Offshore Wind Development and the Environment

POTENTIAL IMPACTS FOR BIRDS, FISH AND THE COASTAL ENVIRONMENT

WEST MICHIGAN WIND ASSESSMENT ISSUE BRIEF #10

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The West Michigan Wind Assessment is a Michigan Sea Grant-funded project analyzing the benefits and challenges of developing utility-scale wind energy in coastal West Michigan. More information about the project, including a wind energy glossary can be found at the website, www.gvsu.edu/wind.

Introduction

Building wind turbines offshore presents many environmental, social, technical and economic challenges.

The United States faces the major dilemma of meeting energy demands while simultaneously reducing the environmental consequences of energy production. How we resolve this dilemma has implications for the nation's economy, environment and energy security. One of the many methods proposed for addressing this challenge is using the wind resource available off the coast of the United States to generate electricity. The offshore wind resources in the coastal regions of the United States are vast and often located near heavily populated areas where electricity demand is high. Building wind turbines[1] offshore presents many environmental, social, technical and economic challenges[2]. This issue brief focuses on the consequences — both positive and negative — that wind farms could have on the coastal environment of West Michigan.

The Great Lakes provide humans with valuable services from drinking water to seafood to recreation. In a recent analysis, Michigan Sea Grant researchers found that the Great Lakes are directly tied to 1.5 million jobs that generate $62 billion in wages [1]. The dynamic and sensitive coastal ecosystems also are home to dozens of power plants. For example, along Lake Michigan, 24 coal-fired and five nuclear power plants operate on the shores and use lake water to cool their steam turbines. A pumped storage facility is also located south of Ludington, Michigan.

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Renewable energy technologies such as offshore wind are now being investigated for use in the Great Lakes to supplement the growing need for electricity for large energy markets such as Chicago, Milwaukee, Detroit and Cleveland. Michigan's Great Lakes coastal zone is a multi-use area and power plants have been a part of the coastline for decades. Conventional forms of thermal power production have had long-lasting effects on the Great Lakes ecosystem. Introducing offshore wind power to Michigan's energy portfolio will affect the environment in new ways, but could also reduce some harmful effects if wind farms reduce the state's reliance on other forms of electricity production.

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[1]A wind turbine is a machine that captures the force of the wind. The West Michigan Wind Assessment website has a glossary of wind energy terms at http://www.gvsu.edu/wind/project-documents-3.htm. Other relevant definitions not found in the glossary will be defined at the bottom of the page.

[2]An issue brief titled *Offshore Wind Energy: Public Perspectives & Policy Considerations* examines the economic, social issues, public acceptance, visibility and regulatory issues in Michigan as they relate to offshore wind. The brief is also available using the link above.

In this issue brief, the environmental impacts of offshore wind energy are discussed in relation to the phase in which they occur (Figure 1). The brief begins with an assessment of the construction and decommissioning phases, which are largely similar. The second section discusses the operational phase impacts, including effects on air quality, birds, bats and fish of the Great Lakes. The brief concludes with a case study of the world's only freshwater offshore wind farm, the Vindpark Vänern in Sweden. The Cape Wind Energy Project is referenced throughout.

No offshore wind farm has been constructed in North America to date.

No offshore wind farm has been constructed in North America to date. One project, the Cape Wind Energy Project off the coast of Cape Cod, Massachusetts, has undergone extensive planning and has received a permit from the Department of the Interior. The permitting process included a Final Environmental Impact Statement (FEIS), which describes the likely environmental and social impacts from this planned offshore wind farm [2]. This issue brief highlights some of the key findings of the Cape Wind Report (FEIS) and analyzes the connection to the West Michigan environment. The Cape Wind Report summarizes the environmental impacts using the following terminology, which is also used in this brief:

- **Negligible**: No measurable impacts.
- **Minor**: Most impacts to the affected resource could be avoided by taking specific actions, or if impacts occur, the affected resource would recover completely without any mitigation once the impacting agent is eliminated.
- **Moderate**: Impacts to the affected resource are unavoidable, and the viability of the affected resource is not threatened, although some impacts may be irreversible. The affected resource is expected to recover completely if proper steps are taken during the life of the proposed action or proper remedial actions are implemented once the cause of the impact is eliminated.
- **Major**: Impacts to the affected resource are unavoidable and the viability of the affected resource may be threatened. The affected resource is not expected to fully recover even if proper steps are taken during the life of the proposed action or remedial actions are implemented once the cause of the impact is eliminated [2].

Potential environmental impacts of offshore wind farms are organized according to the phase in which they occur.

