

Viability of Offshore Wind Energy Across Wisconsin's Great Lakes

Calvin LaDue, Molly Schumacher, Isabel Wilson Orno
Undergraduate Colloquium for Geography Majors (GEOG 565)
University of Wisconsin - Madison
Fall 2016

Abstract:

This research project was designed to determine suitable sites for an offshore wind farm within Wisconsin's jurisdiction of Lake Michigan and Superior. In the research process, we used GIS data to create a map of ideal wind speeds for electricity generation in both lakes, and this was overlaid with a map of excluded sites based on different criteria: human activities, historical sites, view protection, and environmentally sensitive areas. The results showed that there are vast stretches in Lake Michigan where an offshore wind farm would be suitable. We chose three sites determined as most suitable and examined individual factors of each site which included an economic estimate of capital costs. The cost and implementation of each offshore wind farm project is heavily dependent upon geographic location, and individual factors vary from project to project, and therefore exact costs are impossible to determine prior to planning the actual project.

Introduction

In recent decades, the search for economically sustainable renewable energy sources has been explored as concerns over our dependence on fossil fuels increases. Many in-depth research studies have been conducted to identify economically viable locations for renewable energy systems that will have the smallest negative impact on the environment. We will identify areas in Lake Michigan and Lake Superior in Wisconsin's jurisdiction that are the most suitable sites for maximum yields of offshore wind power generation. Additionally, we plan to analyze local area infrastructure and determine if renewable energy sources will provide cost-effective solutions as opposed to non-renewable energy sources. By using a site suitability analysis, combined with an economic analysis, we will determine the current viability of renewable energy for different offshore locations within the boundaries of Wisconsin.

As issues of global warming and imminent climate change create growing social and political interest, policy-makers may look towards renewable energy in an effort to create a more sustainable and secure energy market. The implementation of renewable energy has the potential to satisfy energy needs with fewer negative social and environmental impacts. Thus, wind and solar farms are the fastest growing energy sectors in the United States. The United States leads the globe in wind energy production, but only provided 4.7 percent of the total electricity generated in 2015. More specifically, Wisconsin only generates 2.5 percent of its total electricity from wind power (AWEA 2016), when its potential for offshore wind power alone is 30 percent, and onshore 45 percent (The Solutions Project 2016). This deficit leaves room for investment in the development of renewable energy. A methodology for state land site suitability would be useful in guiding potential investors, planners, and policy-makers in selecting sites best suited for

renewable energy development. This study aims to apply such a methodology to the state of Wisconsin, in order to identify the most suitable areas for offshore wind energy development, bearing in mind the current energy policies and relations between politics and energy that hinder the implementation of renewable systems.

Our goal is to find the best suitable site locations for offshore wind farms that are also the most cost effective, while also discussing bureaucratic policies and agendas surrounding renewable energy systems. A multi-criteria decision-making analysis method will be used that includes environmentally sensitive areas, human activities, navigable waters, view protection, landscape, and available energy resources for site suitability analysis, one typically used by the wind farm industry (Akbari 2016, 5). Once suitable sites are identified, an assessment will show the economic viability of the identified sites. The most suitable sites will be areas of high available energy resources with a low impact on the surrounding environment and a low cost of construction, implementation, and maintenance.

Contextual Material and Background Information

Disputes over energy sources and energy systems is a prevalent issue regarding fossil fuels. Obtaining and securing sources of energy has been an important topic in regards to national security, foreign relations, and the economy in the United States as well as the rest of the world. Historically, countries have only made big energy shifts when confronted with acute fossil fuel crises such as oil embargos, debilitating pollution, or wars, such as the 1973 Arab oil embargo or the 2010 BP oil spill (Ball 2012, 123). However, in recent decades, the argument has been made that policies must change to be more favorable towards renewable energy

implementation in the United States. This is necessary in order to remain a global competitor on the expanding renewable energy market and make a positive impact in regards to reducing greenhouse gas emissions and preventing climate change. This section of the paper attempts to explain some of the current energy policies and practices in the United States compared to other countries and how these policies affect the implementation of renewable energy initiatives.

The Culture Surrounding Renewables in the U.S.

Currently, the United States has failed to organize and rally around a collective, national initiative towards renewable energy. The US has an overly litigious culture that rewards special interest groups for filing lawsuits and delaying or attempting to impair renewable projects (Nussdorf 2011, 29). Offshore wind development is subject to significant local, regional, and state variations resulting in a legal patchwork across the country without a national, concise energy policy (Roek 2011, 27). As a result, the United States lacks incentive to transition to renewable sources of energy. Even though energy companies are slowly starting to state renewable goals, many pull back after realizing renewables are a potential threat to their monopolies, as is the case with We Energies located in the southeastern Wisconsin. To prevent renewable energy from being a real threat to coal, they have imposed regulations that a homeowner or business cannot produce more electricity than it is possible for them to consume, or else they are in direct competition with We Energies. By regulating the size and capacity of the wind turbines or solar panels implemented, We Energies prevents home or business owners from selling their excess energy that would allow another to use less coal, thereby protecting their business (Rutkowski 2016). This is just one example to explain what Nussdorf means by the United States' culture around renewables that inhibits implementation.

Policies in the U.S. versus Europe

The legal policies in place make it often difficult for renewable projects to become more than just a proposal in the United States. Because this project is focused on the Great Lakes and not the oceans, there are several federal authorities that do not need to be taken into consideration for this project. Great Lake states, have jurisdiction over submerged lands out to the center of each lake, which is the reasoning behind our selected project areas in Lake Michigan and Lake Superior. The eight Great Lake states maintain direct control over the development of shoreline and state-owned submerged land, but Wisconsin is different because a submerged lands lease is required from the appropriate agency. Construction activities within navigable waters also require the issuing of a permit from the U.S. Army Corps of Engineers under the Clean Water Act and the Rivers and Harbors Act (Roek 2011, 25). Further, all projects are subject to the Public Trust Doctrine, which states that resources such as air, running water, the sea, beach access, and scenic views cannot be appropriated for exclusively private use. Because of this, projects such as this can be limited in size or capacity to protect a public viewshed, which is a criteria that will be taken into consideration in our analysis (Roek 2011, 25-26).

Compare this to the policies in Europe about renewable energy sources. Within the European Union, the importance of long-range national energy policies is known in the creating and stabilizing conditions required for the development of sustainable energy systems. A study conducted on wind energy policies in the European Union took several factors into consideration, including: technological choice and development, formal energy policies, economic support systems, ownership and control, and possible limitations (Meyer 2007,

347-348). The results found that having a national energy plan with strong government intent to invest in renewables was vital. In order to help underpin investor and incentive scrutiny, long-range national plans with specified targets were necessary in order for projects to succeed (Meyer 2007, 358). The study found that it is also important for governments to have specified and ambitious targets for wind power implementation as well as long-term, stable economic support schemes such as feed-in tariffs or long-term subsidies (Meyer 2007, 360).

Economic Considerations

An important aspect of assessing and implementing an offshore wind farm is the cost behind it. Government subsidies are crucial to getting renewable projects off the ground because of the large initial investment they require. Other leading countries offer large subsidies paired with high electricity prices in order to make renewables matter.

One such country is Denmark, which actively supports renewable energy development and where 18 percent of electricity comes from wind power (Ball 2012, 126). Comprehensive energy plans have been developed every 2-5 years since 1976, which publish their renewable energy development objectives and the means to achieve them (Lipp 2007, 5486). Denmark's policies include a feed-in tariff (FIT), which supports various technologies at varying stages of development. All energy projects are guaranteed grid access and a certain price for the electricity produced with a long-term guarantee, anywhere from 8-30 years. By obligating electricity utilities and grid operators to purchase it, a market demand for renewable energy sources is ensured (Lipp 2007, 5482). The FIT required utilities to purchase wind-generated energy at a rate that equalled 85 percent of the price paid by consumers. Other measures introduced to support renewables include a 30 percent investment subsidy, direct subsidies and tax exemptions to

private turbine owners, tax-free electricity generation up to 7000 kWh, and the establishment of a public wind-power test station. Besides policy, is the viewpoint that renewable sources are complementary to current energy sources rather than an alternative. There is a balance in Parliament that allows small parties to enable various policy measures and Parliament also allocates funds to empower independent lobbyists for technical pilot projects (Lipp 2007, 5486).

The FIT is arguably the most important policy factor that launched Denmark's renewable energy push and made wind power generation take off. There are states in the U.S. that have feed-in tariffs or similar programs, including Washington, Oregon, California, Maine, and Vermont. There are also voluntary offerings from utility companies, mostly in Michigan and southeastern states (U.S. Energy Information Administration 2013). However, an initiative meant to have a significant, lasting impact beyond a handful of states requires a federally mandated FIT policy.

The United States implemented a subsidy in 1978, which was a tax break for every dollar spent on wind projects. This resulted in several investors spending money on wind projects that were never finally implemented because investors already received the breaks. In 1992, this subsidy was reformed as a tax break amounting to the amount of electricity produced, which reflected a greater implementation of working wind turbines being installed. However, renewable subsidies only last for one or two years, resulting in a boom and bust cycle of wind turbine implementation. Investors do their best to have as many wind turbines installed as possible before the subsidy expires, and as a result either overpower the electrical grid or end up with a project they are unable to finish. Compare this to fossil fuel subsidies in the U.S. or subsidies in Denmark, which are long-term and therefore more effective.

A study conducted that compared three different types of offshore wind turbine platforms took the entire lifecycle of a project into consideration when analyzing the cost. The lifecycle of a wind farm was defined in six phases: conception and definition, design and development, manufacturing, installation, exploitation, and dismantling (Castro-Santos 2015, 1218). The study concluded that out of the three types of platforms analyzed (tensioned-leg, spar, and semisubmersible), semisubmersible platforms had the lowest overall cost and tensioned-leg had the highest cost (Castro-Santos 2015, 1221). Although cost is heavily dependent on geographic location, cost information from existing wind farms will aid in assessing the economic feasibility of a wind farm project after suitable sites have been determined.

Stakeholders will have to balance ecological costs and benefits of offshore wind against its economic costs and compare to offshore wind energy's competitors, such as coal in Wisconsin (Kaiser 2009, 1567). There are several groups of criticisms to offshore wind such as navigational safety, federal subsidies, aesthetics, cost and risk, and unpredictable power (Kaiser 2009, 1568), which will be discussed in more detail in later sections as they are taken into consideration for this project. These downfalls must be compared to the benefits of offshore wind power, especially compared to onshore wind power. Location is a big benefit, because offshore wind farms are typically close to major population centers of coastal cities which remove the need for expensive, high-voltage transmission lines. Offshore may also reduce conflicts because turbines can be placed far enough from shore to be inaudible and not block the viewshed of certain areas. There are also benefits in considering offshore wind's power and transportation. Offshore winds are generally stronger than onshore, creating higher yields of energy and larger turbines can be

efficiently erected with transportation of equipment easier in bodies of water versus land (Kaiser 2009, 1569).

