (DOTD) requires an Overweight/Oversize Permit for loads exceeding legal size to operate on highways. The predicted transmission line will cross a highway and therefore a Temporary Occupancy permit through the DOTD will be required for any construction on or near the highway.

Local- At the local level, permits covering construction associated with the onshore cable route and substation are necessary through the Terrebonne Parish. A commercial construction permit is required to begin construction within the parish. A floodplain permit is required as construction of the cable goes through a designated flood plain area.

5.3 Risk and Fatal Flaws

There are various sources of risk associated with developing an offshore wind farm. These risks have been identified and mitigation strategies developed to reduce their impact on the project. Alongside such project risks, several fatal flaws of this project have been identified. If not addressed and properly mitigated early in development, these fatal flaws could pose significant setbacks and delay the development of the proposed wind farm.

Risks:

Preconstruction Energy Estimate- Risk is present in calculations of the projected annual energy production (AEP), as this is based on available data for site wind condition, layout, turbine selection, and loss estimation.

Construction- Offshore wind farm development requires all construction and materials to be transported and conducted by ships, which are not as readily available as onshore equipment such as cranes. Offshore wind development also lacks the reliable and consistent system that onshore has, due to the lack of offshore projects conducted in the United States. Scheduling of construction must also consider hurricanes and inclement weather.

Project Development- The uncertainties of a project reaching commercial operation and energy generation include site control difficulties, lack of transmission access, and unfavorable market dynamics. Access to ports also contains risk as space is needed throughout the construction process.

Regulatory- Policies toward wind energy are always changing. This region is heavily involved in the gas and oil industry and may not always be favorable towards wind energy. Being offshore in federal waters means both state and federal agencies are involved.

Market/Selling Price- Unknown selling price drives risk in uncertainty of revenue source. 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- Reduced energy production and diminished sales of electricity could lower revenue of the project. Some factors associated including curtailment (operation from hurricanes and environmental species impacts), technology reliability, unexpected operations, maintenance (O&M) events, and extreme weather events are already factored into the loss calculation applied to gross energy production. O&M maintenance on the project is more complicated as the offshore wind farm is harder to both access and service.

Fatal Flaws:

Existing Transmission Line Capacity- The transmission line connecting to the proposed point of interconnection might not have the capacity to handle the additional power supplied by the offshore wind farm. A transmission study would need to be conducted to determine the interconnection feasibility. Alternatively, other grid connection points would need to be considered, potentially increasing project costs.

Port/Wharf Availability- The chosen lease may not be available when construction starts. If this is the case, alternative leases would need to be pursued. While there are currently leases that have the area required to stage component delivery to the wind farm, there is no guarantee that those areas would be available when construction starts. If this is the case, a smaller wharf must be used instead. Other ports would need to be considered if no wharfs are available. If not enough space is available, other ports would need to be utilized. With limited port infrastructure in the region, this would cause costs to skyrocket.

Vessel Availability- There are only seven vessels capable of installing the V236[6]. Site construction can be initially planned to accommodate for the lack of ships to ensure there will be availability and mitigate delays.

6.0 Optimization Process

6.1 Turbine Locations

In the original design, lease blocks ST46, ST47, and ST56 were chosen as the site for the wind farm. This L-shaped orientation was optimal for the winds predominantly from the South-East direction. This initial selection was expanded from three lease blocks to eight lease blocks to include ST45, ST58, ST57, ST64, and ST65. The added lease blocks scored well in the preliminary site selection process and were added to increase the wind farm size and thus its financial viability.

Using the wind farm modeling tool Furow[16], 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 spacing, a wake loss of 10%[49] was used as a threshold 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. The cost savings of this additional turbine decreases 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 spacing must be large in both the inter-row and intra-row directions to keep the loses below the 10% threshold. 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 the 8 lease blocks with 8 total rows spaced 8 rotor diameters apart in the North-West to South-East direction. With a total of 44 turbines, each row contained a different amount. Due to the frequent wind out of the North-East, the turbines were then moved from these rows to reduce wake effects in this direction. This led to the more staggered layout used in the final design.

