Lake Michigan Offshore Wind Project Feasibility Report

Alicia Doberstein, Emma Brockley, Collin DeYoung, Joe Bevington,

Nina Hartwig, Ryan Thurston

University of Wisconsin – Milwaukee

School of Freshwater Sciences

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Advisor: Professor Melissa Scanlan

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Introduction

Burning fossil fuels is the largest contributor to climate change, accounting for most of the global greenhouse gas and carbon dioxide emissions. Concerns of extreme weather events from rising temperatures to flash flooding in SE Wisconsin, have raised questions from the public regarding alternative energy solutions across stakeholders. The City of Milwaukee and surrounding municipalities rely on burning coal, oil, and natural gas, for approximately 76% of overall power generation (Wisconsin – State Energy Profile Overview, 2022). Across the United States, burning fossil fuels to power domestic grids accounts for 60% of energy production and only 21.5% comes from renewable sources. Renewable energy sources including solar, wind, geothermal, and hydropower are among the most common with wind energy as the most prominent comprising 10.2% of the U.S. total energy generation (EA, 2022). As President Biden and his administration are pushing for offshore wind projects near the U.S. East Coast and the Gulf of Mexico, interest in expanding wind energy infrastructure is high. With the push towards offshore wind generation along the coast, heads have turned towards the Great Lakes region as an opportunity for Midwestern states to reap benefits of wind powered energy alternatives. National estimates of Great Lakes wind potential have sparked interest. However, there are open questions about evaluating wind patterns in specific areas of the lakes to determine energy production potential, political support, economic feasibility, ecological conflicts, technological concerns, and legal barriers. To inform the City of Milwaukee's evaluation of potential offshore wind projects, we assess why previous Great Lakes offshore wind projects have been successful (one approved, not yet built) and unsuccessful.

In response to a request from the Environmental Collaboration Office for the City of Milwaukee, under the guidance and direction of Professor Melissa Scanlan, graduate students at the University of Wisconsin-Milwaukee's School of Freshwater Sciences produced a preliminary assessment of the feasibility of developing an offshore wind project off the coast of Milwaukee in Lake Michigan. We start the assessment by identifying the complex legal and regulatory considerations involved in this project in Section 1. Section 2 addresses whether the regional atmospheric wind patterns offshore from Milwaukee provide enough momentum consistently to generate energy. Based on our determination that the wind patterns are favorable for wind energy generation, in Section 3 we identify a successful model of offshore wind development in the Great Lakes by analyzing other proposed offshore wind projects in Lake Erie near Cleveland, Lake Ontario near New York, and Lake Michigan near Chicago.

In Section 4, we identify potential environmental concerns and compare them to other Great Lakes wind projects. The three main areas of concern addressed are fish, bird, and bat populations. Section 5 assesses how an offshore wind project is funded, which is one of the biggest obstacles to implementing such a project. When considering how an offshore wind project could be funded, it is important to consider similar projects. Building from the environmental evaluation and funding options, we offer a basic cost-benefit analysis in Section 6 to highlight potential ecological consequences of the construction of wind turbines in Lake Michigan. In Section 7, we developed a comprehensive list of potential stakeholders, quantified their perceived degrees of influence and interest in an offshore wind project, characterized stakeholder groupings based on the interest-influence metrics, then recommended communication strategies to effectively engage each of these groups at various stages throughout the project development.

Finally, based on our multi-disciplinary research approach, we offer recommendations for the City of Milwaukee's Environmental Collaboration Office to consider throughout the project lifecycle. We aim for this report to equip the City of Milwaukee's Environmental Collaboration Office with useful information to begin assessing whether offshore wind will be part of the City's renewable energy future.

Section 1: Legal Considerations

1.1. Overview

For offshore wind projects on the oceans, the Bureau of Ocean Energy Management within the Department of Interior identifies areas available for offshore wind, establishes leases and opens auctions for those leasing rights. This authority does not extend to the Great Lakes. So, for an offshore wind project on Lake Michigan, there's a patchwork of federal and state laws, but no overarching federal control of offshore wind permitting. As discussed in section 7 with Ohio's offshore wind project, that puts a greater emphasis on state control and may allow for faster approvals than ocean offshore wind projects; however, it also makes it more of a legal frontier where the state laws are not designed to address these types of projects.

Federal laws that are applicable include the National Environmental Policy Act (NEPA), the Clean Water Act (CWA), and the Rivers and Harbors Appropriations Act (RHA). These acts play an important role in the permitting process for construction projects in the Great Lakes and all fall under the regulatory authority of the United States Army Corps of Engineers. The State laws that must be considered are the Public Trust Doctrine, the Wisconsin Environmental Policy Act (WEPA), Public Utility Statutes, and Administrative Code Chapter PSC 128 (Wind Energy Systems). The regulatory authority for the Public Trust Doctrine falls under the Wisconsin Department of Natural Resources (WDNR). The WDNR and the Public Service Commission of Wisconsin (PSCW) are the regulating bodies for WEPA and Public Utility Statutes.

1.2. Federal Laws

The three most applicable federal laws to this project are the National Environmental Policy Act (NEPA), the Clean Water Act (CWA), and the Rivers and Harbors Appropriations Act (RHA). The current Icebreaker offshore wind project in Ohio was required to adhere to and apply for permits under these three federal laws. Therefore, a Lake Michigan offshore wind project will similarly require the proper federal construction permits and these three acts are integral to that permitting process.

The National Environmental Policy Act requires all federal agencies to "consider every significant aspect of the environmental impact of a proposed [federal] action, 'and to ensure that the [responsible] agency will inform the public that it has indeed considered environmental concerns in its decision- making process" (Bynum, 2010). Prior to the Army Corps of Engineers approving a section 10 RHA permit or a section 404 CWA permit, they will first need to thoroughly assess the potential environmental consequences of the project. Constructing an offshore wind project in Lake Michigan would most likely require a section 10 RHA permit and a section 404 CWA permit because section 10 will provide authorization to build the structure and section 404 will permit the discharge of dredge or fill material into the lake. Therefore, to obtain the necessary permits for the project, an in-depth assessment of the environmental impacts of the offshore wind project will need to be completed.

The first step towards obtaining a permit is to submit an environmental assessment (EA) for review by the Corps. An EA is a brief analysis of the environmental impacts of the proposed project. The four key elements that must be included are reasoning as to why the proposed activity is needed, possible alternatives, environmental impacts that the proposed project would have, and a list of people and agencies that the Corps consulted (Bynum, 2010). After the EA has been reviewed by the Army Corps of Engineers, they will either issue a finding of no significant impact (FONSI) or request for a more detailed report known as an environmental impact statement (EIS). The specific information required in the EA for this offshore wind project will be discussed in section 4, which describes the environmental considerations as it pertains to this project.

An environmental impact statement focuses on whether the proposed project or action is suitable under current circumstances. To do this the EIS must include five main elements (Bynum, 2010). First it must detail the expected environmental impacts that this action or project would have. Second, it needs to outline and describe any of the unavoidable negative environmental impacts. Third, an EIS should include any alternative options to the proposed action. Fourth, it needs to address the complex relationship between short-term human uses of the environment and long-term productivity of that same environment. Finally, the environmental impact statement must discuss the "irreversible commitment of resources" i.e., any losses to resources that cannot be undone. Similar to an EA, an EIS must also include discussions with other federal agencies. The EIS would then be submitted for review by the Corp, who would then determine whether to move forward with the action or project.

The Clean Water Act regulates the construction process of dredging and filling the lakebed to complete the wind turbine structures. The construction of an offshore wind project could potentially require the dredging and filling of material in the lakebed if wind turbines with supporting lakebed foundations are chosen instead of floating turbines. This dredging and filling will require a section 404 permit to comply with the Clean Water Act. Additionally, a section 404 permit would be required as power lines will need to be embedded within the lakebed to transmit the generated electricity. This process will involve dredging and burying the necessary cables into the lakebed and connecting the offshore wind turbine to an onshore power facility. In addition to a section 404 permit, a section 408 permit will also be necessary to complete any alterations or maintenance of the wind turbines (Department of Energy, 2018).

In order to receive a section 404 permit the Army Corps of Engineers must first hold a public interest review in which they examine the potential impacts as well as accruing impacts on the surrounding interests of the public. The Corps will then analyze the potential costs and benefits of the proposed activity placing varying weights on different factors. These factors can include, "conservation, economics, aesthetics, general environmental concerns, wetlands, historic properties, fish and wildlife values, flood hazards, floodplain values, land use, navigation, shore erosion and accretion, recreation, water supply and conservation, water quality, energy needs, safety, food and fiber production, mineral needs, considerations of property ownership and, in general, the needs and welfare of the people" (Bynum, 2010). While the Corps holds authority to grant section 404 permits, the state of Wisconsin will also have to issue a 401 Water Quality Certification before the permit is valid. So, in addition to the state laws described below, the WDNR would also be involved in this federal permitting. The Icebreaker Project in Ohio received both a section 404 and 408 permit from the Corps (Department of Energy, 2018).

The River and Harbors Appropriation Act was the first act that gave the Army Corps of Engineers regulatory authority to permit construction in navigable waters. Section 10 of the RHA outlines that any construction or excavation in or above waters of the United States is unlawful unless the Chief of Engineers advised it and the Secretary of Defense authorized it (U.S Environmental Protection Agency, 2022). Section 10 is relevant to this project because the Corps not only regulates the construction of piers, wharfs, and canals, but also the construction of power lines and permanently anchored floating vessels, both of which are important aspects of an offshore wind project. To obtain a section 10 permit, an application must first be submitted to the Corps for review. They will review the application within about 45 business days and notify the applicant with a response. This permit will give authorization for the wind turbine and power cable construction in Lake Michigan, which is considered by the Corps to be navigable waters. The RHA section 10 permit was obtained for the Ohio Icebreaker project to move forward with its construction (Department of Energy, 2018). Therefore, this permit will also need to be obtained if an offshore wind project in Lake Michigan is going to proceed.

1.3. State Laws

There are four main state laws that must be addressed when considering the construction of an offshore wind project on Lake Michigan, the Public Trust Doctrine, the Wisconsin Environmental Policy Act, Public Utility laws, and the PSC 128.30 application.

The Public Trust Doctrine requires the state to hold navigable waters and lakebeds in trust for the benefit of the public's interest in those waters (Henning, 2019). The WDNR is the enforcement agency, as delegated by the Wisconsin Legislature, and therefore can permit the construction of a structure on Lake Michigan's lakebed within Wisconsin's portion of the lake. After examining multiple state and US maps, we determined that Wisconsin's lakebed extends to the halfway point of the lake which is approximately 36 miles out into Lake Michigan. Based on the wind analysis, the optimal location will be within Wisconsin jurisdiction and require WDNR authorization. The Public Trust Doctrine would be influential in relation to this potential offshore wind project as public opinion would weigh heavily on this project's success. If the public disagreed with the project, they would likely claim that it violates their public rights in navigation, fishing and recreation. Additionally, wind turbines that must be secured to the lakebed will need a lakebed lease from the WDNR.

Under Wisconsin Statute § 30.12(1) an individual or general permit from the WDNR is required to make deposits on the lakebed. To gain a building structure permit in compliance with the Public Trust Doctrine the WDNR must first examine a multitude of factors to determine if the project upholds the doctrine. These factors include "the desire to preserve the natural beauty of our navigable waters, to obtain the fullest public use of such waters, including but not limited to navigation, and to provide for the convenience of riparian owners" (Bynum, 2010). Additionally, a lakebed lease will need to be secured to obtain access to submerged land for the turbines and the cables. The Ohio Icebreaker project required this as well, and access was obtained through a submerged lands lease through the state of Ohio (U.S. Department of Energy, 2018). In Wisconsin this lakebed lease would need to be approved by the Board of Commissioners of Public Lands (BCPL) and the WDNR. BCPL and WDNR create lease terms that are no longer than 50 years and protect the public's interest in the provisions of the lease (Bynum, 2010). Given an offshore wind project has never previously been permitted by the state, it is unclear how the agencies will protect the public interest for such a project and how much they will charge for the lease.

The Wisconsin Environmental Policy Act (WEPA) is similar to NEPA. WEPA requires that state agencies must evaluate the “environmental, socioeconomic, energy, archeological, agricultural, and other effects of a proposed project before issuing permits or other approvals” (PSCW, 2009). To receive the proper permits and approvals from state agencies, compliance with WEPA must first be met. This will set the foundation for the necessary state chapter 30.12 and PSCW permit, and leasing required to implement the offshore wind project. Prior to any major environmental altering actions, the project proponent must first submit a detailed statement. The lead agency will complete an EA and potentially an EIS.