Ultimately, this project will attempt to determine whether the social and ecological benefits of offshore wind combined with the economic cost provide an effective alternative to current energy systems. Despite the political and cultural limitations hindering renewable energy projects, a transition is inevitable in the near future and offshore wind energy will be highly valuable to the state of Wisconsin and therefore it will be vital to identify the most suitable sites for offshore wind farms in Lake Michigan and Lake Superior.

Variables considered

Looking at site suitability for offshore wind farm potential has been evaluated in the past years, many past studies have been done in a variety of locations. Our multi-criteria decision-making method for our analysis is classified into six broad categories, each criteria consisting of multiple variables (Akbari 2016, 5). This criteria was largely determined by examining similar site suitability studies on potential offshore wind energy. Our literature analysis extracted the variables used in four different offshore wind farm site suitability research studies and determined which variables were most widely considered (see Table 1). Many of the previous studies looked at were implemented on seas or larger bodies of water than the Great Lakes. Due of this, additional variables were accounted for to meet the unique needs of the Lake Michigan and Lake Superior. After examining the previous studies, we determined a broad criteria by grouping the variables to best fit our site location. Our six, broad criteria are environmentally sensitive areas, historical locations, navigable waters, view protection,

landscape concerns, and energy resources. Each criteria combines multiple variables to produce thematic maps that are overlaid to give us the final optimal spots in Wisconsin's Great Lakes waters (see Figure 1).

As we are examining a different location than these previous studies, we constructed our criteria to best fit our unique location. Past criticisms of implementing offshore wind farms on Lake Superior and Lake Michigan include harming of migratory birds and fish spawning areas and destruction of the lake view (Milwaukee Wisconsin Journal Sentinel 2012). Due to this, our research included a view protection in our criteria as well as considering migratory birds through waterfowl stopover habitats and fish spawning locations. Some variables that were used for many of the studies looked at were omitted, as these did not expect to have a large impact on our analysis with our given site location. Economic criteria, when not considered during the thematic map production phase of our project, was considered after we identified our most suitable sites.

Environmentally Sensitive Areas

Renewable energy sources are more environmentally friendly than traditional energy sources, but this does not mean that they are completely harmless to the environment while being constructed, operated, and maintained (Rodríguez-Rodríguez 2016, 9). Disturbance to the surrounding environment is unavoidable, but can be minimized by avoiding sensitive areas. In Europe, it was discovered that mainly marine mammals such as harbor seals and small cetaceans felt the largest impact from the construction of offshore wind farms (Rodríguez-Rodríguez 2016, 9). Solutions have been explored in the past to try to revive or preserve small cetaceous mammals through additional structures on the wind turbine platforms. Some studies, such as a study done off the coast of Spain, suggests basing assessments around "preventative

mechanisms” to protect the environment against future implications from the construction of windfarms (Colmenar-Santos 2016, 7).

Though large marine animals are not an issue in the Great Lakes, we considered fish spawning areas, protected areas, and critical habitats as areas of concern (see Figure 2 and Figure 3). In all four studies referenced (see Table 1), recreational fishing grounds were considered (Kim 2016; Colmenar-Santos 2016; Rodríguez-Rodríguez 2016; Gregg 2015). The fishing industry as well as recreational fishing is taken into account by considering the fish spawning habitats as areas of exclusion, as exact recreational fishing locations are variable and difficult to identify in the large bodies of water. Initial disturbance in these areas could have negative implications in the construction of the wind farms, so avoiding construction directly on these areas will aid in identifying suitable sites.

Another solution to preventing or mitigating negative environmental impacts involves the artificial reef effect. Impact studies done have shown that there are no generally negative impacts on species abundance, composition and biomass of infauna, and only some species specific reactions in some fish in regards to implementation of offshore wind farms (Langhamer 2012, 1). Habitat loss cannot be mitigated, but offshore wind energy installations have good potential to compensate by providing habitat creation. In general, artificial reefs tend to have greater densities and biomass of fish and provide higher catch rates near fisheries compared to surrounding soft bottom areas. Sea cables and wind farm structures can provide shelter from predation and water movements as well as enhanced feeding grounds for species (Langhamer 2012, 2).

This study will preserve environmental sensitivity through avoiding endangered or sensitive areas as much as possible, and considering the role of artificial reefs in areas that cannot be avoided. Factors such as critical species habitats, protected areas, and waterfowl stopover habitats will be considered in our criteria (see Figure 2, Figure 3, and Figure 4).

Historical Locations

Nearly all the previous studies examined how the construction of offshore wind turbines would influence existing historical locations (see Table 1) (Colmenar-Santos 2016; Rodríguez-Rodríguez 2016; Gregg 2015). The Great Lakes house many historical locations onshore and offshore, such as lighthouses and shipwrecks dating back to 1679 (The University of Wisconsin Sea Grant Institute 2016). Vessels such as the *Appomattox*, which sank in 1905 and is still much intact, is regarded as the largest wooden bulk steam vessel constructed in the world and still observed today by divers and preserved by the Wisconsin State Historical Society (The University of Wisconsin Sea Grant Institute 2016). Our analysis will attempt to preserve historical sites on or near the shores of Lake Michigan and Lake Superior by considering these areas as areas of exclusion. The locations that were taken into consideration are confirmed shipwreck locations by the University of Wisconsin Sea Grant Institute in both Lake Michigan and Lake Superior (see Figure 5 and Figure 6) (The University of Wisconsin Sea Grant Institute 2016).

Navigable Waters

Navigable waters as a factor can be seen in many of the previous studies examined (see Table 1). Variables for this criteria include ferries and major average shipping routes. Shipping traffic can prove to cause “logistical issues” in the construction of potential wind farms (Akbari

2016, 123). In our analysis, there will be a focus on excluding high traffic areas of major average shipping and ferry routes to avoid possible collisions (see Figure 7).

The Great Lakes have many critical navigable channels that serve many large cities in and near Wisconsin. These shipping ways are essential to the economy and must be taken into consideration. Looking at previous studies, three of the four studies considered this in their analysis (see table 1). Our goal is to assess potential sites where major shipping routes would be least disturbed.

Further, tourism was used in our navigable waters analysis. Though this was considered in human activities in previous studies, this was grouped with navigable waters to be areas of exclusion (Colmenar-Santos 2016). There are four major ferries in Wisconsin that were accounted for. The S.S. Badger ferry runs from Manitowoc, Wisconsin to Ludington, Michigan, the Door County ferry that goes to Washington Island, Wisconsin, the Rock Island ferry in Door County, and the Madeline Island ferry in the Apostle Islands of Wisconsin. Optimal sites based off of our navigable waters analysis will be located not on or very near to major shipping routes or major ferry routes.

The distance that wind turbines should be positioned from major shipping routes is variable on the size of the ships that navigate the waters, the radar capabilities that the ship has, the specific traffic density and other similar factors (Schnegelsberg 2007, 10-12). Other factors to consider when determining a safe distance from major shipping routes can be the potential for collisions, besides just not disturbing the major shipping routes or changing them (Schnegelsberg 2007, 21). Teresa Messmore, states that changing current shipping routes to accommodate new wind farms could save billions of dollars (Changing Shipping Routes 2014). While a case study

states that shifting these shipping routes could result in increased ship collisions (Schnegelsberg 2007, 21). For our site suitability analysis, we will consider areas that are further away from major shipping routes of higher desirability due to safety concerns.

The longest ship in the Great Lakes major shipping routes is 335 meters long. A simple rule of thumb for safe distance between two shipping vessels is about one times the length of the ship (Schnegelsberg 2007). We will use this same logic in determining the excluded areas and distance that will be buffered out from the major shipping routes.

View Protection

Only one previous study looked at took view protection into account (see Table 1). Past criticisms of possible wind farm construction in the Great Lakes have been of ruining the undisruptive lake view (Holland 2013). In attempts to combat this criticism, a view protection analysis was conducted that looks at the affected areas, or “zone of visual influence” (Bishop 2007, 817). This will look at populated urban and developed areas on the shores of Lake Michigan and Lake Superior.

A previous study done off the coast of Jeju Island, South Korea, a distance of 32 kilometers (12 miles) from the coastline was best (Kim 2016, 620). In the Jeju Island study, the high distance accounted for protecting the coastal view for residents and tourists. A viewshed analysis was not used in the Jeju Island study, only an analysis based on distance from the shoreline. Another report argues that distance and setting may be enough to factor for view protection, but implementing viewshed analysis-based methods will provide a more accurate assessment (Bishop 2007, 815). There is some speculation on the validity of a viewshed analysis for some studies, as many studies check for most ideal atmosphere conditions and not realistic

conditions. This report conducted studies and surveys to see how many turbines people could identify from a variety of distances under various atmospheric conditions (Bishop 2007, 821). Concluding that when implementing a viewshed analysis, accounting for ideal atmospheric conditions is not necessary, but less ideal atmospheric conditions is more realistic and will suffice.

For our research, a viewshed analysis at ideal atmospheric conditions was implemented to get a conservative and safe account for which areas on the Great Lakes would be visible from shore (see Figure 8 and Figure 9). Urban and developed areas, taken from a land cover of Wisconsin, were used as the observer points with a height of 10 meters on top of the digital elevation model. A 10 meter height is the average height of a two story house, as many areas on the lake front are residential. Typically, a viewshed analysis has one observer point and identified areas that are visible and areas that are not visible. As there were many observer points along the shore, a scale of how many times an observer point observed a location in the water was constructed. Areas that higher numbers of observations were considered least suitable and areas that had no visibility or a low amount of observations were considered more suitable.

Landscape

The landscape criteria was not constructed as an overlay in our excluded or optimal sites maps, but used as economic considerations in the end for determining suitable sites. All four of the previous studies looked at accounted for bathymetry and distance from land in their analysis (see Table 1). Economic considerations have not been directly taken into account when completing the geospatial analysis, but can be seen indirectly through our landscape criteria. For example, some studies decided to grouped distance from land and bathymetry into an economic

feasibility analysis (Gregg, 2015, 10). An additional consideration, that was not grouped in landscape concerns with other studies, but as a consideration in their navigable waters analysis was the proximity to ports (Kim 2016). Since we are gauging much of our economic feasibility on landscape characteristics, we decided to group our consideration for proximity to ports into our landscape criteria. Landscape characteristics, such as distance and water depth, proximity to ports, and distance from shore can greatly affect the potential cost of construction and implementation of the offshore wind turbines.

Ports provide valuable access to the wind farms throughout the process of implementation and construction, maintenance, and deconstruction of the wind turbines. Lack of a nearby port can drastically increase the wind farm construction costs as well as maintenance and routine servicing, which can comprise almost 85 percent of the operating costs (Akbari 2016, 122). In previous wind farm construction projects, ports serve as an onshore turbine assembly area (Akbari 2016, 122). As one study suggests, ports can also be ideal locations for possible power generation facilities because of machinery resources and manpower, that is if there are no nearby power grids (Kim 2016, 620). Though we are not looking at power grid proximity at this time, future exploration on the topic could be done. To minimize the cost of the wind farms, we aim to find sites that are in close proximity, giving higher rankings to sites closer to ports.