Upon optimization of the spacing and orientation considerations, the layout was imported into Google Earth. The locations were adjusted by using a 120m buffer to prevent turbine blades from overhanging outside of the lease blocks. Additionally, no turbine was moved into the space between rows 2 and 3 to allow for the easy passage of ships. This enables them to pass through the wind farm instead of forcing ships to avoid the wind farm completely and can be seen in **Figure 7.**

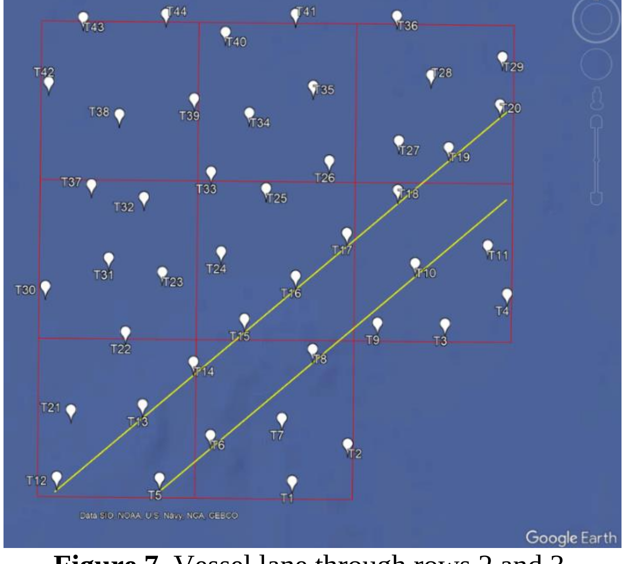

Figure 7. Vessel lane through rows 2 and 3.

6.2 Collection System

Once 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 substation, inter-array cabling and export cabling were all optimized in unison. Two substations were considered to decrease inter-array cable length but was ruled out as costs associated with the substation would outweigh the costs reduced through less cabling. 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. The offshore substation was located in the North-West corner of the lease blocks because the export cable is more costly than the inter-array cabling. For the export cable, once close to shore, it was directed into the navigational channels until it reached the substation. This was done because although slightly longer, this avoids issues associated with the construction feasibility of multiple land-water interfaces. A closer interconnection point was identified in Port Fourchon but was not used in the final design as the transmission line connected to this substation was determined to not be of adequate size to handle the additional power generated from the wind farm[9].

7.0 Financial Analysis

7.1 Initial Capital Costs, Annual Operating Expenses, and Taxes

To assess capital and operational costs of the Bayou Breeze Wind Farm (the Project), unit costs from NREL's 2021 Cost of Wind Energy (COWE) report[51] fixed-bottom model were used. These unit costs served as a baseline and were adjusted based on the differing assumptions between the model and characteristics of Bayou Breeze. The total capital costs of the Project were divided into three categories:

Turbine- These were lowered by $401/kW from the NREL COWE report to $900/kW. The Bayou Breeze Wind Farm uses 15 MW turbines which is nearly double the capacity assumed in the NREL model. As turbines increase in size, the marginal gain in capacity is higher than the marginal increase in cost and therefore the unit costs is reduced.

BOS- These costs, which include assembly and installation, substructure and foundation, development and project management, and electrical infrastructure, were lowered by $345/kW to $1,521kW. This was because the NREL model has nearly double the number of turbines, but a slightly smaller capacity. Although the larger turbines require more material per unit, this increase is less than the decrease in overall material required for the small number of foundations. Additionally, the water depth at the Project is less than NREL model which will further reduce material required and thus the costs of the substructures. The unit costs of assembly and installation was lowered because the marginal costs of the increase in labor hours required for larger turbines is less than the marginal benefit from the decrease in labor caused by a drop in the number of turbines. Development and project management unit costs were also lowered due to the same decrease in overall labor required. Electrical infrastructure costs were raised by a small amount. The project has less inter-array cabling and shallower water depth, which lowers costs. However, the project is a farther distance from shore, resulting in a longer, more expensive export cable.

Soft Cost- These costs, which include plant commissioning, decommissioning, contingency, construction finance, and insurance during construction were lowered by $155/kW to $548/kW. Plant commissioning and decommissioning were lowered as the labor hours required to test and decommission the wind farm will increase due to the larger wind turbines, but decrease by a greater amount due to the smaller number of turbines. Insurance and construction finance unit costs will also be lower because the increase in costs caused by larger wind turbines is less than the decrease in costs due to the smaller number of turbines. Contingency was lowered as fewer turbines means fewer options for turbine failure and therefore less perceived risk.