The Public Service Commission of Wisconsin is the regulatory agency that reviews and authorizes all energy generation facilities in Wisconsin, including renewable facilities. The PSCW works to uphold the goal set by Wisconsin Statute § 1.12(3)(b) that states “to the extent that it is cost-effective and technically feasible, all new installed capacity for electric generation in the state be based on renewable energy resources, including hydroelectric, wood, wind, solar, refuse, agricultural and biomass energy resources” (PSCW, 2023). To authorize an energy generation facility the PSCW can either authorize the project under section 196.49(3) which authorizes construction or 196.491(3) which grants a certificate of public convenience and necessity (Bynum, 2010).

If the PSCW finds the proposed power generation project is in the public's best interest, they may authorize construction under section 196.49(3). However, the PSCW will examine whether the proposed project does one or more of the following: the project impacts the efficiency of the current public utility, increases costs to consumers without also increasing availability and/or value of the service, or allows the facility to produce an unreasonable amount of excess power which does not algin with future projections (Bynum, 2010). If the PSCW finds that the project will cause one of these impacts, they will conclude that the project is not in the public's best interest and deny construction.

Alternatively, the PSCW may issue a certificate of public convenience and necessity. The certificate may only be granted if the agency finds that it meets certain criteria outlined in section 196.491(3) (Bynum, 2010). First, the project must qualify under section 196.49(3) construction standards. Next, the project should be able to satisfy a reasonable amount of the public's electricity needs. Another requirement is that it needs to take the public’s interest into consideration when it comes to location, design, and routing. Additionally, the project needs to address possible alternative sources of supply, locations, routes, engineering, safety, economic, and environmental factors. The possible locations and routing will be discussed in section 2, which analyzes the best possible locations for the wind turbines to be built. The economic portion will be addressed in section 5, which analyzes the costs and benefits of the project. Environmental factors will be discussed in section 4, which analyzes bird and bat migration patterns as well as aquatic species. However, engineering and safety will not be addressed in this report and will require further research if the project is to move forward. The proposed project must not cause any negative impacts on the public’s health, recreational uses, aesthetics, historic sites, or environment. It is also outlined that the project cannot restrict orderly land use and development plans. Finally, the project must not interfere with the wholesale eclectic service market.

PSC 128.30 is a Wisconsin administrative code provision that outlines application and notice requirements specific to wind energy systems. This code is written with political subdivisions in mind. However, 128.105 states: "**(1m)** ADDITIONAL PRE-APPLICATION NOTICE TO COMMISSION. At least 180 days before filing an application to construct a wind turbine with a maximum blade tip height exceeding 600 feet, **or a wind energy system in those portions of Lake Michigan** or Lake Superior **that are within the jurisdiction of the state**, the owner shall provide written notice of the planned wind energy system to the commission." (emphasis added) Thus, it appears an offshore wind project's proponents will need to comply with chapter 128 to obtain PSCW approval.

There are 15 elements that need to be addressed in the application but given that this wind project will not be constructed on land certain requirements will not be relevant. The city has experience filling out the PSC 128.30 application as it was necessary for the construction of the Port wind turbine that was installed in 2012. A few of the relevant requirements that will be addressed for this project are as follows: Wind energy system description and maps showing locations of all proposed wind energy facilities, technical description of wind turbines and wind turbine sites. A timeline and process for constructing the wind energy system. Information regarding anticipated impact of the wind energy system on local infrastructure, noise anticipated to be attributable to the wind energy system, shadow flicker anticipated to be attributable to the wind energy system. Finally, anticipated effects of the wind energy system on airports and airspace and effects of the wind energy system on line-of-sight communications.

1.4. Summary

When considering the construction of an offshore wind project in Lake Michigan, the previously mentioned federal and state laws will be the main regulatory processes required for this project. The federal laws include NEPA, the CWA, and the RHA. NEPA will require the submission of an EA and potentially an EIS. These will both be reviewed by the Corps, and they will determine whether to authorize the project. Compliance with the CWA will require a section 404 permit. The permit will be granted by the Corps after they have weighed the impact that various factors will have and found those impacts to be reasonable, and WDNR has issued a CWA 401 water quality certification. The project will also require a section 10 permit under the River and Harbors Act for construction or excavation in water of the United States. This permit will be granted if the Chief of Engineers advises it, and the Secretary of War authorizes it. The state statutes and regulations that will be important are Wis. Stat. 30.12 and lakebed leasing consistent with the Public Trust Doctrine, WEPA, the Public Utility Statutes, and PSC 128.30. To ensure that the project does not violate the Public Trust Doctrine, the WDNR will need to assess whether it algins with public rights in water, such as fishing, recreation, natural scenic beauty, and navigation. Compliance with WEPA will require an EA similar to NEPA and possibly an EIS. The Public Utility Statutes will either require construction authorization from the PSCW under section 196.49(3) or a certificate of public convenience and necessity under section 196.491(3). Both sections have requirements the project must meet and will be reviewed by the PSCW, including meeting the standards in PSC 128.30 for a wind project.

Section 2: Wind Analysis

2.1 Wind Analysis Background

Determining the wind energy production potential of wind turbines requires a spatial and temporal analysis of the wind speed at the rotor height of the wind turbine (hub height). By knowing the mean wind speed and how it varies above the surface, the wind power potential can be assessed. Shown in Figure 1 are the mean wind speeds for U.S offshore sites, including Lake Michigan from a report conducted by the National Renewable Energy Laboratory (NREL) and Frontier Group (2022). Based on their analysis, offshore wind in the Great Lakes was found to be feasible yet limited in comparison to other offshore regions. The mean wind speed in Lake Michigan was within the range of 8 – 9 meters per second (m s^{-1}). While this is 1 – 2 m s^{-1} slower than the Pacific and Atlantic coastlines, it is 2 – 3 m s^{-1} faster than average wind speeds over land in eastern Wisconsin which are about 6 m s^{-1} (NREL, 2022). Despite this discrepancy, the 2019 offshore electricity potential for Wisconsin was 70% of the total energy usage, assuming full electrification (Reicher & Read, 2021). Purely from the perspective of wind speed and wind power potential, the results found by Frontier Group are promising for the Milwaukee offshore wind turbine consideration. Based on the research done by these organizations, the present report seeks to compare and expand upon their results with a focus on the area offshore from Milwaukee. Furthermore, this section is dedicated to the investigation into the spatiotemporal variations of wind patterns and the resultant power generation for the region.

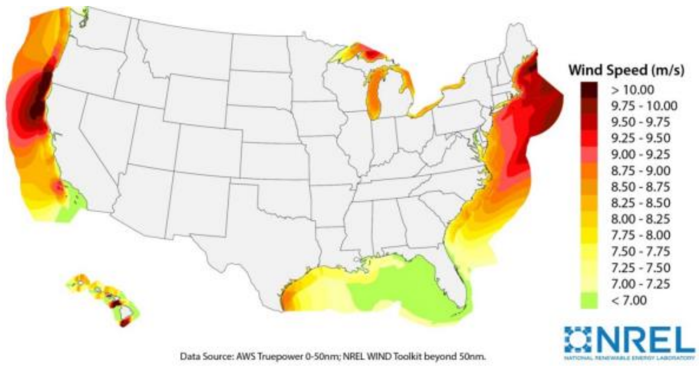


Fig 1. Plot of the mean wind speeds for offshore locations in the United States (NREL, 2021).

To accurately assess the wind potential at a location, the wind speed at the height of a turbine's rotor, the hub height, must be determined. Unfortunately, wind measurements are generally taken near the surface. Thus, the winds above the surface must be estimated. One way to do so is to develop a vertical profile of the wind based on the surface type and wind speed. There are two approaches to estimating the vertical wind profile; the logarithmic wind profile and the power law wind profile given by equations (1) and (2) respectively where U is the wind speed, z is wind estimation height, z_r is the reference height, z_0 is the roughness length, and α is a constant.

$$(1)\ U(z) = U_{z_r} * \frac{ln\frac{z}{z_0}}{ln\frac{z_r}{z_0}} \qquad (2)\ U(z) = U_{z_r} * \left(\frac{z}{z_r}\right)^{\alpha}$$

The choice of profile depends upon the surface from which we are estimating the wind. For example, the value of z_0 depends on the roughness/friction of the surface, causing the profile of $U(z)$ to take on a different shape. Over large bodies of water, the value of z_0 is 0.0002 m whereas its 0.03 m over open land surfaces (Linacre & Geerts, 1999). The value of α plays a similar role given it changes based on the surface type; a value of 0.143 (1/7) is generally used for α, but an α of 0.11 is more representative of the wind profile over large bodies of water (Hsu et al., 1994).

Even when using the appropriate z_0 and α, there will be differences in the wind estimation

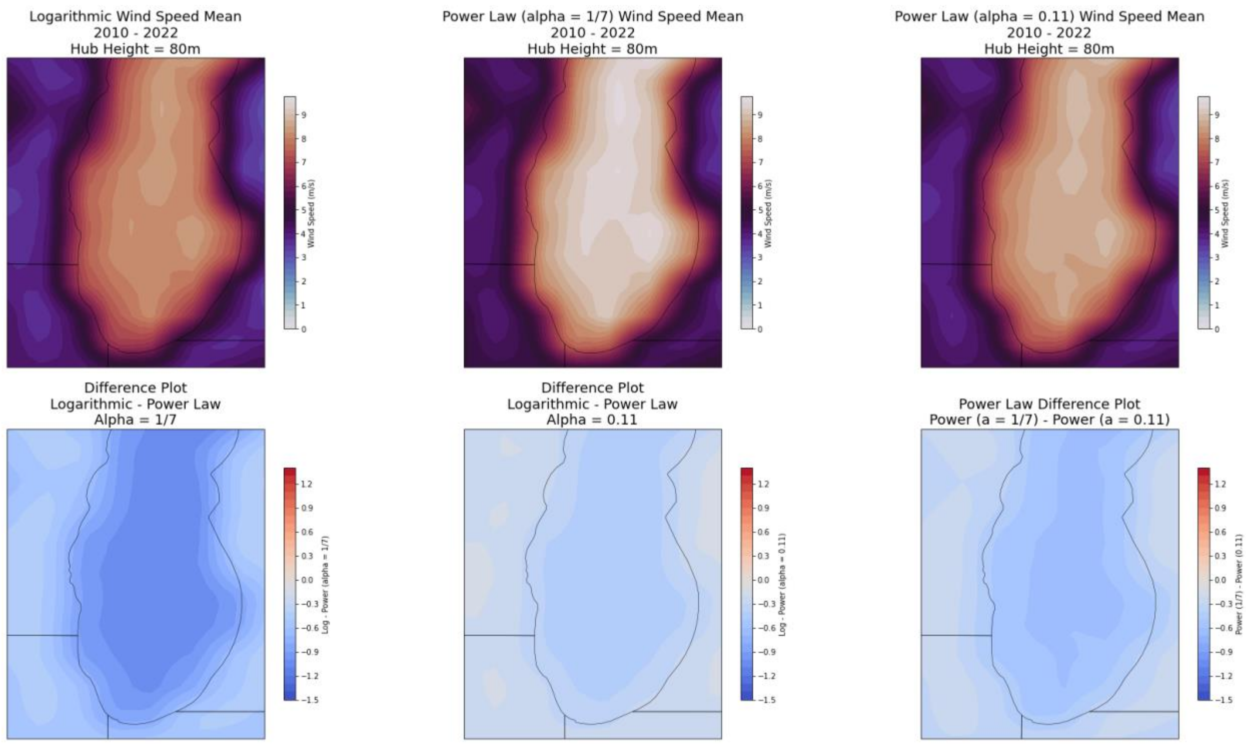


Fig 2. In order of left – right: 2a) logarithmic wind profile, 2b) power law wind profile using an alpha of 1/7, 2c) power law wind profile using an alpha of 0.11, 2d) difference between the logarithmic wind profile and the power law profile with an alpha of 1/7, 2e) difference between the logarithmic wind profile and the power law profile with an alpha of 0.11, and 2f) the difference between the two power law wind profiles. Maps were created using the ECMWF ERA5 Land-Hourly Reanalysis Data (Sabater, 2021).