Another landscape factor to consider is bathymetry, or the depth of the water. The depth of the possible sites determines which platforms are able to be constructed as well as affects the type of technology used to develop the offshore wind project (Schwartz 2010, 9). In 2010, floating platforms that would be able to be constructed in waters over 60 meters deep were in early stages of development, and would result in much higher construction costs (Schwartz 2010,

9). Monopoles and gravity foundations as well as tripods were commonly seen for turbines in waters 0 to 60 meters deep, but may not be as stable for deep waters (Schwartz 2010, 9).

Previous technology limited the depths that platforms could be constructed, but new technologies have made construction possible at higher depths. Now, construction in waters 40 to 50 meters or more can easily be done through new developments in technology and innovative platforms (Kim 2016, 620).

High costs can develop quickly when looking at the relationship between distance from shore and the length of the underwater cables that will need to be laid to connect the offshore turbines to the onshore electricity grid (Schwartz 2010, 11). One study suggests that 10 kilometers (6.2 miles) from the coast, but no more than 20 kilometers (12.4 miles) was considered an optimal site location for off the coast of Jeju Island (Kim 2016, 620).

For our analysis, we considered suitable sites as being as close to shore as possible, without being in an area of exclusion. Having a closer distance is thought to be more accessible for construction and maintenance, while situating the turbines further away might have negative consequences on various costs such as cable needed, platform type, and implementation and maintenance.

Energy Resources

Energy resources can be considered one of the most important factors in our site suitability analysis, as without adequate wind power available in an area, no wind energy can be collected by the turbines (see Figure 10). From an economic standpoint, annual average wind speeds can be an adequate indicator for which areas will be economically viable (Colmenar-Santos 2016, 7). Further, annual average wind speeds are “closely related” to the

available energy that can be obtained at a certain location (Schwartz 2010, 7). All four previous studies that we examined took wind energy potential into consideration by using the estimated annual average wind speeds in their study area (see Table 1) (Kim 2016; Colmenar-Santos 2016; Rodríguez-Rodríguez 2016; Gregg 2015). The Jeju Island study in South Korea suggested a minimum of 8 meters per second as being the most ideal average wind speed at 80 meters above sea level (Kim 2016, 620). A study done off the coast of Spain is more generous, deeming annual average wind speeds greater than 6 meters per second at 80 meters above sea level are sufficient (Colmenar-Santos 2016, 10). Areas with annual average wind speeds of at least 7 meters per second at 90 meter above lake level, class 6 on our potential wind energy map (see Figure 10), are considered to be suitable (U.S. Department of Energy 2014). For our study, we considered higher annual average wind speeds at 90 meters above lake level as more ideal and lower wind speeds less ideal. Areas with wind speeds below 7 meters per second at 90 meters above lake level were not considered as suitable sites, as there were plenty of areas that had high wind annual average wind speeds.

Methodologies

As evidenced by the literature review, site suitability of offshore wind farms must consider a range of variables that are both quantitative and qualitative in type. In order to proficiently address the research question, the project was designed as a multi-part research design that uses publicly available Geographic Information System (GIS) data and other public databases in order to both eliminate unsuitable sites and identify suitable ones. These composite data layers are then buffered or overlaid to create a graphic map of potential wind farm locations.

For our public presentation, we selected three potential sites offshore of Wisconsin that are suitable for an offshore wind farm. The final potential sites are then assessed based on economic feasibility and environmental impacts or concerns.

Geographic resources such as GIS data have great potential for identifying viable wind farm or turbine placement, due to the high degree of geographic variability required for their siting (Gregg 2015, 25). As such, our project's research design takes advantage of many different publicly available GIS data sources and public databases in order to generate the unsuitable and suitable locations sitemaps. We also have created many of our own unique GIS data layers for use in this project, including the lighthouses, confirmed shipwrecks, ferry routes, and urban and developed areas layers (see Figure 1).

Research Design, Part 1

The first part of the research design involves creating a sitemap of unsuitable locations created by exclusionary zones which are represented by buffers or overlays in existing, publicly available GIS data and through the creation of original data layers (see Figure 1). Maps are often one of the strongest tools for communicating spatiality, which is why it was chosen as the main tool to show the different exclusionary and suitable zones (Pearce 2009, 4). The different broad variables considered for the exclusionary zones were influenced by research of several other studies on the site suitability of offshore wind farms, including but not limited to: Kim (2016), Colmenar-Santos (2016), Rodríguez-Rodríguez (2016), and Gregg (2015) (see Table 1). Our variables, drawn from research of the above studies, are as follows: environmentally sensitive areas, areas of human activities, navigable waters, view protection, landscape, and suitable wind

speed energy resources (see Figure 1). Each of these broad variables then have several underlying criteria components which were drawn from the studies above, and created based on our own knowledge and understanding of Wisconsin's Great Lakes ecosystems. For example, Lake Michigan and Lake Superior have a number of historically-significant shipwrecks that need to be considered as exclusionary locations, and this is something that would not have been considered in previous studies.

The six broad variables we have chosen, as mentioned earlier, can be broken down into several underlying criteria which will help us generate both our excluded or unsuitable locations sitemap, and our optimal or suitable locations sitemap (see Figure 1). GIS data layers for most sitemaps will be taken from publicly-available sources, and original maps will be generated from public databases. ArcGIS 10.4 and QGIS 2.18 are the two programs used to manipulate the data layers, and Adobe Illustrator is used for making the maps more visually appealing after exporting from ArcGIS and QGIS. Cleaning up in Adobe Illustrator involved properly placing labels and making sure colors are properly visible on-screen and for print formats. Due to the low visibility of the buffers at a true scale to the other map features, they were exaggerated for visual representation. Maps which this was done on have this denoted on the graphic.

When considering unsuitable locations, a land parcel can be deemed unsuitable based on ecological, landscape, infrastructure, cultural, and developmental reasons (Kumar 2014, 45). Due to the high degree of geographic variability, utilizing GIS-based software in site suitability analysis has been taken advantage of in various disciplines, including urban planning, landscape planning, and the siting of public facilities; these studies can be used to identify suitable

locations based on polygon, linear, or point features, which is why the GIS-based software is often useful (Kumar, 2014, 19).

Each individual exclusionary variable, for which there are five, will have a sitemap comprised of multiple GIS data layers that are drawn from the underlying criteria of each variable that have been chosen for this research project. You can see our full conceptualization diagram below in Figure 1. The sitemap for environmentally sensitive areas contains data layers for endangered species habitats, important fish habitats, migratory bird stopover habitats, and other conservation areas (see Figure 2-4). These exclusionary locations are then identified and overlaid, based on these layers. The sitemap for areas of human activities contains data layers for historical locations, such as shipwrecks and lighthouses (see Figure 5-6). Again, the exclusionary locations are identified and overlaid, based on these layers. The sitemap for navigable waters contains data layers for major ports, major shipping routes, and two major ferry routes in Lake Michigan (see Figure 7). The exclusionary locations for these layers are then buffered. The sitemap for view protection is comprised of an original data layer for residential or developed areas and a digital elevation model (DEM) that used the raster calculator tool in ArcGIS to add 10 meters to each pixel value, and then based on thousands of viewpoints on shore (see Figure 8-9). These layers create more exclusionary locations based on a viewshed analysis. All GIS data layers utilized are in shapefile format, either created by one of the researchers involved in this project, or found at a reputable publicly-available source.

The single variable chosen for generating the optimal or suitable sitemap is based on energy sources, with a specific underlying criteria of average wind speeds. This project has decided to use data of wind speeds at 90 meter height above sea level, because that is the average

height of an offshore wind turbine (WindMonitor 2016). Publicly-available data on annual average offshore wind speed at a 90 meter height for the Great Lakes region can be obtained at no cost from the National Renewable Energy Laboratory (NREL) (NREL 2016). This GIS data on average wind speeds was then reclassified in an equal interval distribution, which divided average wind speeds into equally divided classes, creating unbiased breaks with each category given the same proportion of the range of values. This reclassified sitemap then shows us the optimal areas for wind turbine placement, based on the average wind speeds of each class (see Figure 10). Areas with annual average wind speeds of 7 meters per second (m/s) and greater at 90 meter height are generally considered to be more suitable for offshore development (U.S. Department of Energy 2014).

One can imagine the possibility that much of the optimal area based solely on average wind speed may conflict with exclusionary areas based on the five other variables. To remedy this conflict, sites will be labeled as more or less suitable than others based on average wind speeds, rather than being labeled as included or excluded to give us a wider range of potential sites that can then be ranked on suitability. Then, this research project combined the optimal sitemap with the excluded locations sitemap to create a composite map of potential offshore wind farm locations, which consider all six variables we have drawn from research of various other studies about offshore wind farms. These potential suitable sites for offshore wind farm locations can then be viewed on composite maps as shown below (see Figure 11-13).

Research Design, Part 2

After creating a sitemap based on suitable potential locations for offshore wind farms, our research project then assesses both the economic feasibility of the potential locations, as well as any potential environmental impacts the offshore wind farms may cause.

Economic feasibility based on a cost-to-benefit approach is appropriate in order to optimize the siting of offshore wind farms (O'Reilly 2013, 11). This cost-to-benefit analysis balances the cost of the development and maintenance of offshore wind farms. Standard costs associated with wind turbine construction include the structural cost, the foundational cost (water depth), and the connecting cable cost (interconnecting the turbines, and connecting to the shore) (O'Reilly 2013, 11). Ideally, costs are estimated over the life-cycle of the wind farm, taking into consideration all costs of maintenance and decommissioning (O'Reilly 2013, 11). The benefit of the wind farms is considered to be the power generated. These power benefits are then compared to more traditional, non-renewable energy sources to determine the rough economic feasibility of the potential offshore wind farms.

While potential environmental impacts should be mitigated by the exclusionary siting procedure above, there may be extraneous environmental impacts associated with an operating offshore wind farm over its lifetime. However, there may be significant limitations in collecting and displaying this data. This research project compares environmental costs of some non-renewable energy practices that are currently in place, with the potential ones that may arise from offshore wind farms. One example would be the reduced amount of greenhouse gases, especially carbon dioxide, that would be afforded by offshore wind farms compared to non-renewable energy sources. Additionally, the spatial flow of capital (renewable energy, in this

case) remains in Wisconsin, rather than being distributed to other states that heavily utilize non-renewable energy sources.

Data Collection

As discussed above, the methodology for this research project contains two parts: site suitability analysis based on six different chosen variables, and an economic feasibility and environmental impact analysis of potential optimal offshore wind farm sites. Data sources for this research project are obtained from the Internet, using guidelines from *The Craft of Research* (Booth et al. 2008, 75-80). We have also created several original, unique GIS data layers based on data obtained from the Internet (see Table 2).