The operational expenses, which include turbine maintenance, additional parts, insurance, and administration, was lowered by $40/kW to $70/kW. An operational expenses escalation rate of 2.5% was applied to account for inflation. The cost of maintenance will increase per turbine as they are larger, but overall maintenance costs will decrease because of the lower amount of turbines. Although the parts of the larger turbines cost more, since there are less of them, overall costs will decrease.

The Project will be subject to various taxes on the federal, state, and local level. The federal corporate income tax of 21%[52] and Louisiana corporate income tax of 7.5%[53], the highest tax bracket, were applied. The Louisiana sales tax for electricity of 2%[54] was applied to the revenue generated from the power purchase agreement PPA, while the salvage value of the wind farm will be taxed by the Louisiana 4.45%[53] general sales tax. Since the onshore substation is located in Terrebonne parish there will be a 5.5%[55] sales tax applied to the revenue generated by PPA that is specific to Terrebonne.

7.2 Market Conditions, Power Purchase Agreement, and Revenue

The chosen buyer for the energy generated by the Project will be sold wholesale in a purchase power agreement to Entergy Corporation at a rate of $97.50 per MWh. Entergy is the largest Louisiana municipality energy & power generation utility provider, placing the support and service of local communities and state as its priority. Belonging to Louisiana Energy & Power Agreement[57] opens up future opportunities to provide power to nearly 90% of the residential, commercial, and industrial demand throughout the entirety of the state. This project will also help Entergy increase their renewable portfolio to address climate issues, a long-term company goal.[58] The chosen set price was estimated using both historical and current market prices and trends from the National Research Energy Laboratory (NREL) Offshore Wind Market Report: 2022.[59] Entergy operates within the southern MISO market whose cost of wind energy was also taken into consideration.[60]

Recent passing of the *Inflation Reduction Act* sets a goal of 30 GWs of offshore wind energy development by 2030 in United States[61]. Such enactments push the offshore wind market towards potential exogenous growth. With the rising risk of climate change, clean energy solutions, such as offshore wind, will experience industry growth and reach market saturation thereby dropping component costs. Case studies about PPAs of suggested project proposals were observed throughout the Atlantic region of the U.S., providing sale prices of ~$96 per MWh. The suggested price of the Projects PPA, $97.50/MWh, is higher when compared to the Atlantic Region is primarily due to lower wind resource speeds.

Due to the lack of prior offshore projects, both high operational costs and upfront capital costs of the Project lead to a higher price for offshore development to account for the lack of resources to ensure financial stability. The PPA will have a 2.5% escalation factor to offset turbine component degradation as observed from the Vineyard Wind PPA[62]. The estimated net annual energy production of the wind farm is 1,683 GWh/year. However, an AEP degradation rate of 0.5% is assumed to account for the decay of wind turbine components. This generates an annual revenue for Year 1 of $164,127,500 for a total revenue of $3,983,152,781.18 over the project lifetime.

7.3 Incentives

The main financial incentive used in this project was the Investment Tax Credit (ITC). This is a one-time credit applied in Year 0 that is calculated as a rate of the capital costs. The Inflation Reduction Act allocates a base rate of 6% with a max rate of 30%. Furthermore, a domestic manufacturing and separate energy community bonus of 2% to 10% is available. To qualify for the full credit, prevailing wage and apprenticeship requirements specified by the Inflation Reduction Act must be met. The bonus credits have their own qualifications.[61] It is assumed that the Bayou Breeze Wind Farm will not qualify for the domestic manufacturing bonus as most manufacturing components will be sourced overseas. However, it does meet the employment criteria of the energy community bonus.[63] The total ITC credit applied to the project is 40% of capital costs. This tax credit was converted to dollars at a rate of 92 cents per every dollar of ITC.[64]

The assets of the Project will follow the 5-year Modified Accelerated Cost Recovery System (MACRS).[65] The wind farm will depreciate according to the yearly percentages that the 5-year MACRS deprecation schedule specifies. The yearly deprecation lowers the taxable income and therefore lowers the wind farm's income tax liability in the first 6 years.