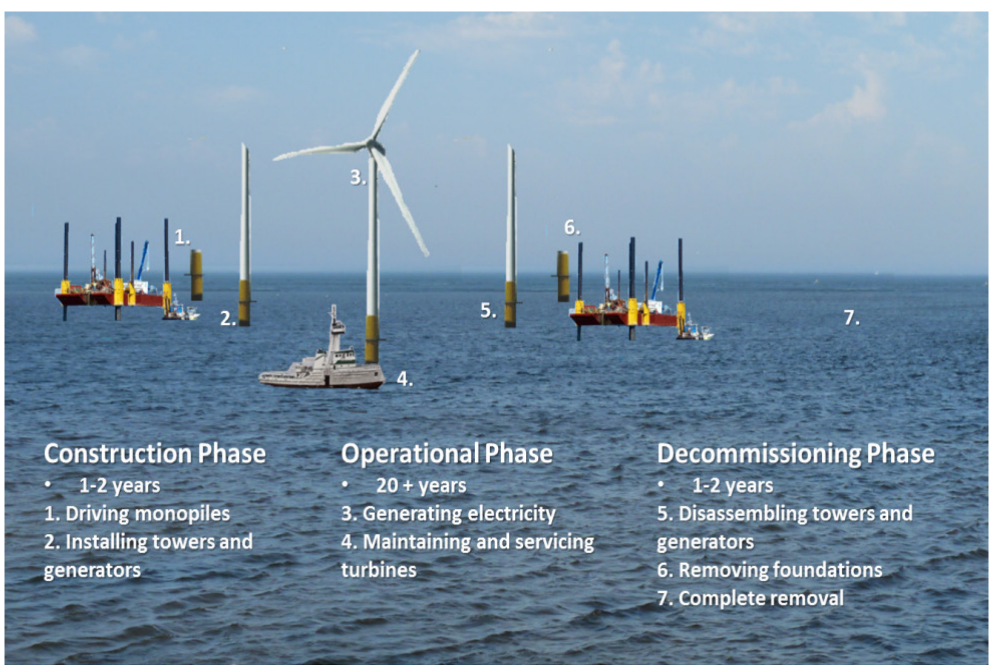

Figure 1: Phases of offshore wind farm life-cycle. Note: objects are not to scale.

Effects During Construction and Decommissioning

The Great Lakes Offshore Wind Council was formed in 2009 to examine the issues and advise the state about offshore wind development. Its reports serve as a reference for this brief.

Constructing and decommissioning — or removing — offshore wind turbines involve many of the same procedures, vessels and equipment. The impacts, therefore, are also similar and are grouped together here.

Any construction activity must be preceded by proper planning to avoid potential impacts. Michigan has already engaged stakeholders in planning for future, potential offshore wind energy development through the Great Lakes Offshore Wind (GLOW) Council. Policy makers, academic scientists, commercial fishermen, resource managers and others have collaborated to identify the areas in which offshore wind energy development would have the least impact. This process included mapping essential fish habitats and other areas that should be avoided [3].

Constructing the Foundation

One of the first steps in constructing an offshore wind farm is building the foundation: the underwater structure that will support the tower. The different types of foundations vary in their environmental impacts. This brief focuses on the most common foundation type for offshore wind turbines: the steel monopile.

Monopile construction can have several environmental impacts, notably sediment disturbance and noise from pile driving.

Monopile foundations are basically a large steel pole driven into the lake bed. A specialized vessel called a jack-up barge is typically used for both construction and decommissioning (Figure 1). Monopile construction can have several environmental impacts, notably sediment disturbance and noise from pile driving. The Cape Wind Report classifies the offshore and underwater construction noise as minor [2]. The duration of the construction period varies by the size of the project. The Cape Wind project, for example, includes 130 turbines, and the pile-driving phase is expected to last for eight months, but is not expected to be heard on land [2].

Constructing and decommissioning wind turbines, particularly noise from monopile installation, will likely result in short-term disturbances to fish [4]. Pile driving noise is loud enough to change fish behavior and cause them to avoid the construction area. The noise, however, is not loud enough to kill fish. Fish species vary in their sensitivity to noise and most of the research has been conducted on saltwater species. In the ocean, Atlantic salmon were found to avoid areas about 0.9 miles (1.4 km) around the construction site [5].

Environmental reports for Cape Wind determined that the construction-phase impacts to fish and commercial and recreational fishing are expected to be minor.

The Cape Wind Report (FEIS) notes that the construction-phase impacts to fish at all stages of development (egg to adult) and to commercial and recreational fishing are expected to be minor. Current plans do no prohibit fishing in the project area during construction and decommissioning, but temporary safety zones around active construction sites and vessels may be enacted [2].