The site suitability analysis uses various GIS data layers, obtained from various publicly-available sources, including but not limited to: National Renewable Energy Laboratory (NREL), United States Geological Survey (USGS), U.S. Fish and Wildlife Service (USFWS), Wisconsin DNR (WIDNR), and the National Transportation Atlas Database (NTAD) (see Table 2). However, these are only some of the largest and most well-known data suppliers; there are many others which are cited as the data is obtained and applied. This research project utilizes publicly-available GIS data layers, or generated unique GIS data layers. If metadata is poor, as in the case of certain shipping routes within our navigable waters criteria, we excluded some locations from our GIS analysis (see Figure 7). These were exclusion zones were chosen if the endpoint of the major average shipping route ended not near shore and not near a port.

The analysis of economic feasibility and environmental impact of potential optimal offshore wind farm locations again utilizes publicly-available information about wind turbine installation, development, and maintenance costs and compares them with our currently in place

energy systems. General economic data sources include Open Energy INFO (OpenEI), American Wind Energy Association (AWEA), and the International Renewable Energy Agency (IRENA). A major environmental data source is the Environmental Protection Agency (EPA). Again, there are others which are cited as the data is obtained and applied. You can view a full table of our major data layers and their sources below, in Table 2. In terms of data quality and coverage, all data sources were assessed based on completeness, correctness, concordance, plausibility, and currency.

Case Study - Cape Wind

Cape Wind is one of the first offshore wind farms being constructed in the United States located on Horseshoe Shoal off the coast of Cape Cod. After several years of research, this location was selected because of several reasons: it has strong consistent winds; it is in protected, shallow water; it has close proximity to electrical transmission lines and the coast; and does not interfere with popular shipping and navigation routes (Cape Wind Assoc. 2014). This project is regarded as the poster child of domestic offshore wind projects in the U.S. and has showcased the advantages of offshore wind, including economic development opportunities it is bringing to the area (Roek 2011). The final project, which is currently in its financing and final commercial contracting stage before construction, is going to consist of 130 Siemens 3.6 megawatt turbines with a capacity of 468 megawatts which will produce 75 percent of the electricity used on Cape Cod and the islands of Martha's Vineyard and Nantucket (Cape Wind Assoc. 2014). While Cape Wind has strong stakeholder and public support, the project has highlighted the complexity of

development, permitting, and operating regimes of implementing a renewable energy project in the United States.

Local, state, and federal regulators battled private interest groups and Native American tribes, over the Cape Wind project for over a decade. Project coordinators needed several different types of approvals from several different organizations including: approval from the Cape Cod Commission in Massachusetts; a license from MA Department of Environmental Protection (MDEP); a water quality certification from MDEP; road permits and conservation commission approvals from two counties within Massachusetts; approval from the MA Highway Commission; certifications from the U.S. Department of the Interior, Army Corps of Engineers, Advisory Council on Historic Preservation, and Federal Aviation Administration; and finally, approval from MA Energy Facility Siting Board (Nussdorf 2011, 30). Requiring permits and approvals from these agencies and groups that have overlapping jurisdiction on county, state, and federal levels have been immediate obstacles to the development of the project and the industry of wind energy itself. Apart from these permits, the Cape Wind project has had a difficult time receiving the green light to begin construction because of special interest groups interfering, including: the World Wildlife Fund, Greenpeace, Conservation Law Foundation, and the MA Audubon Society (Nussdorf 2011, 30). These groups have repeatedly filed lawsuits in attempts to delay or halt the project from continuing under claims that the project violated different acts such as the Endangered Species Act, the Migratory Bird Act, and the National Environmental Policy Act (Nussdorf 2011, 30).

The project has thus far been successful in receiving all permits and winning or settling against lawsuits, however the example given by Cape Wind is much different than Europe's. The

first European offshore wind farm was built in 1991, and today there are currently 66 operating offshore wind farms employing more than 58,000 people in the industry (Cape Wind Assoc. 2014). It has been 25 years since the first offshore wind farm was constructed in Europe and the United States is still struggling to implement the first is a puzzling fact that reverts back to issues regarding policy. This project can look to Cape Wind as an example of what would theoretically be encountered while attempting a renewable project in Lake Michigan or Lake Superior.

Economic Feasibility Assessment

Gathering data for the economic feasibility assessment proved to be difficult due to the fact that many offshore wind farms are partially or entirely privately owned, and therefore total cost breakdowns were unavailable for many. Data, when accessible, on capital costs of other existing offshore wind farms was gathered and assessed in order to most accurately estimate the cost of construction of an offshore wind farm at the different sites chosen in Lake Michigan. Due to the variability of operation and maintenance (O&M) costs, these factors were unable to be estimated with any certainty. What is known about O&M costs is that they are typically higher than onshore projects because there is a higher cost of transportation and reduced site access, and that they can constitute up to 30 percent of overall costs for offshore wind farms (Blanco 2009, 1377). There are also few turbines that have reached the end of their life-cycle, and therefore dismantling costs are inaccessible as well. Capital costs can be as much as 80 percent of the total cost of the project over its lifetime, which includes the turbines, foundations, construction, and grid connection, and is therefore most important in determining the feasibility of a project (Blanco 2009, 1373-74). Capital costs are easier to estimate, and one research article estimated a

capital cost breakdown for an offshore wind farm which can be referenced. Again, due to the variability of projects and heavy dependence upon geographic location, these are subject to change country to country and project to project. Turbines and the foundation along with their installation are the most expensive parts of a project, estimated to be 35 percent and 25 percent of the total. Cables are the next most expensive, with the cables themselves and their installation adding up to another 19 percent of the total. Consenting, from government agencies and other groups, adds up to 7 percent. Other costs such as project management, installation of other parts, scada, and substation add up to the remaining 14 percent (Blanco 2009, 1377).

A completely accurate total cost estimate is unavailable without the assessment of a specialist or engineer for each specific project. The existing wind farms examined for this project are currently located in the seas or oceans, and therefore certain anti-corrosive materials needed in those projects would not be necessary for those in the Great Lakes. The criteria of the other existing wind farms taken into consideration were distance from shore, proximity to ports, water depth, and the number of turbines. The capital costs of each wind farm was recorded and then this criteria was compared to the selected sites in this project, which gave the estimate of what the potential total capital cost would be.

Site 1 (see figure 11), based on the criteria would cost around 12.5 million USD for 10 Vestas turbines, as it was most closely compared with Tunø Knob offshore wind farm in Denmark (Fakta om Vindenergi 2014). This cost would increase dramatically depending on the number of turbines chosen to install. A wind farm of 20 turbines extends over an area of 1 km while the potential area of Site 1 is 153 sq. km. and therefore, many more than 10 turbines have potential to be installed. The number of turbines installed is also dependent upon grid connection

however, and ensuring the electrical grid will not be overwhelmed and all turbines can be operational is important to a wind farm's success.

Site 2 (see figure 12) was estimated to have capital costs of greater than 417 million USD for 90 turbines and site 3 (see figure 13) was estimated at greater than 14 million USD for 10 turbines. These costs were determined again by taking data from existing wind farms and comparing it to the criteria of the selected sites (Fakta om Vindenergi 2014 and 4C Offshore 2016). The estimated capital cost is assumed to be greater than the two amounts given due to water depth at the selected sites. Site 2 has a water depth of 65-90 meters and site 3 has a water depth of 55-75 meters. Technological development for offshore wind farms in waters this deep are ongoing and incomplete. Innovative foundations and floating structures are under development for use in deep waters and have potential for implementation in the near future, however will be much more expensive due to the novelty of the structures (Bureau of Ocean Energy Management).

Taking into consideration the analysis from above, Site 1 is determined as most suitable due to current technology. Sites 2 and 3 have great potential for implementation when the foundations and supporting structures become available.

Conclusion and Further Research

This GIS-intensive research project had the goal of determining whether there are any suitable locations for an offshore wind farm off the coast of Wisconsin in Lake Michigan or Lake Superior and estimating a construction and implementation estimate. The most optimal sites should have a high energy wind energy potential, low environmental impact, not disrupt any

navigable waters, not be constructed on historical areas, not disrupt the view from urban areas, and be economically feasible. By taking into consideration several factors of what would classify a site as unsuitable, and using a map with optimal sites based on average wind speeds, we determined that many locations in Lake Michigan would be suitable. Due to the relatively low wind speeds and vast amounts of protected lands, there were no areas within Lake Superior that identified as suitable in our analysis.

Potential Site 1

The first potentially suitable site selected is perhaps the best, based on our criteria and reasoning. It is an area of 153 square kilometers approximately 6.34 kilometers offshore of Wisconsin's largest urban area, Milwaukee (see Figure 11). In fact, the Port of Milwaukee is roughly 7.02 kilometers away from the edge of this potential site. It boasts a strong wind speed class of 7, which averages between 8-8.5 meters per second at 90 meter elevation. The potential site is shaped by several historic shipwrecks in the area, but only poses minimal impact to environmentally sensitive areas. The area is not visible from anywhere on shore, and does not interfere with any major shipping routes. For 10 turbines in the area, an estimated cost of 12.5 million US dollars would be required.

Potential Site 2

Our second selected potential site is the largest potential area for an offshore wind farm (see Figure 12). This potential site is slightly further from shore than the other potential sites, but contains the highest wind speed class, class 8, which denotes an average of 8.5-9 meters per second at 90 meter elevation. The 510 square kilometer site is located approximately 9.2 kilometers offshore of Wisconsin, near the cities of Manitowoc and Two Rivers. The western

edge of the site is approximately 11 kilometers away from the Port of Two Rivers. Although there is an onshore protected area (Point Beach State Forest) near the potential site, we still feel that this site could be a good area for a potential wind farm, due to offshore wind farms' ability to create an artificial reef effect. For this large area, more turbines can be placed, so we estimated a cost of over 417 million US dollars for 90 turbines in the area.

Potential Site 3

The third and final selected potential site for our research project is again found in Lake Michigan. This site is the closest to Wisconsin's shore, being roughly 5.65 kilometers from shore and roughly 6.3 kilometers from the Port of Kewaunee (see Figure 13). However, it is the smallest site at 125 square kilometers. Wind speeds for this potential site are also very suitable, class 7, which averages from 8-8.5 meters per second at 90 meter elevation. Potential environmental impact is low, although there are a few important fish spawning locations near the area, so this potential site could also be a good area to test offshore wind farms' artificial reef effect. For this potential site, we estimated a cost of over 14 million US dollars for 10 wind turbines.

Further research

The sites identified take up large areas in Lake Michigan, ranging from 125-510 square km. Further analysis could be done to narrow down smaller sites within these areas that would limit the cost of the potential wind farm implementation and construction. One possibility is taking more exclusionary factors into account, or determining the type of platform and turbine that would perform best in the waters of the potential sites, as a few of these sites are in deep waters that may not support all types of platforms. Other factors could include revising site

locations with consideration for existing onshore infrastructure, a closer look at requirements for installation, proximity to existing power grids, and the amount of energy that could potentially be generated by these offshore wind farms. Though our analysis determines suitable sites in Lake Michigan for offshore wind farms, further analysis can be completed to pinpoint exact geographic locations. Once exact geographic locations are determined, more precise cost evaluations can be completed and proposed.