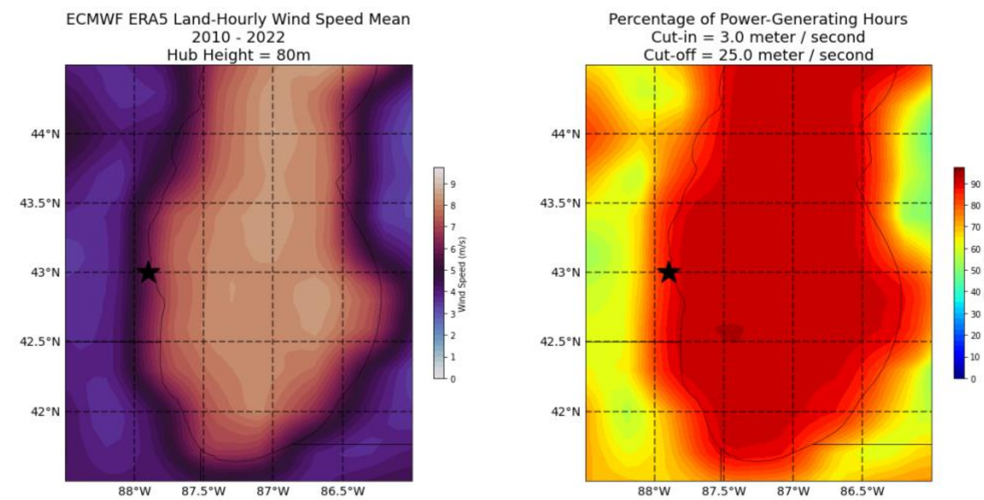
between the log and power wind profiles. An example of this difference is plotted in Figure 2. Using a typical height of 80 m (262 ft) for offshore wind turbines, the logarithmic estimate had the slowest wind speeds compared to the power law profiles with an alpha of 0.143 and 0.11. To avoid an overestimation of the wind speed, the logarithmic wind profile was chosen to assess hub height wind speeds. The logarithmic profile is a more conservative estimate compared to the power law and will provide a baseline for the wind speed mean and variability for this analysis. Furthermore, the log wind profile will be estimated for a hub height of 80 m (262 ft). While offshore wind turbine hub heights vary from 80 m to 160 m (525 ft), the selection of the former hub height will provide a *reference point* for the wind analysis given wind speeds increase with height (Lantz et al., 2019). The subsequent section will determine the feasibility of a wind project at the smallest scale based on the assumption that larger turbines at higher heights have access to faster winds on average (Hartman, 2020).

2.2 Wind Analysis Results – Model Data

To determine the wind speed over Lake Michigan (and Milwaukee) where observations are sparse, weather model data can be used to determine the spatiotemporal variability of the wind. The type of weather model chosen for this analysis was a reanalysis dataset. Reanalysis datasets are created by combining observations and short-range weather forecasts, determined by existing weather models. Furthermore, reanalysis datasets utilize our understanding of physical processes to provide a spatiotemporally complete and consistent dataset of meteorological variables.

Of the reanalysis models available, the European Centre for Medium-Range Weather Forecasts' (ECMWF) ERA5 Land-Hourly dataset was chosen given its high spatial (9 km) and temporal (1-hour) resolution (Sabater, 2021). This dataset was used to determine the wind speed at the hub height based on the 10m winds provided in the data. It is necessary to acknowledge that model data has some degree of uncertainty due to interpolation and parameterization of the physical processes. Therefore, this data will primarily be used to assess general patterns, rather than to make definitive conclusions about the mean wind speed. The analysis will be confined from 2010 – 2022 to match the availability of data sources, such as in-situ buoy and Automated Surface Observing System (ASOS), which will be described in section *2.4*.

Plotted in Figure 3a is the mean wind speed from 2010 – 2022 using a hub height of 80m, along with the percentage of power generation hours, hereafter referred to as power hours. As seen in Figure 3b, the model data suggests most of Lake Michigan has wind speeds sufficient to produce power for at least 90% of the twelve-year period. Right along the Milwaukee coastline, the mean wind speeds were between 6 – 7 m s^{-1} which well exceeds the cut-in speed necessary to spin the turbine and generate power. The mean wind speeds increase substantially as distance increases away from the Milwaukee coastline, suggesting a higher power potential the further east a wind project is built offshore.



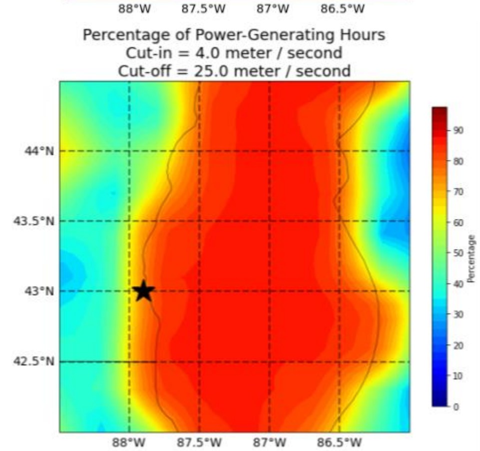


Fig 3. Plot of the 3a) mean wind speed, 3b) the percentage of power generation hours using the ERA5 Land-Hourly Dataset based on a cut-in speed of 3m/s and a cut-off of 25m/s, and 3c) percentage of power generation hours using a 4m/s cut-in speed and a 25m/s cut-off speed. The black star denotes the location of Milwaukee. Power generating hours are defined as the number of times the wind speed

On the contrary, the wind speeds are lower within the city and further west with a range of 5 – 6 m s^{-1}. Such a result is to be expected considering the lower friction over Lake Michigan compared to the city; higher friction means slower wind speeds near the surface and aloft. Plotted in Figure 3c is the same analysis but with a cut-in speed used for a moderate-sized wind turbine. The power hours are about 20% less for the spatial domain, suggesting that larger scale turbines would spin up less often. The power hours were also assessed with a higher cut-off speed, yet the power hours were essentially unchanged, meaning the cut-in threshold holds more weight within the domain.

Further, an assessment into the seasonal variation of the wind pattern was done to provide an idea of which months would provide the most/least amount of power. This was done by determining the mean wind speeds and power hours for each month from 2010-2022. The analysis showed that the winter months had significantly higher wind speeds in comparison to the summer months. A comparison of the maxima/minima is shown in Figure 4 in which the January mean wind was ~50% faster than the August mean wind for the entire domain. The impact of this seasonal discrepancy on the power hours was also significant with the August power hours being much lower, particularly along the Milwaukee coastline with power hours of around 70% and 90% for August and January, respectively. Since solar generation falls off substantially in the winter months, adding offshore wind energy with its higher winter power yield could be beneficial in maintaining sufficient energy production from renewables all year.

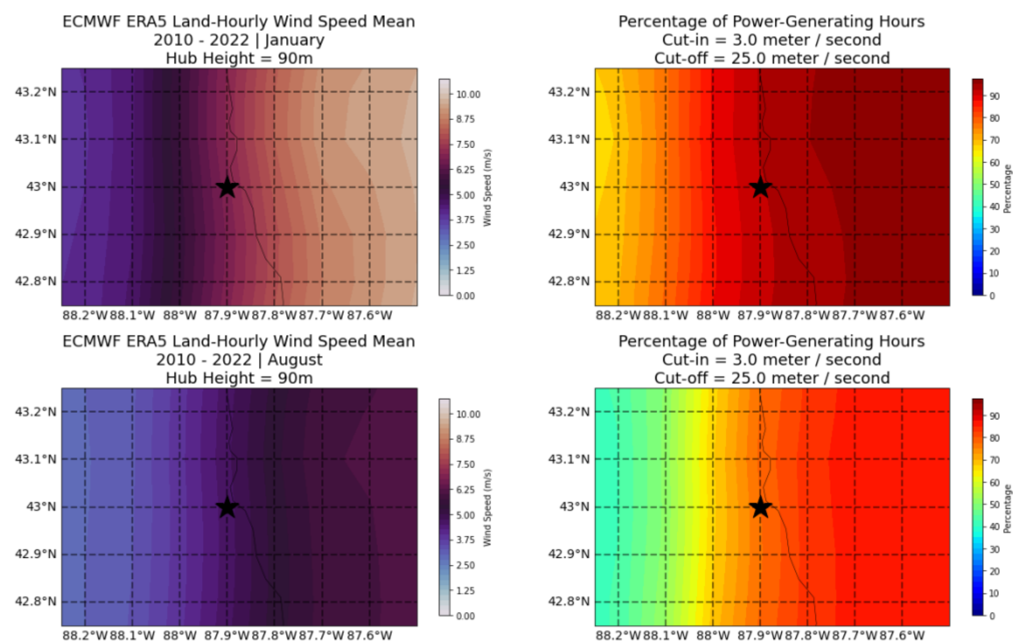


Fig 4. A comparison of the January and August mean wind speed (4a, 4c) and percentage of power generating hours (4b, 4d).

The spring and fall seasons serve as a transition between the winter and summer in terms of the mean wind. During the wintertime, the environment is more baroclinic, meaning the density and pressure gradient contours are misaligned from each other due to the interaction between polar and continental (warm) air masses. Such an environment is more favorable for the development of cyclones that lead to faster wind speeds, on average, as these cyclones progress through their life cycles. On the contrary, the baroclinicity of the environment is weaker in the summertime, thus the winds are slower on average. The spring and autumn months have *moderate* wind speeds on average in comparison to the winter/summer. As a result, the mean wind speeds in the spring are slower than the winter months & the autumn winds are faster than the summer months. Thus, the power hours in the spring/autumn are between 70 and 90% as the season transitions from the maxima/minima in mean wind speeds, respectively.

By comparing the maxima and minima mean wind speeds, it seems that the offshore wind speeds are sufficient to spin wind turbines for substantial lengths of time. However, model data needs to be taken with a grain of salt as there is a level of uncertainty. The magnitudes and gradients of the mean wind speed patterns are consistent with our understanding of wind patterns within the boundary layer (Shaw et al., 2022). However, the onshore wind speeds from the model analysis are lower than research done by organizations such as NREL. Onshore wind speeds near the Lake Michigan coastline range from 6 – 6.5m s^{-1} with locally higher winds right along the coast (WINDExchange). Such a result is to be expected considering the approach presented in this report is a *conservative* estimate, whereas an analysis done by NREL likely estimates the winds aloft using more parameters than a derived wind profile. The offshore mean wind speed presented here is consistent with prior analysis by NREL who demonstrated offshore wind feasibility. However, a more in-depth analysis into how the winds translate to power generation will be assessed in section *2.4*.

2.3 Power Generation Potential Background

The theoretical power produced by a wind turbine can be calculated with an equation using parameters of density, blade area, and the wind speed. However, these equations fail to factor in the efficiency of the wind turbine and times where the wind turbine is not spinning. Using operational wind turbines, a power curve can be developed based on measurements to determine *actual* power generated by the wind turbine (Sohoni et al., 2016). An example of a power curve is shown in Figure 5 which plots the wind speed as a function of power output. A wind turbine's power curve is dependent upon the cut-in, cut-off, and rated wind speeds and measurements taken on existing wind turbines to assess the shape of region 2 shown in Figure 5. Given there are no offshore wind systems present near Milwaukee, there is no explicit power curve for Lake Michigan. Fortunately, the power curve of a wind turbine can be modeled to determine how much wind power Lake Michigan could yield for Milwaukee.

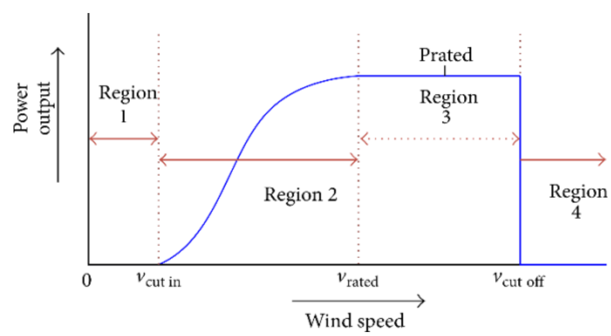


Fig 5. Typical power curve of a pitch regulated wind turbine (Sohoni et al., 2016).

There are many different types of power curves to choose from, as identified by Sohoni et al. (2016) such as linear, quadratic, cubic, binomial, and derived models. The power curve of choice was the quadratic power curve due to its relative simplicity without sacrificing the shape of region 2 in the power curve. To calculate the power output for an offshore wind project, the next decision is the parameter selection described in *2.4*. Rather than use arbitrary values, the relevant parameters were determined using existing offshore wind turbine specifications. Three different offshore wind and two onshore wind turbines will be used to develop power curves & calculate power potential based off NREL's report for their WIND Toolkit that assessed wind project potential across the United States (King et al., 2014).

To determine the potential power generation, in-situ data will be used to determine the variability in the power generation based on the type of wind turbine chosen. The first three wind turbines from Table 1 are all offshore wind turbines, listed from small scale to large scale, as described by King et al. (2014). The latter two are the general specifications of onshore wind turbines, classified into their power generation potential. For each of the turbines listed in Table 1, the total power, average power, and mean wind speed will be assessed for offshore and onshore locations using in-situ observations from ASOS and buoy data. A comparison between the wind turbines will also be performed to highlight the onshore versus offshore power potential differential, as well as variability within the respective turbine type.

Table 1. Choice of Wind Turbine for Power Generation Analysis

	Hub z	Cut-in	Rated Speed	Cut-out	Rated Power
GE 4.1M	85m	3.5m/s	14m/s	25m/s	4.1MW
Seimens 3.6M	90m	3.5m/s	12m/s	25m/s	3.6MW
Repower 6.1M	95m	3.5m/s	14.0m/s	30m/s	6.1MW
Small Onshore	80m	3.0m/s	12m/s	25m/s	2.5MW
Large Onshore	80m	4.0m/s	14m/s	30m/s	3MW

2.4 Wind & Power Analysis using In-situ Data

Near Milwaukee's coastline, there are two stations in which data is available: the Port of Milwaukee station, which is close to the main shoreline, and the Atwater buoy, which is about 1 km out. Out of the two stations, the preferential location is the Port of Milwaukee buoy given the Atwater buoy does not have data available during the wintertime. The Port of Milwaukee takes its wind observations at 7.3 m above site elevation and provides wind data every fifteen minutes to every hour based on multiple 5-second averages over the temporal domain (US Department of Commerce, 1996). This station will highlight the *minimum* wind speeds and power generation potential given the proximity of the site to the coast and the understanding that the power potential will only be greater further offshore.