Wind farm construction will disturb sediments, making the surrounding water more turbid temporarily and potentially releasing any contaminants in the sediments. The Cape Wind Report indicates that certain sensitive animals such as marine mammals may be moderately affected by the turbidity caused by pile driving.

Construction can also affect bottom-dwelling invertebrates. The base of the foundation is usually covered with scour protection to protect it from abrasion from currents. Engineers have used boulders, gravel, and even synthetic sea-grass fronds as scour protection. Benthic (bottom-dwelling) organisms will colonize the foundation and scour protection rocks. The complex, three-dimensional structure of the foundation provides habitat for aquatic creatures, although, as discussed later, the foundations will likely be colonized by invasive species.

Decommissioning the turbines will entail removing the foundation and will result in a loss of this additional habitat, and the fish that depend on these communities would disperse [2] (see also section below on Fish and Benthic Invertebrates). In the Cape Wind Report (FEIS), the planned decommissioning process calls for cutting the steel monopole 15 feet below the ocean floor [2]. That is, a 15-feet deep hole is excavated around the monopile, the steel tube is cut, and the remaining structure is buried.

The complex, three-dimensional structure of the turbine foundation provides habitat for aquatic creatures.

One study assumed that each offshore turbine structure, including the tower and scour protection, would cover about 5,000 square feet (0.1 acres) of seabed [6]. Using Cape Wind as an example, the total affected seabed area is expected to range between 11 and 47 acres, depending on the technology used. Because wind turbines are spread across a large area, the turbine foundations would change less than one percent of the total project area. The construction impacts for bottom-dwelling organisms including shellfish are expected to be minor [2].

In addition to monopiles, gravity foundations and "suction buckets" as well as emerging technologies like floating wind turbines are possible, although there are very few examples of these technologies being used for wind energy applications. Table 1 provides a brief description of some of these foundation types. The HyWind floating wind turbine, located off the coast of Norway, is a single, 2.3 MW floating wind turbine located in 220 meters (722 feet) of water. Installation of the HyWind turbine can take place in water depths up to 700 meters (2,300 feet) [7]. The relative environmental impacts of these alternative designs in wind energy applications are largely unknown.

Monopile foundations, the most common type of foundation, require sediments that are suitably thick, compacted, and homogenous.

Foundation types differ in their requirements for suitable lake bed geology. Monopile foundations, the most common type in wind energy applications, require sediments that are suitably thick, compacted and homogeneous. Sand deposits are more suitable for monopile foundations than clay deposits. Gravity foundations, on the other hand, are restricted to regions that are relatively smooth, gently sloping or flat, with sediments that are fairly stable [8].

Foundation Type	Advantages	Disadvantages
Monopile	Most common foundation type No bed preparation Simple to construct and install Low sensitivity to underwater erosion Foundation flexibility	Installation is noisy Sensitive to sediment composition such as rocks Not good in weak sediment Hard to equip with ice cone May not work for large turbines or deep water
Concrete Gravity	Well-known technology for other applications Can construct onshore	Large and heavy Removal is more complicated
Steel Gravity	Can construct onshore Lighter than concrete Fast installation No piling and can be removed	Needs filler to withstand ice and waves Needs large lay down area to build Requires time-consuming welds
Suction Bucket	Simple and quick to construct Less equipment required for installation Can be removed easily Inexpensive to install	New technology Proven only in limited materials

Table 1: Comparison of shallow water foundation types [9].

Laying the Transmission Cable and Erecting Towers

Many locations in the Great Lakes and other coastal areas have legacy pollutants in the sediment from previous industrial activity. In these areas, construction and dredging can risk re-suspending the pollutants into the water column [10]. If pre-construction tests revealed that a project site was contaminated with legacy pollutants, then project developers would likely be required to take steps to reduce the risks, such as removing the contaminated sediment or relocating the project [11].

Construction and dredging can risk re-suspending pollutants into the water column in areas with legacy pollutants in the sediment from previous industrial activity.

Several construction activities could affect sediments, including positioning the legs of the barge, driving the monopiles, and burying the electricity transmission cable. In a typical setting, the cable is buried six feet below the lake bed. Installers use a jet plow to create a trench in which the cable will lay. The jet plow uses a pressurized flow of water to "fluidize" the sediment — essentially turn it to quicksand — and then the cable sinks into the trench under its own weight. The fluidized sediment then covers the cable as it resettles into place [2]. The effect of cables and cable installation through shoreline habitats would need to be considered and planned carefully.

It is possible that exposed undersea cables can affect fishing methods, for example, by interfering with bottom trawling gear. Burying the cable six feet under the seabed should avoid this issue [2]. Bottom trawling is rarely used by the major commercial and recreational fisheries of the Great Lakes, though it is used in scientific studies [12].