Conclusion

If the political climate is conducive to and supportive of the development of renewable energy infrastructure, then the implementation of offshore wind farms in Wisconsin's Great Lakes may be worth considering. However, there are some unavoidable trade-offs involved, as evidenced by this project: greenhouse gas reduction versus species protection, new job creation versus aesthetic risks to tourism industry, along with many more. To improve our offshore wind development and implementation process, there is a need for more research and a political paradigm shift regarding renewable energy in the United States as a whole.

Appendix

All figures and tables below are original graphics produced during our research.

Criteria	Data	Kim (2016)	Colmenar-Santos (2016)	Rodriguez-Rodriguez (2016)	Gregg (2015)
		Jeju Island, Japan	Spanish Coast	Spanish Coast	North Carolina
Environmentally Sensitive Concerns					
	Marine Water Quality	o			
	Endangered Species Habitat/ Conservation Areas	o		o	o
	Fish Habitats/Marine Mammals	o	o	o	o
	Sea Bird Habitats	o	o	o	
	Migratory Bird Flyways		o		o
	Parks	o		o	
Historical Locations/Human Activities					
	Fishing Grounds	o	o	o	o
	Electrical Transmission Lines		o		
	Proximity to Populations				
	Highways, Roads				
	Tourism		o		
	Historical		o	o	o
Navigable Waters					
	Shipping Routes (Ferries (Washington Island, MI to WI))	o		o	o
	Ports/Harbors	o			
View Protection					
	View Shed	o			
Landscape					
	Existing Infrastructure/Existing Wind Farms		o	o	
	Bythmetry	o	o	o	o
	Distance from Land	o	o	o	o
	Sea bed			o	o
Energy Resources					
	Wind Energy Potential/Average Wind Speed	o	o	o	o

Table 1: Four previous studies were used to determine variables to consider for our analysis.

Other variables considered to cater to unique location and attributes of Lake Michigan and Lake Superior.

Criteria	Layer	Source
Energy resources	Average wind speeds at 90-meter elevation	National Renewable Energy Laboratory
Environmentally-sensitive areas	Endangered species habitat	MarineCadastre.gov
	Protected or conservation areas	World Database on Protected Areas
	Fish spawning areas	Great Lakes Aquatic Habitat Framework
	Migratory bird stopover habitat	Great Lakes Migratory Bird Stopover Portal
Human activities	Historical shipwrecks	Molly Schumacher 2016 with data from The University of Wisconsin Sea Grant Institute
	Lighthouses	Molly Schumacher 2016 with data from National Parks Service
Navigable waters	Major shipping routes	United States Bureau of Transportation Statistics
	Ferries	Molly Schumacher created 10/20/2016
View protection	Residential or developed areas on shore	Molly Schumacher 2016 with data from Wisconsin State Cartographer's Office
Landscape concerns	Bathymetry	National Geophysical Data Center

Table 2: Major criteria, data layers, and their sources.

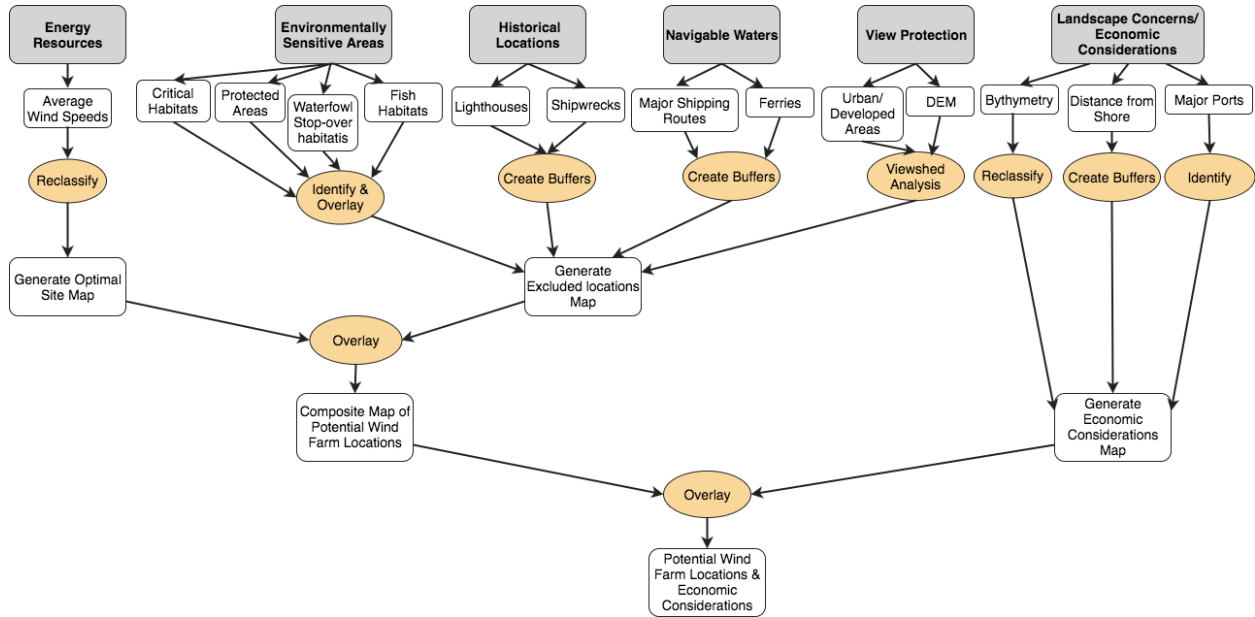


Figure 1: Conceptualization diagram denoting six criteria and variables used and layers created.

Highlights GIS operators and workflow of analysis.

Environmentally Sensitive Areas in Lake Superior

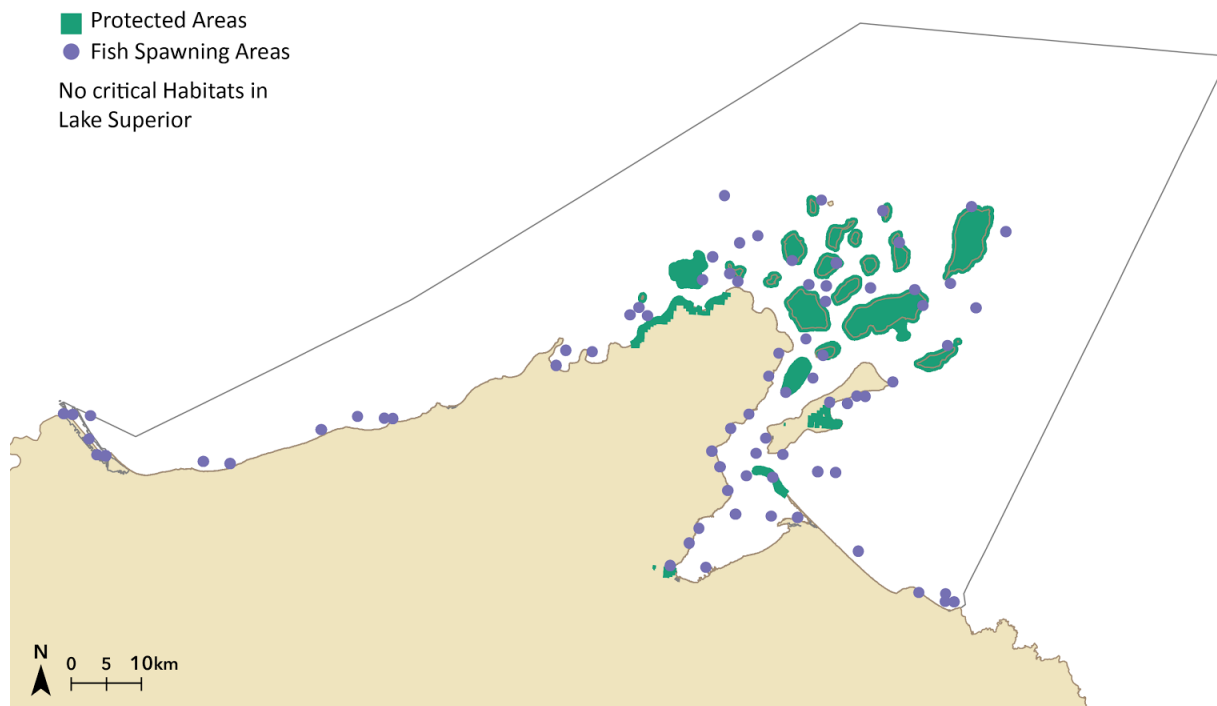


Figure 2: Map of environmentally sensitive areas in Lake Superior. Uses protected areas and fish spawning areas, no critical habitats identified in Lake Superior.

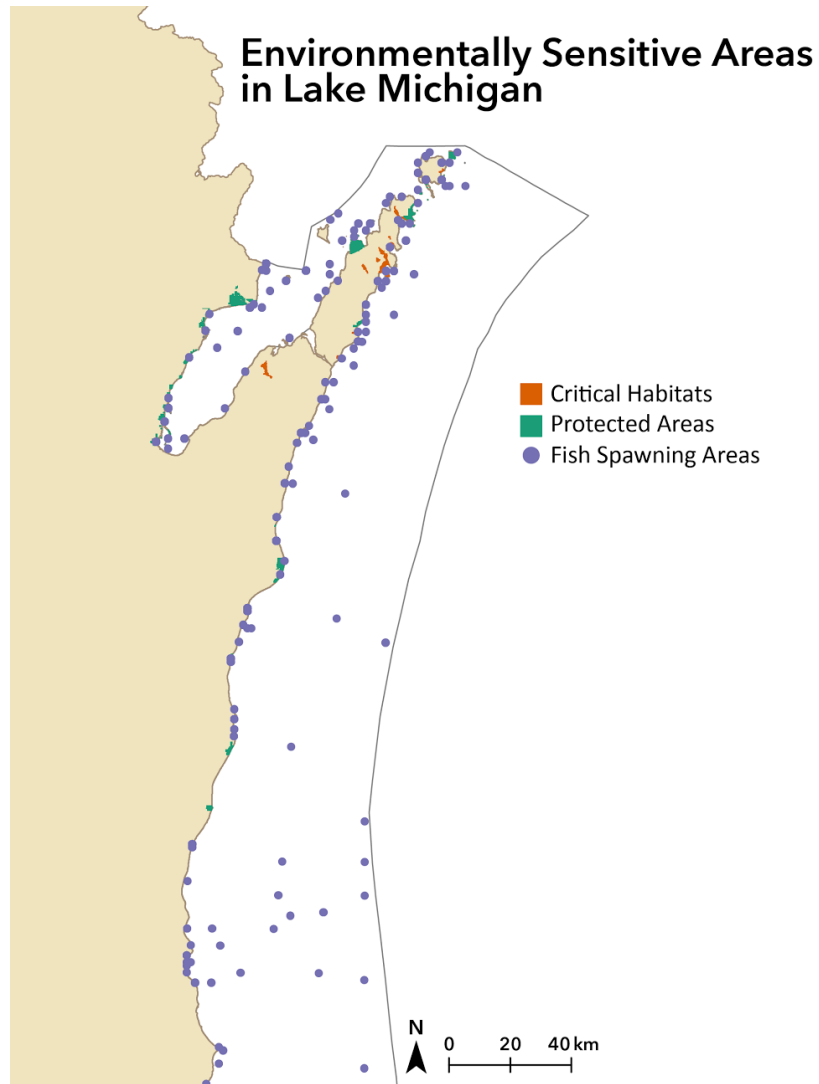


Figure 3: Map of environmentally sensitive areas in Lake Michigan. Uses protected areas, fish spawning areas, and critical habitats.