To assess the power generation potential over land for comparison to the offshore potential, three ASOS stations were selected to have one coastal station, one further west into the city, and another west outside of Milwaukee. The respective stations chosen for this criterion were the Milwaukee Airport (MKE), the Lawrence-Timmerman Airport (MWC), and Watertown Municipal Airport (RYV). Each of these ASOS stations have similar surface friction given each station is at an airport that has minimal obstructions; therefore, a roughness length of 0.03 m was used to determine the hub height wind speed. The selection of these three sites will help investigate the magnitude of the gradient in the wind speed/power generation potential from west-to-east. Furthermore, the MKE and MWC stations will be used to assess the wind potential within the city of Milwaukee, whereas RYV will be used to determine the potential in a rural environment.

With the offshore and onshore sites chosen, a more substantive analysis into the wind speed mean, variability, and its relationship to the wind power potential is performed. The results of this analysis are presented in Table 2. Focusing initially on the wind speed, the west-to-east gradient in speed highlighted in the model analysis is consistent with the in-situ observational data. The wind speeds at the RYV site furthest inland experienced the slowest wind speeds on average, whereas the Port of Milwaukee had the highest average wind speed. The variability in the wind speed was similar for all the sites with standard deviations around 3m s^{-1}. Assuming most of the wind variation falls into a range of $\bar{V} \pm \sigma_V$ (wind's standard deviation) with typical cut in speeds ranging from 3 m s^{-1} to 4 m s^{-1}, there will be periods when the wind speed is not sufficient to spin the wind turbine for all the sites. This is especially true for the onshore wind turbines further inland such as MWC and RYV.

The implication of the wind speed mean and variation on the amount of power produced at each site is substantial. For the offshore wind turbines, the amount of power produced has a positive relationship with the size of the wind turbine. Larger wind turbines generally have higher hub heights and higher power ratings, thus have more available wind energy, and produce more power. Larger wind turbines have higher cut in speeds, which can reduce the total power output if the average wind speed is closer to that threshold. For the offshore location, the influence of the cut-in speed is minimal compared to the onshore environment. While all three offshore wind turbines had the same cut-in speed, the cut-in speed of 4m s^{-1} was also tested for all three offshore wind turbines. The change in the total power output was less than five percent for all offshore turbines for each year with 4 m s^{-1} cut-in speed which was determined to be insignificant.

For onshore wind turbines, the larger wind turbines produce less power than the smaller-scale wind turbines. The mean wind speeds are closer to the cut-in and cut-off speeds for both scales of onshore turbines, therefore the wind will be less than the cut-in speed more often. Combined with the higher cut-in and rated wind speed of the larger scale onshore wind turbines, the mean wind speed is simply too slow to produce as much power as the smaller-scale turbines or even the offshore wind turbines. This discrepancy is one of the primary reasons for the push towards larger and taller wind turbines (Hartman, 2022). The slower onshore winds cause the larger wind turbines to spin less often and, even when the turbine is spinning, the winds are too slow on average to reach the rated power level. Thus, we see a negative relationship between the scale of the onshore wind turbine and the amount of power produced because of the higher-friction onshore surface.

The comparison of the wind power potential of the offshore and onshore wind turbines reflects the results found from the model data; the east-to-west wind speed gradient is present in both the in-situ and model analysis. However, the results from the in-situ data analysis were significantly lower than model data results and the NREL assessment of wind potential. For reference, NREL's assessment found the offshore/onshore wind speeds were around 7 m s^{-1} (immediately along the Milwaukee coastline) and 6 m s^{-1}, respectively (NREL, 2021). This means that the in-situ data analysis presented here is about 1m s^{-1} slower at the hub height for both offshore and onshore locations. Such a result suggests the utilization of the log wind profile may have been too conservative. Furthermore, the assumption of neutral stability with the log wind profile may also have contributed to this discrepancy as the stability of the surface has consequences on the shape of the vertical wind profile. Because of this discrepancy in the wind speeds, the average power generation from Table 2, P_{avg}, is also an underestimation of the power generation potential. Knowing that the mean winds presented in Table 2 are about 1 m s^{-1} slower than the actual wind speed at the hub height, an adjusted power average (P_{adj}) is computed in Table 2 that accounts for the wind speed discrepancy. The result is a 30% increase in the average yearly power for both the offshore and onshore sites. These values for wind power are likely more realistic and should be used to assess the power generation potential of an offshore wind project.

Table 2. In-situ Wind and Power Analysis for Offshore & Onshore Wind Turbines

Location Type of Turbine	$\bar{V}_{80}$ (m/s)	σ_v (m/s)	P_{hour} (MWh)	P_{avg} (MWh)	P_{σ} (MWh)	P_{adj} (MWh)
Port of Milwaukee	5.907	3.13	-	-	-	-
GE 4.1M	-	-	0.412	3,609.8	753.43	4692.7
Siemen 3.6M	-	-	0.521	4,560.8	903.72	5929.0
Repower 6.1M	-	-	0.634	5,558.7	1,155.96	7226.3
MKE Airport	5.758	3.22	0.490	4,295.5	275.39	5584.2
(S, L)	-	-	0.346	3,032.5	217.75	3942.3
MWC Airport	4.131	3.19	0.353	3,089.5	325.04	4016.4
(S, L)	-	-	0.244	2,136.5	251.57	2777.5
RYV Airport	4.004	2.99	0.237	2,074.2	146.09	2696.5
(S, L)	-	-	0.153	1,336.9	111.80	1738.0

Table 2. List of the wind speed at an 80m hub height(V), average hourly output (P_{hour}), average yearly power (P_{avg}), adjusted power assuming a 30% increase in the mean wind speed (P_{adj}), and the standard deviation (σ) for an offshore and onshore wind turbine using the respective buoy & ASOS sites from 2010 - 2022. Onshore sites are denoted with an (S, L) where the top and bottom values of the row correspond to small (S) and large (L) wind turbine parameters, respectively.

A comparison of the wind power potential from the offshore to the onshore sites is consistent with the results presented in section *2.2*; the wind speeds are clearly the fastest near the Milwaukee coastline and slower further inland. Based on this result, it is not surprising that the Port of Milwaukee and MKE sites have a higher wind power potential, given by the higher P_{adj} presented in Table 2. Particularly for the Port of Milwaukee site, the Siemen and Repower turbine models outperform all the turbine models at the three onshore sites. Consistent with the model analysis and NREL's assessment, an offshore wind project over an onshore project is ideal for maximizing the wind power. Immediately along the coastline, a wind speed average of about 7 m s^{-1} would yield up to 5 – 7 GWh of power in a year, depending on the turbine model. The further away from the coastline the wind turbines are sited, the wind power yield is expected to be even greater.

2.5 Summary

The report by Frontier Group determined that offshore wind energy was feasible but had some limitations. The primary limitation was the fact that the Great Lakes are frozen over for part of the winter, complicating the development and siting of the turbine. However, the analysis presented in this report concludes that the offshore wind potential far exceeds onshore wind potential, and the offshore wind patterns are sufficient for significant wind power generation for Milwaukee. With mean wind speeds averaging about 7 m s^{-1} within a few kilometers of the shore, wind turbines within this range would output power 70% of the time, at a minimum. At most, a wind project off the coast of Milwaukee has the potential to generate power up to 90% of the year with the amount of power dependent upon the size of the wind turbine. The larger the wind turbine, the better it will be at utilizing the faster offshore wind potential better than the smaller turbines. Smaller offshore turbines, such as the GE 4.1M, could yield up to 5 GWh of power each year, compared to 7 GWh for the larger Repower 6.1M offshore turbine. Based on this result, a propensity towards larger wind turbines is recommended. If the city decides to develop an offshore wind project, a turbine model comparable to or better than the Repower 6.1MW turbine at a hub height of 100 m (328 ft) or greater is suggested.

Regarding the location, to optimize power generation, the ideal location for the wind project is as far away from the coast as possible. The downside is that the further from the coast the system is built, the more expensive it is to build and maintain as will be discussed in Section 6. To escape the frictional influence of the land surface, it is recommended to build a wind project at least 6 miles (10 km) away from the Milwaukee coastline to reach the 7 – 8 m s^{-1} range in the mean wind speeds shown in Figure 3. By comparison, the offshore wind leases in the Gulf of Mexico that the Department of Interior announced in 2023 are 24 – 56 nautical miles off the coast and Ohio's Icebreaker will be 8 – 10 miles offshore. Given that a turbine within 6 miles (10 km) of the shoreline could produce up to 7 GWh of power each year, a singular wind turbine placed further than 6 miles out could produce up to 9.1 GWh of power each year.

To put the amount of power generated into perspective, the power produced by the Repower turbine is compared to the existing Port of Milwaukee turbine. The Port of Milwaukee wind turbine is sited right along the Milwaukee coast at a hub height of 120 ft (36.5 m) with a rated power of 100 kW (0.10 MW). Clearly, the Port of Milwaukee turbine is much smaller in scale compared to the turbines analyzed in this report. Thus, it is not surprising that the annual power production of the Port turbine ranges from 109 – 152 MWh (Howard, 2011). Compared to the Repower 6.1MW turbine, an offshore wind turbine would produce 44 – 64 times more power than the Port turbine if both were situated in the same location. Considering the Repower turbine rated power is 61 times larger than the Port turbine and is ~50 m (164ft) taller than the Port turbine, such a discrepancy is not unreasonable as the Repower turbine can produce and has access to substantially more wind energy. It's apparent an offshore wind project has the potential to generate substantially more power than the existing turbine within the City of Milwaukee. The implementation of more than one turbine is also recommended considering the substantial wind power potential of a singular turbine. Purely from the perspective of the presented wind analysis, there is a large region of untapped wind energy present off the coast that could be utilized by the city to smooth out annual renewable energy production when paired with solar.

Section 3: Review of Proposed and Current Offshore Great Lake Wind Projects

3.1 Offshore Wind Projects in the Great Lakes

In this section, we review proposed offshore wind projects in Michigan, Ohio, New York, and Chicago. Average wind speeds in the Great Lakes are considered very good for wind energy production and are on par with mid-Atlantic regions (NYSERDA, 2022a). Lake Eire, due to its shallow nature, is best suited for fixed bottom structures while Lake Ontario is much deeper, and floating structures are considered the best option (NYSERDA, 2022a). Both lakes freeze and create waves that need to be taken into consideration for design and vessel types (NYSERDA, 2022a).

Most vessels used in offshore wind construction are too wide to fit through the locks and canals into the Great Lakes; restricting the size of the turbine and complicating installation. When New York analyzed this, it concluded this would result in higher costs and inefficiencies and lead to more in-depth investigation on substructure types, vessel alternatives, and port requirements (NYSERDA, 2022a). It further suggested major port upgrades would be required to support the installation and maintenance.

However, we note that Fincantieri Shipbuilding in Sturgeon Bay, Wisconsin recently announced it will be building offshore wind service operation vessels (Schuler, 2023). Thus, offshore wind in the Great Lakes may necessitate the creation of Great Lakes-based industries and jobs to supply the industry rather than importing through the locks and canals. Unlike coal, oil, and natural gas, all of which must be imported into Wisconsin, offshore wind could not only be a home-grown energy source but the supply chain that supports it could be locally sourced.

3.4 Michigan

From 2012 through 2013, Grand Valley State University led the Lake Michigan Offshore Wind Feasibility Assessment, which was the first comprehensive offshore wind assessment over Lake Michigan intended to evaluate the feasibility, economic viability, and environmental impacts of an offshore wind project (Grand Valley State University, 2014). The study found that there is significant potential for wind energy generation in Lake Michigan, particularly towards the middle of the lake and farther north. The wind in this area was generally considered to have high wind speeds and relatively constant wind direction. Researchers determined that wind turbines only need to be 100 meters off the water surface for optimal wind energy. Under most conditions, the noise impact of a wind turbine 10 km from shore would be less than 40 dB(A). The background sound level at the beach was 47.7 dB(A), suggesting that wind turbines will not be audible from the beach above the background noise. They concluded that floating platform structures for the wind turbines were most likely to be deployed (Grand Valley State University, 2014).

During the deployment of the wind assessment buoy approximately 35 miles from either shore, using bat echolocation calls from one half hour before sunset until one half hour after sunrise, bat activity was assessed. These calls indicated that bat activity over the lake was steady throughout the spring, summer, and fall months, but they were found to be most active from late June through mid-September. Bird activity was monitored through bird calls during daylight hours with the majority of approximately 97% being identified as gulls. All non-gull calls were recorded by early June. After June bird activity was low, but constant (Grand Valley State University, 2014).