7.4 Financing Plan

The Bayou Breeze Wind Farm assumes a debt fraction of 60%. This was chosen based on the debt fraction recommended by NREL's System Advisor Model[66] and Annual Technology Baseline: The 2020 Electricity Update.[67] The sponsor equity of the wind farm is $783,816,000.00 and the other $1,175,724,000.00 of the capital cost will be financed by long term debt. A single loan will be taken out to cover this debt. This loan will consist of 20 equal principal payments over the 20-year life of the wind farm. The rate of the interest payments was calculated based on NREL's Annual Technology Baseline: The 2020 Electricity Update[67] and the rate at which the U.S. 10-year treasury[68] is trading. Summing the 2020 Electricity Update's predicted interest rate for offshore wind loans in 2020, 4%[67], with the change in the U.S. 10 year from 2020 to now, 3.3%[68], yielded a nominal interest rate of 6.6%. The nominal rate was converted to a real rate of 3.5% by assuming 3% inflation[69] based on the Congressional Budget Office's economic look out for 2023 to 2033. Total interest on the loan is $432,198,452.36. The financing plan for the wind farm has a nominal Weighted Average Cost of Capital WACC of 5.71% and a real WACC of 2.63%.

7.5 Financial Analysis

The twenty-year cash flow diagram is shown in **Figure 8** and represents the annual gains and losses of Project components. Using the WACC of the project, 5.71%, the yearly real cash flows were discounted to calculate a Net Present Value (NPV) of $97,084,765.72. The Internal Rate of Return (IRR) for this project is 12% with a payback period of 11 years. 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 The Bayou Breeze Wind Farm is projected to be $.0917/kWh. These values imply that the project is worth pursuing as it is projected to bring in profits to developers and investors barring any setbacks.

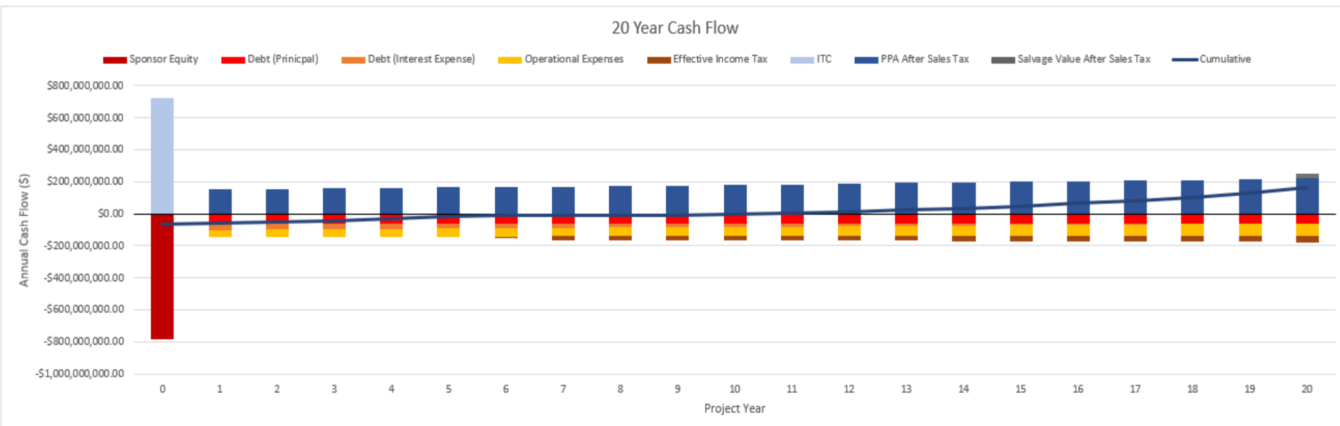

Figure 8. 20-year cash flow diagram for the proposed wind farm.

8.0 Conclusion

The goal of this report was to detail the proposal of the Bayou Breeze Offshore Wind Farm off the coast of Port Fourchon Louisiana that was attractive to investors including a rigorous financial analysis. Thorough research was conducted, turbine models and annual energy productions were compared, and a site layout was designed. Environmental, social, and legal factors were also factored in. Based off these factors, WiscWind LLC is prepared to pay $99,000,000 for the eight selected lease blocks.

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