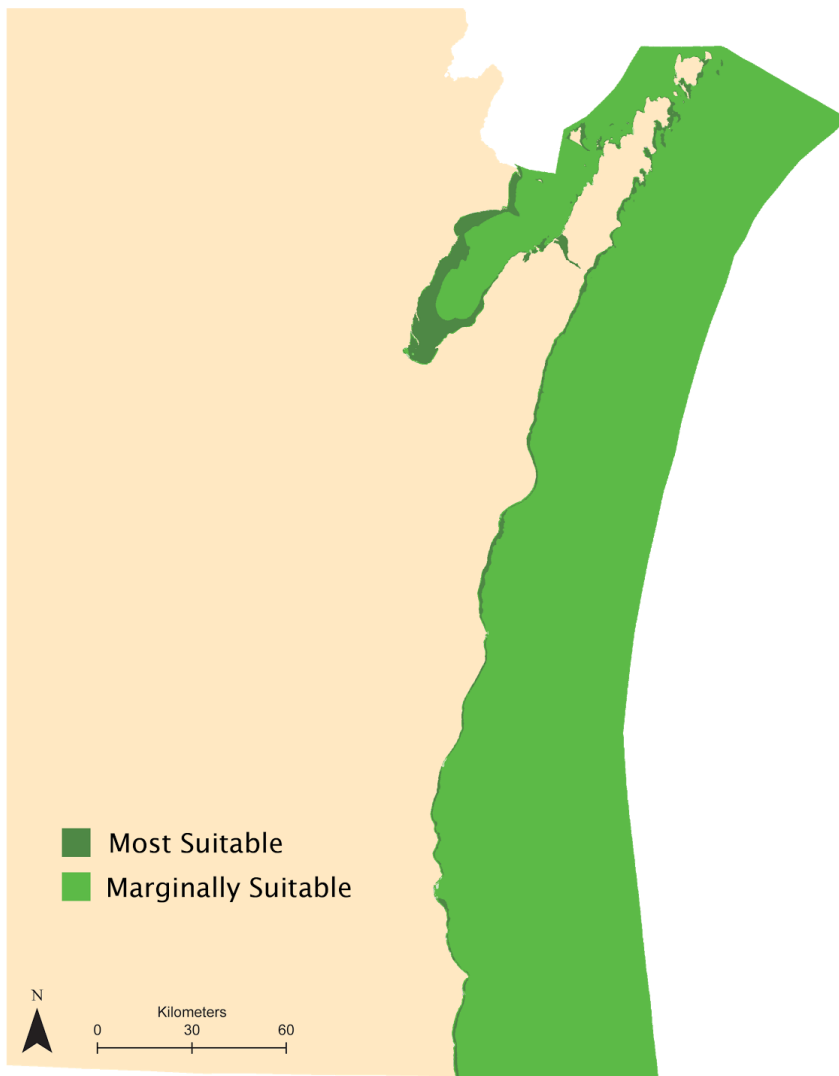


Figure 4: Map of waterfowl stopover habitats in Lake Michigan. No data available for Lake Superior. Scoring attributes include water depth, habitat patch size, amount of wetland covered within 3 kilometers, and adjacent cover type within 100 meters.

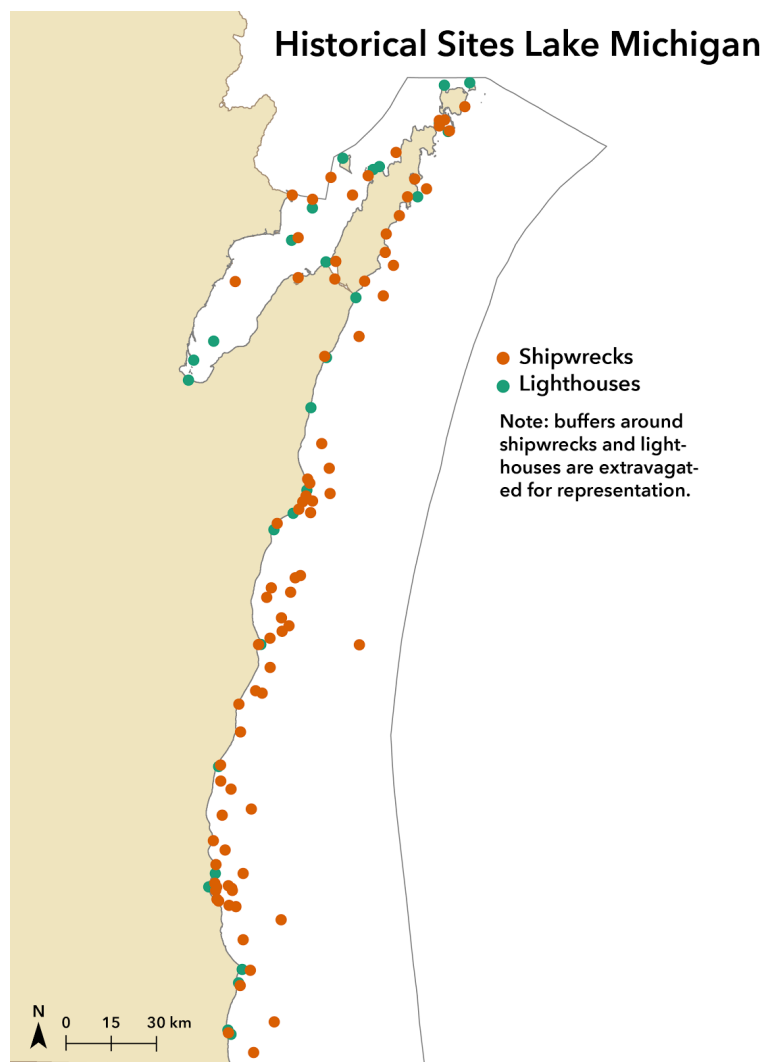


Figure 5: Map denoting historical locations considered in Lake Michigan. Includes confirmed shipwreck locations by the The University of Wisconsin Sea Grant Institute and lighthouses.

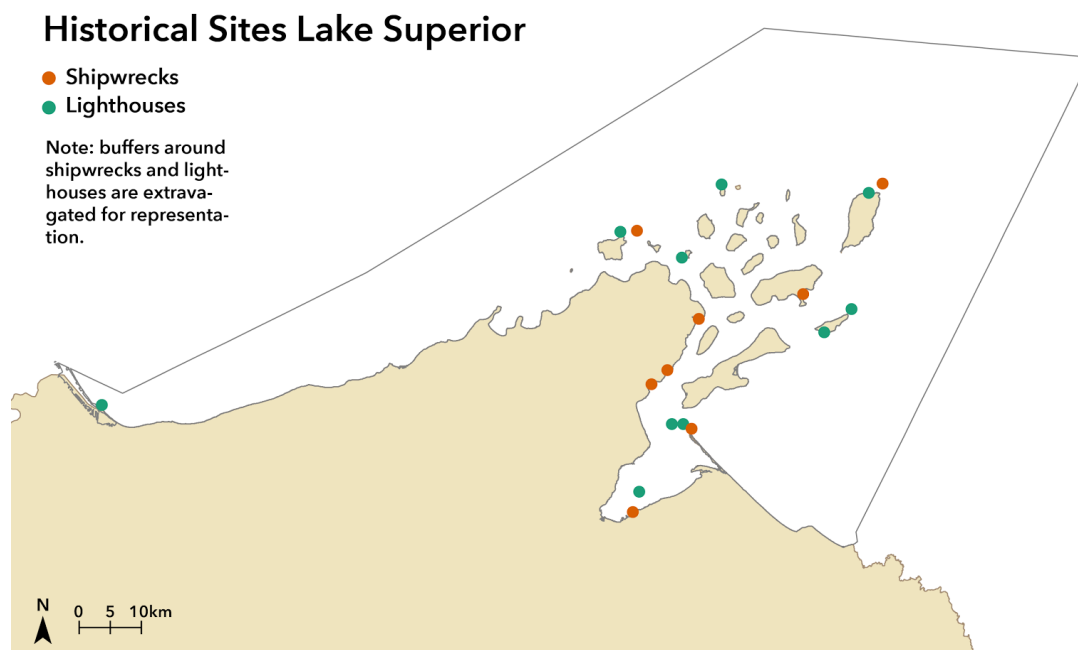


Figure 6: Map denoting historical locations considered in Lake Superior. Includes confirmed shipwreck locations by the The University of Wisconsin Sea Grant Institute and lighthouses.