3.2 Ohio – Icebreaker

The Icebreaker Wind project is a proposed offshore wind energy pilot project of 4.2 acres off the coast of Cleveland, Ohio to test the feasibility of offshore wind in Lake Erie (In re Application of Icebreaker Windpower, Inc., 2022). This project has been approved by Ohio and survived a legal challenge through the Ohio Supreme Court in 2022. It is poised to be the first offshore wind project to be built in any of the Great Lakes, so can be viewed as a model for creating an approvable offshore wind project for the Great Lakes.

Icebreaker filed an application with the Ohio Power Sitting Board for a certificate to build a six-turbine offshore wind project on February 1, 2017. The board approved the application but was appealed on the issues of whether Icebreaker sufficiently demonstrated its effect of probable environmental impact on birds and bats and the claims that the project violates the public trust doctrine (In re Application of Icebreaker Windpower, Inc, n.d). The case was taken to the Ohio Supreme Court, and on August 10, 2022 the court affirmed the board's decision to allow the project to go forward (In re Application of Icebreaker Windpower, Inc, n.d.).

The developer of the project is the non-profit Lake Erie Energy Development Corporation (LEEDCo), which was founded in 2009 to help promote the development of offshore wind energy in Lake Erie and eventually stimulate other Great Lake projects (Pacific Northwest National Laboratory, n.d.). In 2017, LEEDCo assigned their lakebed lease from the state of Ohio to Icebreaker Windpower Inc. (In re Application of Icebreaker Windpower, Inc.). There will be six wind turbines located 8 to 10 miles off the shore of Cleveland with each being constructed using mono-bucket foundations that uses suction technology to attach to the lakebed instead of foundations that would require pile driving (U.S. Department of Energy, n.d.). Icebreaker's estimated total electric generation capacity is 20.7 megawatts (MW) for all six turbines (3.45 MW each), around enough to power 7,000 homes per year (Wagner, n.d.). The electricity would then be sold back to the grid.

The turbine foundations require no dredging, clearing, or drilling, with only the top 0.3 meters of the lakebed at risk of being disturbed through suction; resulting in a minimal localized suspension of sediment near each turbine (U.S. Department of Energy et al., 2018). The jack-up vessel used to install the turbines, as well as the vessel anchoring, could result in minor, localized, and short-term suspension of lakebed sediments when the jack-up legs are moved and would have a negligible impact on water quality (U.S. Department of Energy et al, 2018). There would be a temporary increase in total suspended solids during the construction as well as the installation of the submerged electric cables (U.S. Department of Energy et al., 2018). Contaminants like metals, hydrocarbons, and PCBs from Lake Erie's sediments pose a low potential for toxicity (U.S. Department of Energy et al 2018). The proposed turbines are approximately 4.2 miles from the nearest potable water intake for Ohio (U.S. Department of Energy et al, 2018). There will be an approximately 2.8-mile-long inter-array cable connecting the turbines and another 9-mile-long export cable connecting the project to the Project Substation in Cleveland, Ohio. The export cable will be buried approximately 1 foot in water depths of 60 to no shallower than 30 feet and buried at least 12 feet below the breakwater and the authorized dredge depth of the Outer Harbor Navigation Channel (U.S. Department of Energy et al., 2018).

According to the Final Environmental Assessment of LEEDCo's Project Icebreaker, the long-term impact on fish species from operations and maintenance are minor. These impacts are a loss of 0.3 acres of substrate habitat from the turbine foundations as well as noise impacts from high wind speeds at short distances from the foundations (U.S. Department of Energy et al., 2018).

Bat collisions are most frequent at night when wind speeds are lower and during the late summer. So, to address this, LEEDCo agreed to stop the turbine blades at night from March 1st through November 1st and can later seek to modify this condition once it has collected and submitted monitoring information to the Ohio Power Sitting Board (OPSB, 2020). Instead of non-flashing lights, LEEDCo has committed to using red flashing obstruction lights, which should decrease avian fatalities. Hooded lighting, not facing the sky, and smart lighting are to be used where it is consistent with safety guidance (U.S. Department of Energy et al, 2018).

The United States Army Corps of Engineers ensures that LEEDCo's purpose and need statement meet the following: serve the need of electric utilities and their consumers; help reduce air pollution in an area that historically has been in non-attainment for 2.5-micron particulate matter, lead, and ozone; reduce greenhouse gas emissions; and create local jobs and spur economic development. The agency is also involved in ensuring that LEEDCo follows the EPA's guidelines for the Specification of Disposal Sites for Dredged or Fill Material (U.S. Department of Energy et al., 2018). The agency has regulatory and permitting authority under Section 10 of the Rivers and Harbors Act of 1899 and Section 404 of the Clean Water Act. Section 10 concerns itself with the authorization of structure of work in affecting navigable waters of the U.S. Section 404 regulates discharges of dredged or fill material into waters of the U.S. The project requires Section 10 and Section 404 permits and has been granted both (U.S. Department of Energy et al., 2018). The United States Coast Guard, because of the Ports and Waterways Safety Act of 1972, has regulatory responsibilities to conduct studies to ensure safe access routes for vessel traffic in U.S. waters. The agency assisted and provided recommendations to the Department of Energy and the United States Army Corps of Engineers in their permitting approvals (U.S. Department of Energy et al., 2018).

The Icebreaker Project in Ohio will be a model for how Great Lake states in the future will create approvable offshore wind projects. The Ohio Supreme Court affirmed the Ohio Power Sitting Board's decision to approve the Icebreaker Demonstration Project after it sufficiently demonstrated it would not have a significant adverse environmental impact or violate the public trust doctrine.

3.3 New York

The New York State Energy Research and Development Authority (NYSERDA) engaged three contractors to conduct a Great Lakes Wind Feasibility Study focused on Lake Eire and Lake Ontario with the intentions of gathering data, synthesizing information, technical analysis, and develop recommendations for New York to achieve their Clean Energy Standard (NYSERDA, 2022).

Their environmental analysis states that generally waterbirds spend most of their time within 10 miles of shore and that shorebirds rarely travel more than 100 meters from shore. Gulls and terns can forage over open water, but typically nearshore. Also stating that it is uncertain how many birds travel over open water, but migratory birds tend to migrate around the lakes rather than over. Similar details are given about bats in that they are thought to move across lakes and nest using islands and peninsulas, so it is assumed that important habitats for birds constitute important habitats for bats as well. Mussel species in both lakes are said to potentially use turbine structures to spread. Not enough is known about specific distribution and use patters for fish in the Environmental Study Area only stating that fish are generally distributed according to habitat preference but move widely between these zones and that most fish spawn in nearshore areas making those areas the most vulnerable to adverse impacts. Terrestrial habitats will be potentially affected with activities like cable landing and port development (NYSERDA, 2022).

The study states that a fixed bottom substructure would be best for the shallower waters of Lake Eire (less than 60 meters) and that floating structures would be more appropriate for the deeper waters present in Lake Ontario. The Saint Lawrence Seaway and the Welland Canal would complicate installation logistics as most offshore wind vessels need to construct and maintain the projects are larger than what is allowed to pass through, leading to higher costs and inefficiencies (NYSERDA, 2022).

Ultimately the NYSERDA White Paper concluded that, based on the analysis, “Great Lakes Wind currently does not offer a unique, critical, or cost-effective contribution toward the achievement of New York State’s Climate Act goals beyond what existing, more cost-competitive programs are currently expected to deliver”. They also stated that the study did not find any insurmountable barriers to Great Lake Wind development but found many challenges when compared to open ocean development. Because of this, NYSERDA expressed the desire for a regional upscaling and a supply chain with other Great Lake states to synergize wind energy development and lower costs (NYSERDA, 2022).

3.5 Chicago

The proposed Rust Belt to Green Belt Pilot Program Act in Illinois would create a fund in the state treasury and amend the State Finance Act. The funds would be used by the Department of Commerce and Economic Opportunity to encourage and facilitate the employment of underrepresented communities in Chicago. The Act would amend the Illinois Power Agency Act concerning the procurement of renewable energy credits, delivered annually for at least 20 years from one utility-scale offshore wind project and limit the net increase for all eligible retail customers to no more than 4.25% of the amount paid per kilowatt-hour to customers during May 31, 2009. The proposed law gives the agency 360 days after the effective date of the Act to conduct at least one new utility-scale offshore wind procurement. It is projected that over 1000 jobs will be created in the first 4 years and another 50-100 for long-term maintenance. There is no site location, but the senators leading the effort intend to locate an offshore wind project in Lake Michigan off the coast of the Southeast side of Chicago, where communities have experienced manufacturing and industrial pollution. If enacted, the Illinois Power Agency will obtain 700,000 renewable energy credits (as of 2021 ranging from $10 to $400 depending on the market) every year for 20 years from one utility-scale offshore wind project. Funding will come from the federal government that is currently available for the port infrastructure needed to support offshore wind. The wind developer who builds the wind project pilot will fund the costs of building and maintenance. The project will be built 10 to 15 miles offshore and will appear very faintly from land. As of April 2023, the bill is being amended and debated by the Illinois House of Representatives (S.B. 0193, 2023).

3.6 Summary

Wind energy potential in the Great Lakes is adequate for wind energy production. Ohio's Icebreaker project has been approved by the Ohio Supreme Court, which upheld the Ohio Power Sitting Board's decision that the project does not violate the public trust doctrine and there is not enough evidence provided to demonstrate an adverse environmental effect on birds and bats. This set a viable pathway and a precedent for other states to pursue offshore wind energy generation in the Great Lakes. There could be negative environmental impacts primarily through the construction of the turbines, but they should be marginal during operation with proper enforcement of proposed environmental mitigation techniques. Though the NYSERDA White Paper concluded that New York should not immediately pursue offshore wind in the Great Lakes, it did state that there are no insurmountable barriers to it and that there should be a regional upscaling of infrastructure to support potential future projects. The Rust Belt to Green Belt Pilot Program Act making its way through the Illinois House of Representatives shows positive movement towards offshore wind generation in Lake Michigan and will be useful to observe its development over time.

Section 4: Environmental Analysis

4.1 Introduction

Each aquatic environment has a unique biological composition that performs a balancing act in reaction to human interference. Lake Michigan's offshore environment is no exception. Over the centuries, the lake and its inhabitants have endured a barrage of changes brought on by anthropogenic sources ranging from invasive species and climate change to pollutants. In looking forward to a potential offshore wind project, the City may want to ensure that the construction and ongoing operation of the turbines would not have significant detrimental effects on the already delicate ecological structure of Lake Michigan.

As discussed in Section 1, NEPA and WEPA would require an environmental analysis of any proposed offshore wind project. For a project off the coast from Milwaukee, impacts on fish, bird, and bat populations as well as wind turbine aesthetics, impacts on navigation, and potential mitigation strategies will need to be considered in the analysis. As seen in Section 3, this type of analysis was conducted for the Icebreaker project and these topics were discussed in multiple feasibility studies for proposed projects discussed below.

4.2 Environmental Considerations of Past and Current Projects

The Icebreaker Project's Environmental Assessment (EA), completed in 2018, discusses the effects of a 6-turbine wind project on Lake Erie's environment (U.S. Department of Energy et al., 2018). While the study is based on Lake Erie, their findings are relevant to this proposed project as Icebreaker is the only offshore wind project on the Great Lakes that has completed an EA and survived legal challenges. Their EA dove into each potential impact, alternative, and no action alternative of environmental topics.

In 2022, a feasibility study was published by the State of New York regarding the possibility of installing offshore wind turbines in Lakes Erie and Ontario. They determined the optimal site for turbine placement by considering the following: wind speed, distance from shore, water depth, lakebed slope, ice cover, and sediment depth. The study also compiled impacts and mitigation efforts regarding biological and environmental processes (NYSERDA, 2022). The second feasibility study considered was published in 2014 by Grand Valley State University. Among other topics, this study observed offshore bird and bat activity in Lake Michigan and could be used as a guide for further study on the Western side of Lake Michigan (Grand Valley State University, 2014).

Additionally, the wind turbine built on the Port of Milwaukee, while not offshore, had similar environmental concerns (ECO, 2011). The scale and location of the turbine will change and affect wildlife differently, however the proximity of the turbine to Lake Michigan as well as the relatively recent time frame also makes this a good source of information.

In the interest of learning from past projects, another important aspect of this work would be to prevent the spread of misinformation by making environmental concerns (and lack thereof) clear to the public from the start. Scientists and local officials on the East Coast are struggling to contain the erroneous idea that offshore wind turbines are causing a large-scale whale die off (Wilensky & Radde, 2023). Ensuring the public of this project's safety early in the process will be essential to its success.

4.3 Impacts on Fish Populations

An EA for an offshore wind project near Milwaukee would identify fish populations in Lake Michigan as an issue of concern. Many native fish species like the Lake Sturgeon are already under strain due to invasive species such as the round goby and the Sea Lamprey as well as a rapidly changing habitat (Campbell, 2012). Continuous noise during construction, electromagnetic fields surrounding underwater cables, and turbidity from installation are the three main effects of concern regarding the interaction between fish and offshore wind turbines by officials reporting to the Great Lakes Wind Cooperative (Great Lakes Wind Collaborative, 2013).

According to the Great Lakes Wind Cooperative, continuous noise during operation has not been found to be largely impactful on fish populations; however, construction noise is significantly louder and has been found to potentially interrupt fish spawning and nursery activity. Lake Michigan's endangered fish species including Lake Sturgeon and American Eel spawn from late April to mid-July (DNR, 2014). Lake trout have been found to spawn as far out as the Mid-Lake Reef Complex (MLRC), a reef situated 20 miles west of Milwaukee and over 40m (131ft) below the surface (Janssen et al., 2006). Large, encapsulated bubbles could potentially absorb the sound and reduce the negative effects on fish (Great Lakes Wind Cooperative, 2013). Electromagnetic fields surrounding underwater cables can disorient fish and affect their migration and behavior patterns. Two Great Lakes species of concern, the lake sturgeon and American eel, have been found to be sensitive to electromagnetic fields (Great Lakes Wind Cooperative, 2013). Project Icebreaker's EA found the electromagnetic fields to be negligent with proper insulation of the underwater cables (U.S. Department of Energy, 2018).

On the other hand, there is evidence that the bases of offshore wind turbines can create habitats for aquatic life (Hall et al., 2020). Turbines that are anchored can provide habitats for spawning and increase native fish populations; however, the decommissioning of a turbine at the end of its life would destroy those habitats if the base was removed. Considering not only the effects of construction and operation but also those of decommissioning is important for a project of this magnitude.

Turbidity increases when sediment is disturbed from the bottom of the lakebed. Construction of turbines can vastly increase the turbidity of the water which decreases visibility and the ability of sunlight to reach through the water column. The lack of sunlight can affect aquatic biological and chemical processes including disturbing fish spawning habits (Great Lakes Wind Collaborative, 2013). As discussed in Section 3, NYSERDA observed that Lake Erie, a shallow lake, would be ideal for anchored turbines while Lake Ontario, a much deeper lake, would require floating turbines (NYSERDA, 2022). At 6 miles from shore, which was the distance discussed above in the wind analysis, Lake Michigan's depth would be closer to that of Lake Erie which plans to use an anchored turbine design. However, these issues can be mitigated if the turbine construction employs mono-bucket foundation with suction technology instead of foundations that would require dredging, following the Icebreaker Project model as outlined in Section 3.2.

4.4 Impacts on Bird Populations

Lake Michigan is home to a variety of native birds year-round and a temporary home to many migratory birds. The primary concern of the interaction between wind turbines and birds is the potential for collision. The EA for Project Icebreaker claims that avian fatalities can be significantly lowered by using flashing lights (U.S. Department of Energy, 2018). By analyzing flight patterns and tendencies of the bird species found in and over Lake Michigan, one can find a location for the turbines that minimizes conflicts with birds.

The New York Feasibility Study claims that most migratory birds tend to avoid open water and instead, choose to fly around large lakes. They acknowledge that, of the species that do fly over water, little is known about what paths they take. However, migratory birds are known to use islands and peninsulas as resting places while flying over large bodies of water. Waterbirds tend to forage up to 10 miles offshore (NYSERDA, 2022). As discussed in Section 2, the further the turbine is offshore, the higher the wind power and energy collection potential with the highest being at least 10-20km or 6.2-12.4mi offshore. This range provides sites for the turbine outside of the foraging zone for waterbirds and would only affect the small portion of migratory birds choosing to fly overwater.

Migratory and non-migratory birds have vastly different vertical distributions to their flight paths. Although flight paths vary greatly, migratory birds tend to fly at altitudes well above 200 ft while non-migratory birds tend to fly well below that (ECO, 2010). This distribution implies that the ideal height for offshore turbines would be less than 200 ft. However, as stated in Section 2, the minimum height for energy efficient offshore turbines is 100m (approximately 328ft) to the rotor and 163m (about 535ft) to the tip of the blade. In addition, studies have shown that most bird fatalities occur due to collisions with other manmade structures like buildings and windows. Only 0.1-0.2% of avian fatalities result from collisions with wind turbines (ECO, 2010).

4.5 Impacts on Bat Populations

Bats can be negatively affected by wind turbines both through collision and depressurization also known as barotraumas (Gehring et al., 2011). Many bat populations in the US are already dwindling due to habitat loss and the deadly disease, white-nose syndrome. There are mitigation efforts being made in other wind turbine projects that attempt to prevent harm to bats and could be applied to this project (Bats and Wind Energy Cooperative).

Collision with turbine blades can cause mortality through extreme physical injury but according to Gehring et al., up to half of the bat fatalities showed no obvious physical injury. These mortalities were caused by acute pulmonary hemorrhage due to barotrauma. When the turbines spin quickly, they create a zone of low pressure which the bats can be sucked into and subsequently, suffer fatal lung damage.

To ensure bat populations are not significantly impacted, the turbines should be placed outside of bats' common migration patterns. Using the ideal location for wind power generation identified above at 6 miles (10 km) offshore will minimize harm. According to Gehring et al., on the eastern shoreline of Lake Michigan, bat migration patterns were not found to significantly overlap with the Rotor Swept Area (RSA) of wind turbine placement optimized for power generation.

Curtailment is another mitigation strategy which involves reducing the speed at which blades spin during times of peak bat activity. Bats tend to be most active in late summer during nights when wind speeds are low (National Wind Coordinating Collaborative, 2010). Curtailment does result in a loss of power generation. Project Icebreaker's solution is to "feather" or adjust the pitch of the turbine blades during that late summer timeframe. The third option for mitigation is ultrasonic deterrents. Devices are attached to turbines which emit high-frequency sound to disrupt echolocation and discourage bats from approaching turbines. These frequencies are above the range of human hearing (Bats and Wind Energy Cooperative, 2021).

4.6 Aesthetics

Project Icebreaker's EA addresses the environmental impacts related to aesthetics and visual resources. The visual concerns related to construction and maintenance would be short term and mild. The visual impacts of operation would be semi-permanent fixed turbine structures near the horizon line. They would be equipped with warning lights attached to the hubs. Project Icebreaker's EA takes into account the overall aesthetic character of the area and found that the wind project's impact would be insignificant to appreciable.

4.7 Navigation

Lake Michigan boasts many forms of marine traffic including ferries, shipping vessels, research vessels, recreational vessels, sailing regattas and more. The Lake Express, a daily car ferry, operates between Milwaukee, Wisconsin and Muskegon, Michigan. The route begins in Bay View, situated in south Milwaukee and proceeds in a straight line west and slightly north (Lake Express, 2023). The proposed location for the turbines should be slightly north of the ferry route although close enough to require discussions with the ferry company.

As discussed in the Icebreaker EA, large shipping vessels primarily follow shipping lanes (U.S. Department of Energy, 2018). The turbine placement should be located outside of shipping lanes to avoid potential interference with shipping vessels. Recreational vessels will be able to reach the turbines, but each turbine should be placed far enough apart to allow recreational vessels to pass between if necessary. The U.S. Department of Energy found there would be minimal to no impact to communication systems used by large vessels and the US Coast Guard (U.S. Department of Energy, 2018).

4.8 Summary

Offshore wind energy generation has varied impacts on the environment. However, there is an ever-expanding list of mitigation efforts that can be enacted to reduce these potential impacts. Ensuring that the placement of each turbine does not overlap with fish hatcheries, bird migration and foraging flight patterns, or bat hunting patterns, decreases the potential for population-level impacts and may require further study on the western side of Lake Michigan. It will also be important to place the turbines outside of shipping lanes and ferry routes to avoid impacts to navigation. Timing is also a consideration in wind energy production; turbine construction should not occur during fish spawning season (late April-July), nor should turbines be active during peak bat activity (overnight, late summer, low-wind) without the use of other mitigation tactics like curtailment.

Section 5: Funding Options

5.1 Introduction

This section covers the different possible funding options for offshore wind projects in Great Lakes. This is done by examining grants, loans, and credits offered through the Inflation Reduction Act and the Department of Transportation's Maritime Administration. The range of recipients for these investments will include stakeholders, manufacturers, developers, and port authorities. An examination of ocean bed leasing and the lakebed lease for Icebreaker will also be discussed.

5.2 Inflation Reduction Act

Section 50153 of the Inflation Reduction Act appropriates $100 million, available until September 30, 2031, for convening stakeholders and conducting analysis related to interregional transmission development and development of transmission for offshore wind energy (GovTrack.us, 2023). The planning, modeling, and analysis include topics such as clean energy integration; effects of climate change on the reliability and resilience of the grid; effect of increased electrification on the grid; energy storage opportunities; economic development opportunities; and a planned national transmission grid network to optimize the interconnection of offshore wind (GovTrack.us, 2023).

The Advanced Technology Vehicle Manufacturing Loan Program provides loans to support the manufacture (reequipping, expanding, or establishing a manufacturing facility) of eligible advanced technology vehicles and components including offshore wind vessels, but cannot exceed 80% of project costs. The vehicles must emit low or zero exhaust emissions of greenhouse gases. There is a funding amount of $3 billion available through September 30, 2028 (GovTrack.us, 2023). Further, $10 billion in investment credit could be available for these manufacturers if their project either re-equips, expands, or establishes an industrial or manufacturing facility for the production or recycling of clean energy equipment and vehicles or re-equips an industrial or manufacturing facility with equipment designed to reduce greenhouse gas emissions by at least 20% (GovTrack.us, 2023).

The Energy Investment Tax Credit is a federal tax provision supporting offshore wind providing a 30% tax credit that does not phase out for projects beginning construction before January 1, 2026 (GovTrack.us, 2023). There is also a tax credit of 2.6 cents/kWh for electricity generated through wind (United States Environmental Protection Agency, 2023). Section 13502 of the IRA provides a 10% tax credit on the sales price for offshore wind vessels. The credit is a function of the type of component and the total rated capacity of the project for other offshore wind components (blades, towers, platforms) (GovTrack.us, 2023).

5.3 Department of Transportation Maritime Administration

The Department of Transportation Maritime Administration announced that it is designating offshore wind vessels as Vessels of National Interest for support through the Federal Ship Financing Program. This will give these applications priority for review and funding, will assist U.S. shipyards in modernizing their facilities to be able to build and retrofit vessels, and assist shipowners with obtaining domestically produced new vessels (The White House, 2022).

The Department of Transportation Maritime Administration announced $230 million for port authorities to invest in port and intermodal infrastructure-related projects through the Port Infrastructure Development Program with a Federal cost-share not to exceed eighty percent. These grants will support projects to strengthen and modernize port infrastructure as well as shore-side wind energy projects such as storage areas, laydown areas, and socking of wind energy vessels to load and move items to offshore wind systems (The White House, 2021) Since Milwaukee is home to an important port, it could benefit from this program.

The Department of Energy's Loan Programs Office offered $3 billion in funding to facilitate access to the offshore wind industry through the Innovative Energy Loan Guarantee Program. The Loan Programs Office wants to partner with offshore wind and transmission developers, suppliers, and other financing patterns (The White House, 2021)

5.4 Lakebed Leasing

Between 2012 and 2022 offshore wind lease prices have gone up significantly off the Atlantic coast hovering around a few thousand dollars per km^2 to now $700,000 up to $2.6 million depending on the site. Factors such as lower wind speed, limited port, supply chain, and grid infrastructure, and hurricane risk. Factors that have been driving up the prices include a scarcity of new lease areas and more competition from new offshore wind companies entering the market (Musial et al., 2022). Revenues for federal leasing of offshore ocean beds for wind go to the federal treasury (United States Department of the Interior, n.d.).

Revenues for leasing offshore lakebeds in the Great Lakes, by contrast, would go to the state issuing the lease. The single lease that exists shows that Ohio's lease terms for the Icebreaker project are quite low compared to some of the recent federal leases. The Ohio Department of Natural Resources will manage the leasing of the submerged lands for the Icebreaker project. Lease payments are estimated to be approximately $8,000 per year for the submerged lands lease and another $60,000 per year for a docking location in the Port of Cleveland. The estimated payments in lieu of taxes are between $124,000 and $186,000 per year (Staff Report of Investigation, 2018). This is a significant area the state of Wisconsin would need to review and establish policy in order to secure lease terms that are in the public interest.