Navigable Waters in Lake Michigan and Lake Superior

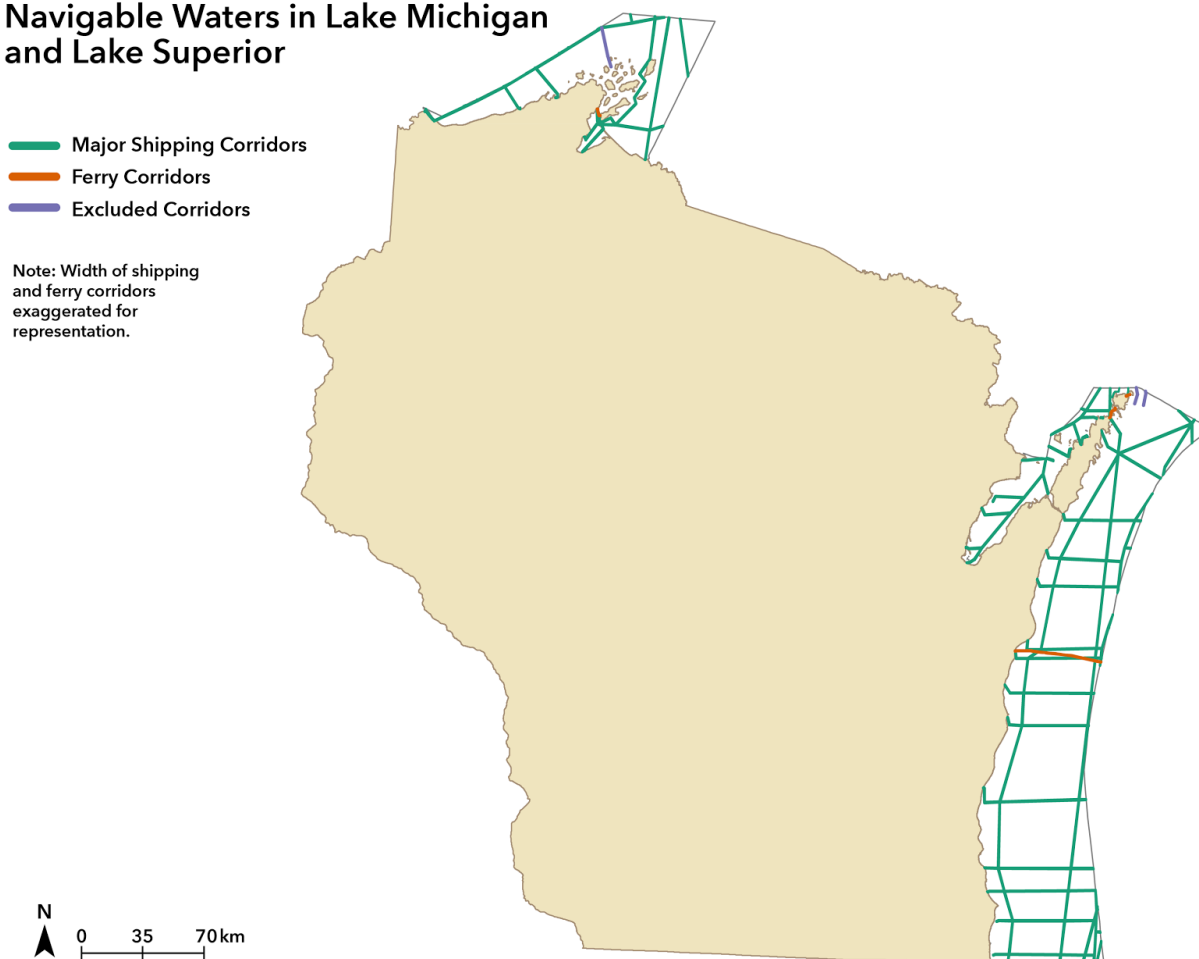


Figure 7: Map of navigable waters in Lake Superior and Lake Michigan. Includes major shipping corridors and ferry corridors. Excluded corridors consist of routes that were not considered. Due to poor metadata of the data, routes not considered were routes that stopped in middle of lake with no logical end point, possible far from land or from a port.

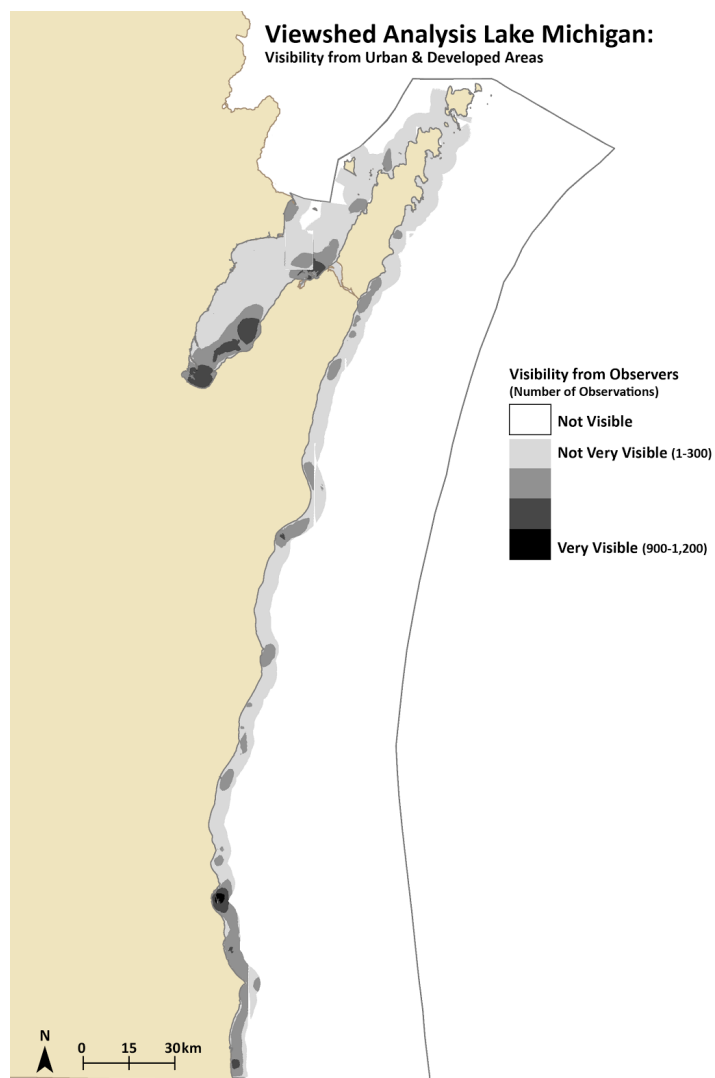


Figure 8: View protection analysis completed with viewshed analysis to determine the visibility of locations in the lake from shore. Took into account urban and developed locations on shore, determined from Wisconsin land cover. Due to many observer points, a scale was produced denoting how many times an observer point on shore observed the location in water. Equal interval breaks used.

Viewshed Analysis Lake Superior: Visibility from Urban & Developed Areas

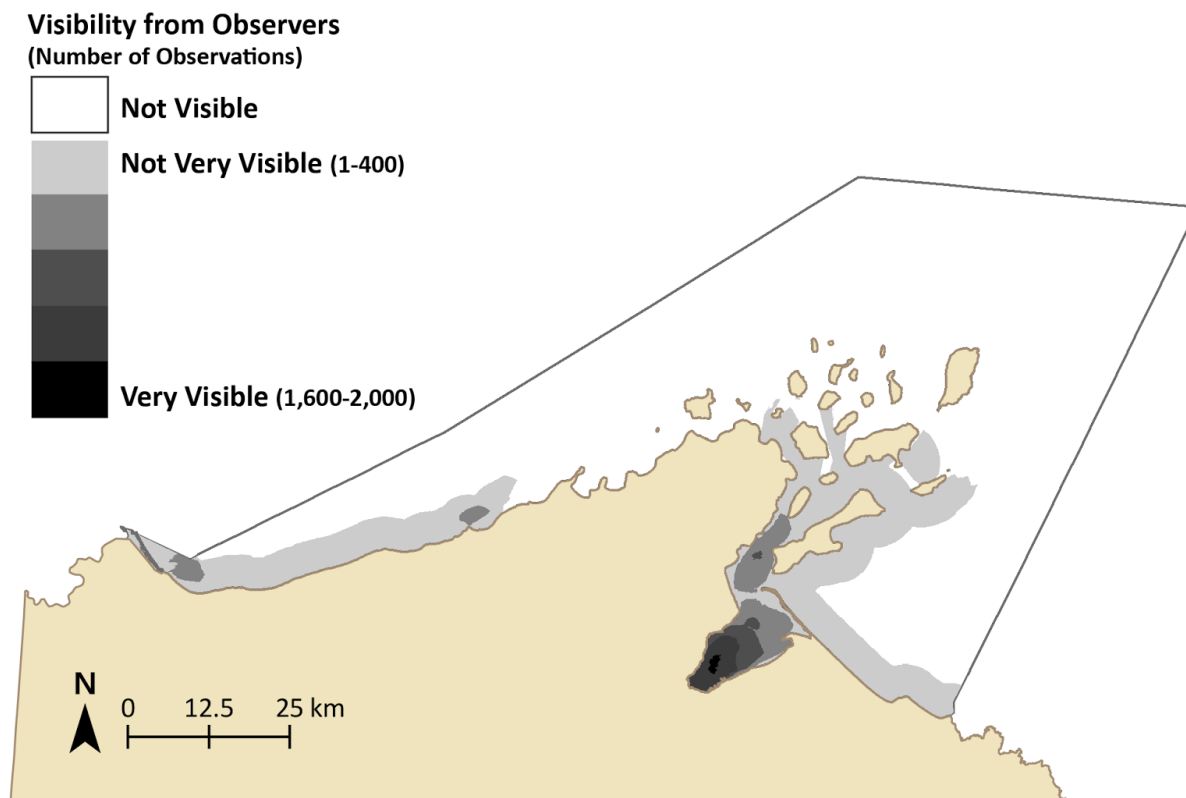


Figure 9: View protection analysis completed with viewshed analysis to determine the visibility of locations in the lake from shore. Took into account urban and developed locations on shore, determined from Wisconsin land cover. Due to many observer points, a scale was produced denoting how many times an observer point on shore observed the location in water. Equal interval breaks used.

Potential Wind Energy Resources

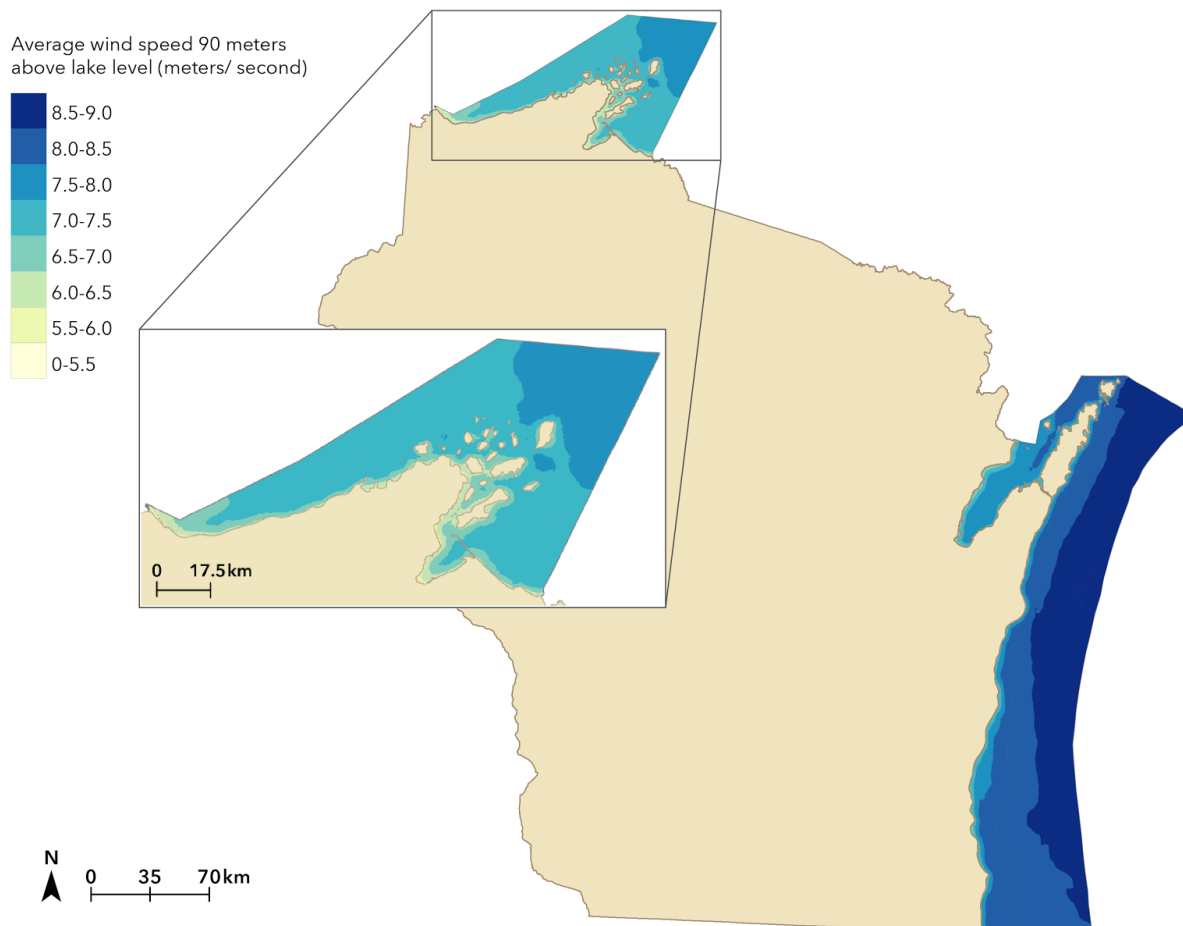


Figure 10: Optimal locations map based on average wind speeds at 90 meters above lake level.