5.5 Summary

There is significant funding through these programs for manufacturers, developers, and port authorities to begin investing in offshore wind projects in the Great Lakes. There are time limits and a set amount of funding in place for many of these investments which does limit the amount of time states have to begin these projects. The Advanced Technology Vehicle Manufacturing Loan Program lasts only until September 30, 2028, and the Inflation Reduction Act's funds of $100 million available for convening stakeholders and conducting analysis related to interregional transmission development and development of transmission for offshore wind energy until September 30, 2031. Leasing lakebeds in the Great Lakes has been shown through Ohio's lease to Icebreaker Windpower Inc. to be a viable method for states to generate revenue, but Wisconsin should thoroughly evaluate federal offshore lease terms to set an appropriate price that promotes the public interest.

Section 6: Cost Benefit Analysis

6.1 Introduction

Wisconsin, Milwaukee, and energy utilities have established climate goals to reduce carbon emissions. Milwaukee's goal is a 45% reduction of community-wide net greenhouse gas emissions by 2030 (City of Milwaukee, 2022). In 2019, Governor Evers signed Executive Order #38 pledging the state of Wisconsin to achieve 100% carbon-free electricity consumption by 2050 to mitigate climate change risks. The order also includes requisite for fostering renewable energy and energy efficiency across the state and marks adherence to the carbon reduction goals of the 2015 Paris Climate Accord.

In March 2023 the PSCW approved the purchase of the Koshkonong Solar Energy Center by WE energies. The Koshkonong Solar Energy Center is projected to be built in Dane County and features 300 MW of solar energy generation capable of powering an estimated 90,000 homes. This move was a step in achieving an investment goal by Wisconsin Energy Group of $5.4 billion dollars for renewable energy projects in Wisconsin and provides residents an estimated $2 billion in savings over the next 20 years. Project will begin construction in 2023 to be complete by the end of 2025.

A variety of state and federal policies are encouraging the addition of renewable energy sources. The PSCW works to ensure that adequate and reasonably priced service is provided to utility customers. PSCW also governs a renewable resource and energy efficiency program called Focus on Energy (Focus) for the state of Wisconsin under Act 141. Before any utility can implement rate changes or build large-scale power plants and major transmission lines, approval through PSCW is required. Approval can be acquired by obtaining either a construction authorization or a certificate of public convenience. To obtain either, the project must meet economic benefit requirements and demonstrate a no-action alternative (Public Service Commission Report, 2023). In this section, we will analyze the costs and benefits of using offshore wind in Lake Michigan to meet state and local goals for renewable energy.

6.2 Comparative Studies

The Focus program demonstrated high cost-effectiveness in their 2021 Public Service Commission Report, which showed a cost-benefit ratio of 1.48 for gross lifecycle renewable energy impacts. The program boasts high cost-effectiveness in achieving economic and environmental benefits reaching $4.84 worth of benefits to $1.00 spent. This includes prevention of 4,550 tons of sulfur dioxide, 3,408 tons of nitrogen oxides, and 7,323,422 tons of carbon dioxide (Energy Efficiency and Renewable Resource Program Activities in Wisconsin, n.d.)

The economic impact of the Icebreaker project estimated the creation of 500 jobs spanning maintenance, planning and administration, and supporting industries such as construction, machinery, manufacturing, fabricated metal manufacturing, water transportation, electrical, plastics production, and primary metal manufacturing.

The Energy Policy Act of 2005, per 42 USC 16231(a)(1), directs the Department of Energy to conduct programs of renewable energy research, development, demonstration, and commercial application (Parke et al., 2018). The agency issued the U.S. Offshore Wind: Advanced Technology Demonstration Projects Funding Opportunity Announcement to financially support the Icebreaker Demonstration (Parke et al., 2018). LEEDCo's Icebreaker project has received nearly $13.7 million in funding from the Department of Energy and has $37 million left on the federal grant which will be used for construction (U.S. Department of Energy, n.d.). The project in total is projected to cost $173 million to develop; with Fred Olson Renewables likely to invest a large part of that. Because of the litigation surrounding the project, Fred Olson Renewables has wavered its commitment but has not dropped out (Krouse, 2022).

6.3 Cost Considerations

One of the most controversial cost considerations is shoreline aesthetic among the public as some consider wind turbines a visual nuisance. The Icebreaker turbines will be 10-12 miles from shore, therefore visibility from the shoreline would be a low but long-term impact. The Icebreaker visual impact assessment suggested that the selected turbines would not present a significant contrast in terms of line, form, color, or existing land use (Cultural Resources Effects Analysis, 2017).

Initial cost of offshore turbine installation is among the top limiting factors as the cost for offshore wind compared to onshore or conventional electricity production is greater by a factor of 2-3. For a single 3 MW turbine in shallow water and electrical connection to the grid in shallow water, the rate of return on initial capital investment was estimated at 11.85% according to Fingersh et al. Capacity was assumed to operate at 38% resulting in predicted total costs to be $95/MWh. Compared to onshore and conventional methods for generating electricity, this model was consistent with other cost predictions as it demonstrated that cost of offshore wind was twice as much as onshore and conventional. Cost estimates of offshore wind by Snyder et al., 2009, demonstrated that the turbine itself 60% of the total cost, followed by installation at 20% of total cost, and operation / maintenance at 20% of total cost. Initial costs of offshore wind implementation are in decline and the supply chain can offer a strong job market (Southeastern Wind Coalition, n.d.).

6.4 Benefit Considerations

The benefits of offshore wind may justify high initial expenditure. Wind power has low carbon emissions throughout its operational lifespan and reports negligible mercury, nitrous oxide, and sulfur oxide emissions. Because turbines do not use fuel, generation of electricity by means of offshore wind is immune from the price volatility that is associated with fossil fuel generated electricity. Offshore winds in Lake Michigan are stronger compared to onshore alternatives therefore offshore wind turbines can operate predictably and at their mechanical capacity for longer. Additionally, wind power generation is maximized during the winter months and at the same time solar power generation is minimal due to the low angle of incoming solar radiation. Operationally, offshore wind carries a lower cost of operation compared to electricity generated from fossil fuels although installation costs will be the greatest (Snyder, 2009).

6.5 Challenges of Cost Benefit Estimations

Challenges in estimating a true cost-benefit analysis at a feasibility stage reside in the novelty of offshore wind as a form of renewable energy production. Empirical data on costs associated with offshore wind is sparse because there is a limited amount of active offshore wind systems in the Great Lakes. Research and development for engineering effective freshwater offshore wind generated energy is still young and current costs fluctuate at a rate that is not parallel with publications. Further, electricity cost trends are volatile for fossil-fuel derived energy as small reductions in energy available or price changes can cause national economic disruptions (IEA, 2021).

6.6 Additional Considerations

There are additional considerations to keep in mind which depend on local and federal politics. Job markets will include ground break and development, operation and maintenance of turbines and grid. Nationally, offshore wind installation is estimated to generate $100 billion in revenue to supply chain industries, forecasted for U.S. offshore wind power. Transmission planning will need to take careful consideration. Location should be strategic and requires negotiation across desired energy production, seasonality, cost of grid connection, maintenance cost, and societal implications. Desired energy production is an element to keep in mind. According to WE energies, the average month energy use is 660 kWh per residential customer. According to Ohio State University, the Icebreaker project estimated that the 6 turbines could power 10% of homes in Cleveland, which provides a large energy potential for a small-scale wind project.

Winter months are best for wind speed potential but create challenges due to ice cover. Technologies are available, such as ice skirts, that can be installed for reducing the impact of harsh winter conditions. Closer to the shore will be exposed to higher ice coverage and further from the shore will be less ice but access could be restricted. Summer months will have a lower output creating inconsistent supply over the year. Seasonal inconsistencies will require additional energy sources and energy storage because of seasonally distinct power generation capacities.

Geomorphology of lakebed will dictate the foundation options. Bedrock of the area of interest is near the Mid-Lake Reef Complex of Lake Michigan, which is situated approximately 20 miles east of Milwaukee’s shoreline (Menza, 2019). It is characterized by a flat sheet of limestone. Post-glacial sediments are thin suggesting that strong currents may be sweeping away any sedimentation on path for deposition at the lake bottom. The path of line connecting to the electricity grid will also require investigation of the lakebed to ensure it is not in the path of shipwrecks protected under Public Act 184. Cost related to grid connection increases further away from shore because it requires a longer line to be installed. Section 3 discussed structural designs selected by the Icebreaker project in Cleveland. That project opted for an array of lines linking turbines and a 9-mile transmission cable to connect to the grid. The cable would be buried which would require a dredge in compliance with authorized depths. Installation of array cables includes four steps preceded by a lakebed analysis which are laying cable, cable burial, connecting to towers, and testing as outlined in Interreg (2022). Bandwidth for getting maintenance crews out during winter months should be determined. Though seasonal complexities should be considered, overall maintenance cost and operation is miniscule compared to the fossil fuel industry.

There are also ecological and aesthetic considerations which include impact to fisheries, coastline property values, and imposing on historical markers. Fishery monitoring plans should be devised as the fishing industry has a high revenue stream for the state of Wisconsin. The effect on property values is an additional concern. One study suggested that offshore wind turbines had some impact on property values and found that 8 of 10 property values actually increased faster compared to controls (Synder, 2009). This area requires more research focused on growth projections for Milwaukee and additional influences of property values. Deciding to move forward with offshore wind in the Great Lakes is complex and will require careful balance of local and governmental issues, ecological costs, and economic cost, and uncertainties with effects of climate change should be considered. Acceptance of offshore wind is more likely when turbines have low visibility from shore. This is achieved by situating turbines further away from shore.

6.7 Summary

Globally we are on a narrow timeline to reach emission goals to lessen the impact of the irreversible effects of climate change. Feasibility is not equal across engineering, political procedures, community value, economical which complicates commitment to an offshore wind project. By taking no action now, it does not mean that there may not be an opportunity to revisit offshore wind later down the road. While there is evidence that offshore wind lends supporting evidence that the economic benefits outweigh the initial cost, the level of risk lends caution. There are greater uncertainties and difficulties with the offshore environment in comparison to market-ready energy solutions.

Energy generation from offshore wind is technologically feasible, and the necessary environmental conditions are present. Solar compared to wind offers a shorter and less intrusive implementation does not provide enough energy generation in the winter. The public may more easily accept offshore wind as a source of energy production if they understand that it smooths out renewable generation due to its high value of providing consistent fall and winter energy when the sun is most scarce in Wisconsin.

Section 7: Stakeholder Mapping

7.1 Stakeholder Mapping

The term “stakeholder” has a wide range of definitions and interpretations, thus, to develop a comprehensive stakeholder map for an offshore wind-turbine project, we must first define what a stakeholder is. For the purposes of this report, we will operationalize the term “stakeholder” used by Freeman et al. 1983 as "any group or individual who can affect or is affected by the achievement of the organization's objectives." By identifying and analyzing key stakeholders, organizations can better understand their needs and priorities, anticipate potential challenges, and develop effective strategies to engage with and manage these groups (Styk, 2022).

7.2 Stakeholder Mapping Methodology

Stakeholder mapping is a valuable tool for organizations seeking to understand and engage with the various individuals and groups who have an interest in their project or operations. This process involves several steps, starting with identifying the key stakeholder categories involved in analogous offshore wind projects primarily across northern Europe, but also within the Great Lakes region as well. First, literature review identified the categories of stakeholders as: government bodies and regulatory agencies, developers and operators, investors and financial institutions, local communities, environmental and conservation groups, boating industries (shipping, fishing, and recreational boating), labor unions, academic and research institutions, and suppliers/maintenance technicians (Ahsan, 2018). From these categories, we identified specific stakeholders by reviewing and analyzing the City of Milwaukee's ECO webpage, Climate and Equity Plan, Annual Report, Green Infrastructure Plan, and other documents to build a list of 32 stakeholder groups that could be involved in a potential offshore wind project (Table 3). Once stakeholders are identified, they are typically mapped based on their level of influence and interest in the project.

Organization/Category	Abbreviation
US Coast Guard	CG
FAA	FAA
Other Suppliers/Technicians (category)	OST
PSC	PSC
WDOA	DOA
WE Energies	WE
Great Lakes Commission	GLC
IBEW	IBEW
Labor Unions/Workers (category)	LU
WDNR	DNR
American Great Lakes Ports Association	PA
Milwaukee CC	CC
US Great Lakes Shipping Association	SA
US EPA	EPA
FERC	FERC
RENEW Wisconsin	RW
Clean Grid Alliance	CGA
USFWS	FWS
Bay View Neighborhood Association	BV
Historic Water Tower Neighborhood	HW
Neighborhood Assocations (category)	NA
Audobon Society	AS
McKinley Boat Owners Association	BOA
Wisconsin Lakeshore Business Association	BA
Clean Wisconsin	CW
Local Groups Opposed to Wind Energy (category)	OG
Wisconsin Industrial Energy Group	EG
South Shore Sailing Club	SS
UWM SFS	SFS
Fincanteiri Bay Shipbuilding	FB
Cimbria Capital	CI
Environmental Law Sec of WI State Bar	ELS

Table 3. Stakeholder name and abbreviations.

Stakeholders vary in their involvement, degree of impact, and amount of influence which we mapped using an "Influence-Impact Matrix" Model. ECO staff were interviewed on March 29, 2023 to first quantify their perceptions on each stakeholder's degree of influence and interest on this project. Staff were asked to evaluate the stakeholder's degree of influence and interest on a scale of 1-10 (Table 4). We followed the "Power/Interest Matrix" model implemented by Ahsan et al. to categorize the key stakeholders based on their influence and interest (Figure 6). This involved creating a matrix that plots stakeholders along two axes, with influence on the x-axis and interest on the y-axis. This matrix categorizes stakeholders as "Crowd" (low interest, low influence), "Context Setters" (low interest, high influence), "Subjects" (high interest, low influence), and "Players" (high interest, high influence).

Organization/Category	Interest	Influence
CG	10	10
FAA OST PSC DOA WE	10	9
GLC IBEW LU DNR	10	8
PA CC SA	10	5
EPA	9	5
FERC	8	7
RW	8	5
CGA FWS	8	4
BV HW NA	8	3
AS BOA BA	7	4
CW	7	3
OG EG	6	4
SS	6	3
SFS	5	3
FB	5	2
CI	4	3
ELS	3	4

Table 4. Perceived influence and interest of each stakeholder based on response to March 27th interview with ECO staff.

7.3 Stakeholder Mapping Results

The findings of this evaluation reveals the stakeholders with the most influence and interest ("Players") in an offshore wind project off the coast of Milwaukee include: US Coast Guard, Federal Aviation Administration, Technicians and Suppliers, Public Service Commission, Wisconsin Department of Administration, WE Energies, Great Lakes Commission, Labor Unions (IBEW), Wisconsin Department of Natural Resources, Federal Energy Regulatory Commission, American Great Lakes Ports Association, Milwaukee Common Council, US Great Lakes Shipping Association, US EPA, and RENEW Wisconsin (Figure 7). Categorically, these "players" primarily consist of federal, state, and local governmental bodies that will be involved in the regulatory and approval processes associated with the development of this project.

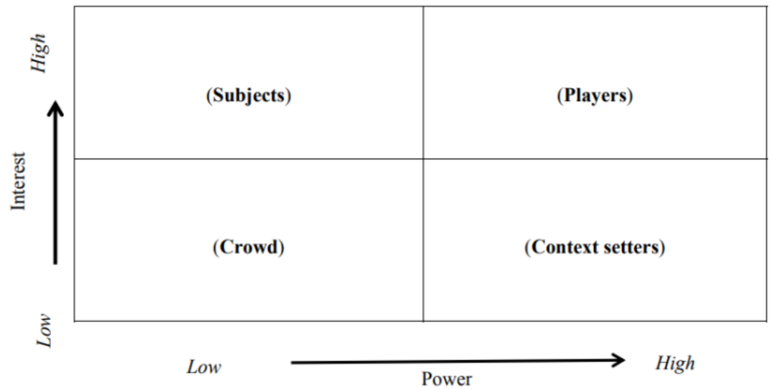


Figure 6. "Power/Interest" model of stakeholder characterization by Ahsan et al. (2018)

The primary power distributor in southeast Wisconsin is WE Energies, who will ultimately own, operate, and distribute the power generated from these turbines. As such they will also be a critical financer and cooperator on this project and are therefore considered a key player. Additionally, suppliers/technicians and laborers involved in the construction and maintenance of wind turbines are considered critical stakeholders involved in this project.

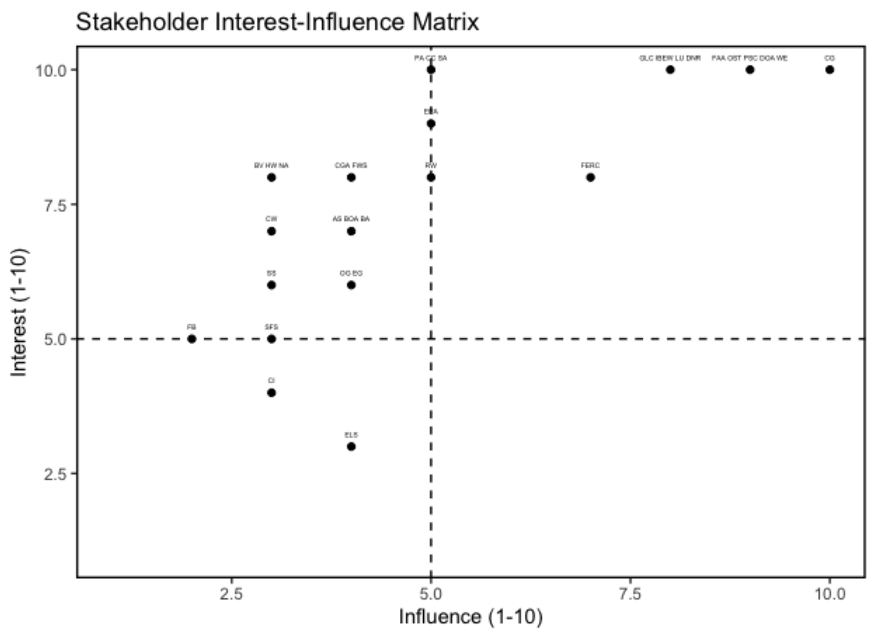


Figure 7. "Interest/Influence" matrix modeled after Ahsan et al.'s "Power/Influence" model results based on March 27, 2023 survey responses from the City of Milwaukee ECO staff.

The next most important cluster of stakeholders are described by Ahsan and others as the "Subjects". This stakeholder grouping is characterized by having a high degree of interest; however, the power or influence is moderate to low. This group will include: Clean Grid Alliance, US Fish &Wildlife Service, Audubon Society, neighborhood associations, McKinley Boat Owners Association, Wisconsin Lakeshore Business Association, Clean Wisconsin, Opposition groups, and the South Shore Sailing Club. Categorically, these groups consist of state and local special interest groups, community organizations, and advocacy groups.

Ahsan et al. 2018 describes the final grouping of stakeholders with a low degree of interest and low influence as the "Crowd". Based on the survey responses from ECO staff, this stakeholder grouping includes academic institutions that may provide research to the project such as the UW-Milwaukee School of Freshwater Sciences or the Environmental Section of the Wisconsin State Bar. Some financing institutions such as Cimbria Capital may also be included with this group if they are interested in financing a portion of the project. Although the results of the Interest-Influence survey suggest financial backers of this project fall in this category, the analysis of the Icebreaker project and other offshore wind projects in the Great Lakes region as described in Section 5 indicates that investments from the private sector will be critical for the long-term feasibility of this project. Therefore, while an initial assessment places these stakeholders within the "Crowd", it is likely they will become more interested and influential in later stages of the project development and will transition into the "Player" category.

7.4 Communication Strategies

When engaging with the "Players" in an offshore wind project, it is important to maintain clear and consistent communication channels throughout the project lifecycle (Freeman, 1983). This includes regular project updates, progress reports, and stakeholder meetings to discuss any challenges, risks, or opportunities (Del Rosario, 2007). It will also be important to establish clear lines of communication with these groups, identify the regulatory responsibilities, and establish working groups to foster collaboration and to ensure project objectives and timelines are met. Further, ECO should ensure that everyone has access to the latest project information and that feedback is sought and acted upon in a timely manner. By fostering an environment of open communication, trust, and collaboration with the identified key players involved in a Milwaukee offshore wind project, ECO can help align all parties towards achieving a compliant offshore wind project with public support from key non-governmental and impacted organizations.

Christidis et al. 2017 focuses on incorporating the concerns among "Subjects" into the decision-making processes and developing options to address the raised concerns throughout the development of wind turbine projects. It is therefore imperative the stakeholders within this category be invited to participate throughout the decision-making process to afford opportunities to bring ideas, opinions, and concerns to decision-makers and allowing decision-making processes to incorporate these perspectives into policy and development decisions. When communicating with "subject" groups, it will be important to approach the dynamic with an open mind and a willingness to listen and understand their concerns and priorities. Clearly communicating the goals, costs and benefits of the project, while acknowledging any potential drawbacks or impacts can facilitate collaboration and build trust with these concerned groups. Providing regular updates and opportunities for feedback throughout the project development can also build and maintain trust and transparency with these groups. Lastly, project leaders should be prepared to make compromises and adjustments to the project plan, if necessary, in order to address any legitimate concerns raised by these stakeholders.

While stakeholders classified as the "Crowd" may not play a critical role in the decision-making processes, it will be important that information regarding the development of the project be available to these groups. Wright et al. 2012 highlights effective public participation strategies employed in wind system development projects. They suggest effective communication materials including written plans/reports and invitations to public meetings. Additionally, some audiences within the general public may be included within this group. Therefore, a broad ranging communication strategy for a general public audience should be considered including; use of social media, visual aids such as maps, illustrations, and short video clips, and press releases through conventional media outlets including television, radio, and local news outlets. Effective policy communication is critical to building trust and support for the offshore wind project and will require a multi-faceted approach.

7.5 Summary

Using this "Interest-Influence" Matrix model can help Milwaukee ECO identify and categorize the various stakeholders involved in this project, navigate the complex dynamics within these groups, and prioritize their interests, and degrees of involvement throughout the project's lifespan. It can also be used to develop effective strategies for engaging with stakeholders and addressing their needs and concerns, as well as strategizing which stakeholders should receive attention at critical junctures throughout the development process. Ongoing monitoring and continuous evaluation of stakeholder relationships will be an ongoing part of the stakeholder engagement process.

Recommendations

Based on the wind analysis presented, there is sufficient wind power to generate consistent and substantial energy at a minimum of 6 - 12 miles east of the Milwaukee shoreline. However, an ideal distance would be greater than 12 miles, but this does not consider the environmental, economic, and legal considerations. Furthermore, large turbines such as the Repower 6.1MW turbine have a higher capacity to yield more power compared to smaller-scale turbines. The proposed height for the offshore turbines should be, at minimum, a height of 100 m (328 ft) to maximize the wind power potential. A single turbine in this location could produce 7 – 9.1 GWh. Given the highest energy production will be in winter, this is a valuable addition to a mix of renewable sources to smooth out the energy supply year-round.

Based on the recommended location of the offshore wind project determined by the wind analysis in Section 2, a lakebed lease from the state of Wisconsin will be required. This lakebed lease would need to be approved by the Wisconsin Department of Natural Resources and the Board of Commissioners of Public Lands. Wisconsin should establish a leasing policy for offshore wind that determines under what conditions it will be allowed, at what rate, how the revenue will be used, and other factors, consistent with protecting the public interest under the public trust doctrine. In addition to this lakebed lease, there will be multiple federal and state laws that will require proper permits for construction and operation.

There are a variety of mitigation strategies to lessen environmental impacts of an offshore wind energy project. Starting with construction, the noise levels could be decreased using underwater encapsulated bubbles. The construction should not occur in fish spawning areas and should not overlap peak fish spawning season (late April-July), nor should the operation of the turbines occur during peak flight hours for bats, specifically overnight in late summer with low wind. Ideally, the height of the turbines would not significantly intersect migratory bird flight patterns (above 200 ft), however, given that birds do not typically fly over open water 6-12 miles from shore, the larger wind turbines optimized for power generation should not have a significant effect on bird populations. Before choosing an exact location for the wind turbine placement, we recommend conducting a survey of bird, bat, and fish population activity in the proposed locations as there is currently limited information available for the western side of Lake Michigan. Shipping lanes and ferry routes should also be taken into consideration and avoided while choosing the turbine placement locations.

The approximate location of the proposed wind system should maximize wind power generation while balancing environmental, economic, and legal concerns. We recommend this project be constructed at the shallowest depth contour located between 6-12 miles from shore to avoid additional construction costs, minimize bird and bat interactions, reduce visual impacts from shore, and avoid fish spawning habitats. Given that the offshore wind power generation potential increases further from coastline, the tradeoff the farther the project goes out from shore will be higher construction, operation, and maintenance costs in exchange for greater power generation.

Effective communication with identified stakeholders will be an essential aspect for the successful development of an offshore wind project near Milwaukee. We recommend using the “Influence-Interest” matrix in this report to identify the roles of each stakeholder group. From this matrix, unique communication best practices to each group should be employed to effectively share relevant information, incorporate and address concerns, and build relationships and trust within these communities. Doing so will allow ECO to develop robust support among the public and private partners involved in this project with the Inflation Reduction Act's $100 million for convening stakeholders available until September 30, 2031, and the $3 billion available for the Advanced Technology Vehicle Manufacturing Loan Program until September 30, 2028.

In conclusion, based on the research presented in this report, an offshore wind project development is feasible based on wind power generation potential, legal considerations, environmental factors, and the economic costs and benefits. The feasibility and success of this project will be dependent on strategic public engagement and effective communication with interested and influential stakeholders throughout the project lifespan. These recommendations and analyses are consistent with other offshore wind projects among other Great Lakes states pursuing a clean and sustainable energy grid.

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