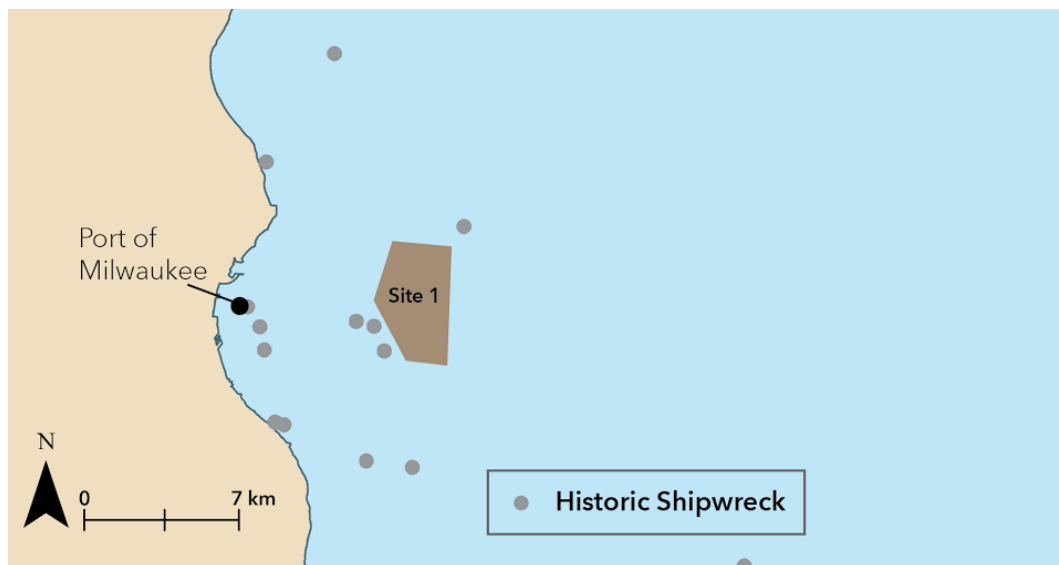


Figure 11: Map identifying the location of chosen site 1.



Figure 12: Map identifying the location of chosen site 2.

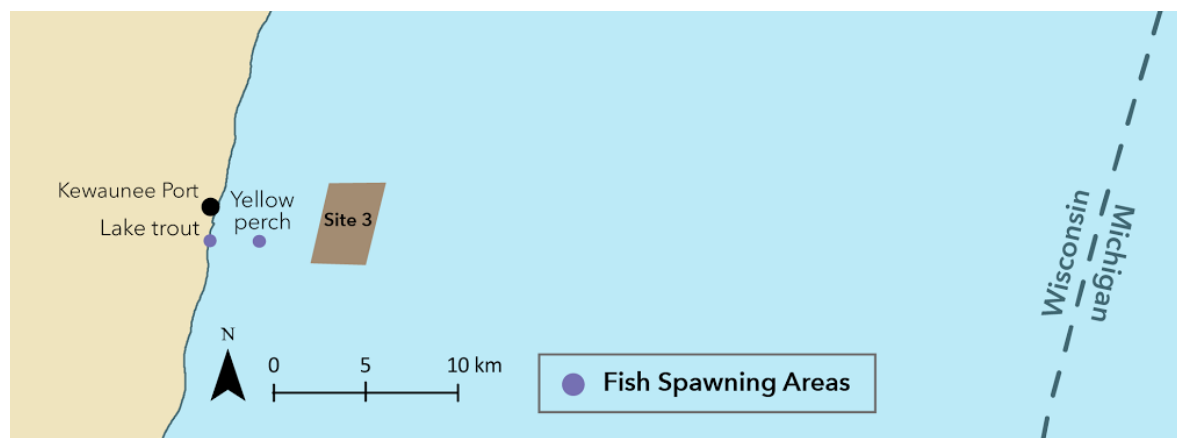


Figure 13: Map identifying the location of chosen site 3.

References

- Akbari, N., C.A. Irwan, D.F. Jones, D. Menachof. 2016. A Multi-Criteria Port Suitability Assessment for Developments in the Offshore Wind Industry. *Renewable Energy: An International Journal*. 102:118-133.
- Bishop, I., D.R. Miller. 2007. Visual Assessment of Off-shore Wind Turbines: The influence of distance, contrast, movement and social variables. *Renewable Energy*. 32:814-831.
- Ball, J. 2012. Tough Love for Renewable Energy: Making Wind and Solar Power Affordable. *Foreign Affairs*. 91:122-133.
- Blanco, María Isabel. 2009. The Economics of Wind Energy. *Renewable and Sustainable Energy Reviews*. 13:1372-1382.
- Booth, W.C., G.G. Colomb, J.M. Williams. 2008. The Craft of Research. *The University of Chicago Press*. 3:75-80.
- Bureau of Ocean Energy Management (BOEM). N.d. Offshore Wind Energy. Retrieved from: <https://www.boem.gov/Offshore-Wind-Energy/>
- Cape Wind Associates. 2014. *Cape Wind: Energy for Life*. <http://www.capewind.org/> (last accessed 3 November 2016).
- Castro-Santos, L., and V. Diaz-Casas. 2015. Cost Comparison of Three Floating Offshore Wind Platforms. *Journal of Coastal Research*. 31:1217-1221.
- Changing Shipping Routes. 2014. UDaily. Available at: <http://www1.udel.edu/udaily/2014/may/shipping-routes-051914.html>
- Colmenar-Santos, A.. 2016. Offshore wind energy: A review of the current status, challenges, and future development in Spain. *Renewable and Sustainable Energy Reviews*. 64:1-18.
- Gregg, K.L. 2015. Multi-criteria analysis of offshore wind energy site suitability in North Carolina. *ProQuest Dissertations Publishing*. 1:1-75.
- Holland, A. 10 June, 2013. Lawmakers Resist Wind Turbines in the Great Lakes. *Michigan Radio Newsroom*. <http://michiganradio.org/post/lawmakers-resist-wind-turbines-great-lakes> (last accessed 2 November, 2016).
- Kaiser, M.J., and B. Snyder. 2009. Ecological and Economic Cost-Benefit Analysis of Offshore Wind Energy. *Renewable Energy*. 34:1567-1578.

- Kim, T., J.-I. Park, and J. Maeng. 2016. Offshore wind farm site selection study around Jeju Island, South Korea. *Renewable Energy* 94:619–628.
- Kumar, I. 2014. A framework for statewide analysis of site suitability, energy estimation, life cycle costs, financial feasibility and environmental assessment of wind farms: A case study of Indiana. *ProQuest Dissertations Publishing*. 1:1-236.
- Langhamer, Olivia. 2012. Artificial Reef Effect in Relation to Offshore Renewable Energy Conversion: State of the Art. *The Scientific World Journal*. 2012:1-8.
- Lipp, Judith. 2007. Lessons for Effective Renewable Electricity Policy from Denmark, Germany and the United Kingdom. *Energy Policy*. 35:5481-5495.
- Meyer, N.I. 2007. Learning from Wind Energy Policy in the EU: Lessons from Denmark, Sweden and Spain. *European Environment*. 17:347-362.
- Milwaukee Wisconsin Journal Sentinel. 2012. Offshore Wind Farms Have Great Potential for State. <http://archive.jsonline.com/news/opinion/offshore-wind-farms-have-great-potential-for-states-0i53cf7-148344455.html>.
- NREL. 2016. Wind Data. Available at: http://www.nrel.gov/gis/data_wind.html
- Nussdorf, B. 2011. Emulating Europe: Setting a Course for Offshore Renewable Energy. *Natural Resources & Environment*. 25: 29-32.
- O'Reilly, C.M. 2013. Offshore wind farm siting procedures applied offshore of Block Island, Rhode Island. *ProQuest Dissertations Publishing*. 1:1-108.
- Roek, K.A. 2011. Offshore Wind Energy in the United States: A Legal and Policy Patchwork. *Natural Resources & Environment*. 25:24-28.
- Rodríguez-Rodríguez, D., et al., 2016. Achieving Blue Growth through maritime spatial planning: Offshore wind energy optimization and biodiversity conservation in Spain. *Marine Policy* 73:8-14.
- Rutkowski, Tom. Solar Racine. 6 October, 2016. Interview.
- Schnegelsberg, S.. 2007. Offshore Windfarm development and the issue of maritime safety. *Baltic Master maritime safety across borders*.

Schwartz, M., D. Heimiller, S. Haymes, W. Musial. 2010. Assessment of Offshore Wind Energy Resources for the United States.

The Solutions Project - 100% Renewable Energy. 2016. The Solutions Project. Retrieved from: Available from: <http://thesolutionsproject.org/>

The University of Wisconsin Sea Grant Institute. 2016. *Wisconsin Shipwrecks*. Wisconsin Sea Grant, Wisconsin State Historical Society. Retrieved from: <http://www.wisconsin-shipwrecks.org/Shipwrecks>

U.S. Department of Energy. 2014. WINDEXchange. Available at: http://apps2.eere.energy.gov/wind/windexchange/windmaps/offshore_states.asp?stateab=wi

U.S. Energy Information Administration. 2013. Feed-in Tariff: A Policy Tool Encouraging Deployment of Renewable Electricity Technologies. Retrieved from: <http://www.eia.gov/todayinenergy/detail.php?id=11471>

Fakta om Vindenergi. 2014. Vindmøller på Havet. Retrieved from: <http://www.dkvind.dk/fakta/p4.pdf>

Wind Measurement International. N.d. FAQ. Retrieved from: http://www.windmeasurementinternational.com/wind-info/wind-energy_faq.php

WindMonitor. 2016. Turbine size. Available at: http://windmonitor.iwes.fraunhofer.de/windmonitor_en/4_Offshore/2_technik/3_Anlagen_groesse/

4C Offshore. 2016. Rødsand 2 Offshore Wind Farm. Retrieved from: <http://www.4coffshore.com/windfarms/r%C3%B8dsand-2-denmark-dk11.html>

Viability of Offshore Wind Energy Sources Across Wisconsin's Great Lakes:

An analysis of site suitability for offshore wind farms off the Wisconsin shoreline in Lake Michigan and Lake Superior