Wind turbine construction can have a moderate impact on birds. Birds may be disturbed by construction activities or may collide with towers and turbines under construction. Some of the birds affected by the Cape Wind project are the very same species found in Michigan as residents or migrants, such as the common loon [2]. One can reasonably expect that an offshore wind farm in Lake Michigan would have a similar moderate impact on water birds during construction, though project-specific analyses would be needed.

The operational, electricity generating phase of an offshore wind farm could last 20 years or more.

Effects During Wind Turbine Operation

The operational, electricity-generating phase of an offshore wind farm could last 20 years or more. The electricity generated by the offshore wind farm will have benefits but will also come with risks. The benefits are primarily to air quality improvements. Out of 47 environmental resources analyzed in the Cape Wind FEIS, the following resources were most at risk:

- Marine birds: *negligible to major impacts*
- Coastal birds: *negligible to moderate impacts*
- Terrestrial birds: *negligible to moderate impacts*
- Threatened and endangered birds: *minor to moderate impacts*
- Fishing vessel traffic: *minor to moderate impacts* [2]

Recall that, in this context, a moderate impact is one in which the viability of the resource is not threatened and specific best practices can help the resource completely recover, but some impacts may be irreversible. Major impacts are those in which the resource would not fully recover — even if appropriate best practices are applied [2]. The following sections provide more detail about the impacts offshore wind farms may have during operation, especially on air quality, birds and fishing.

Air Quality Benefits

Like onshore wind energy facilities, offshore wind turbines should have a beneficial impact on air quality. Electricity generated from wind power does not produce harmful air pollutants and can reduce our reliance on more polluting forms of electricity generation. A companion wind issue brief examines the air quality impacts of wind power in more detail [13]. Expected air quality benefits of expanded wind power production include:

- If wind farms reduce the use of fossil fuels, then emissions of harmful pollutants including sulfur dioxide (SO_2), nitrogen oxides (NOx), and carbon dioxide (CO_2) will also be reduced [14].
- Improving air quality can result in measurable improvements in human health and reduced health care expenses [15].
- Wind farms could also avoid climate-disrupting CO_2 emissions, with economic and social benefits [15].
- If wind farms reduce the use of coal-fired power plants, mercury emissions and the resulting toxic accumulation in fish could also be reduced [16].

A hypothetical 100 MW offshore wind farm could produce 262,800 MWh of electricity and avoid 630 tons of sulfur dioxide per year.

For details about the studies and analysis behind these effects, see the companion issue brief, *Wind Power and Air Quality: Reducing Air Pollution and Carbon Emissions in West Michigan* [13].

Potential Impacts for Birds

Many North American bird species move through the Great Lakes region and many other species form resident populations. As noted above, operating offshore wind turbines can pose a risk to birds, particularly water birds. Offshore wind energy is most advanced in Europe and most of the studies of offshore wind turbine-bird interactions have taken place in European waters. Though the European environment is different from Michigan's Great Lakes, especially the saltwater ecosystem, some researchers have studied birds that live in Europe and North America or have close relatives such as mergansers, various gull species and cormorants [17]. However, the effect of wind turbines for the many smaller birds, such as songbirds that migrate through the Great Lakes region, are less well studied. Operating offshore wind turbines can affect birds in three ways: by causing collisions, reducing habitat and creating barriers [18].

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Collisions

Studying bird-turbine collisions in the offshore environment is considerably more difficult than on land. Remote sensing techniques such as radar can be used to document the number of birds that fly near a wind turbine and estimate the chance of collisions [18]. For example, scientists used radar to study the Nysted wind farm off the coast of southern Denmark where thousands of waterfowl migrate between wintering and breeding grounds. Figure 2 illustrates the flight paths of these migrating birds, revealing that most birds avoided the wind development.

The researchers at Nysted estimated that less than 1 percent of all ducks and geese migrating in this area flew close enough to the turbines to risk a collision, and only 0.022 percent would die as a result of a collision with a turbine blade [19]. Accord-

[3] The authors estimated that 1 MWh of wind-generated electricity would avoid 4.8 lbs of SO2.
[4] Kaffine et al. estimate that in the Midwest grid, 1 MWh of wind energy avoids 1.025 tons of CO2.

ing to the research team, these estimates for potential collision are inflated since birds flying within the reaches of the turbine blades could actually fly below, above or even unharmed through the sweep area [20]. This study focused on large migrating birds (ducks and geese) and it is unclear if small or resident birds behave in a similar manner. There are many smaller bird that migrate through the Great Lakes that would need to be studied carefully.

Researchers estimated that less than 1% of all ducks and geese migrating in southern Denmark flew close enough to the Nysted wind farm turbines to risk collision.

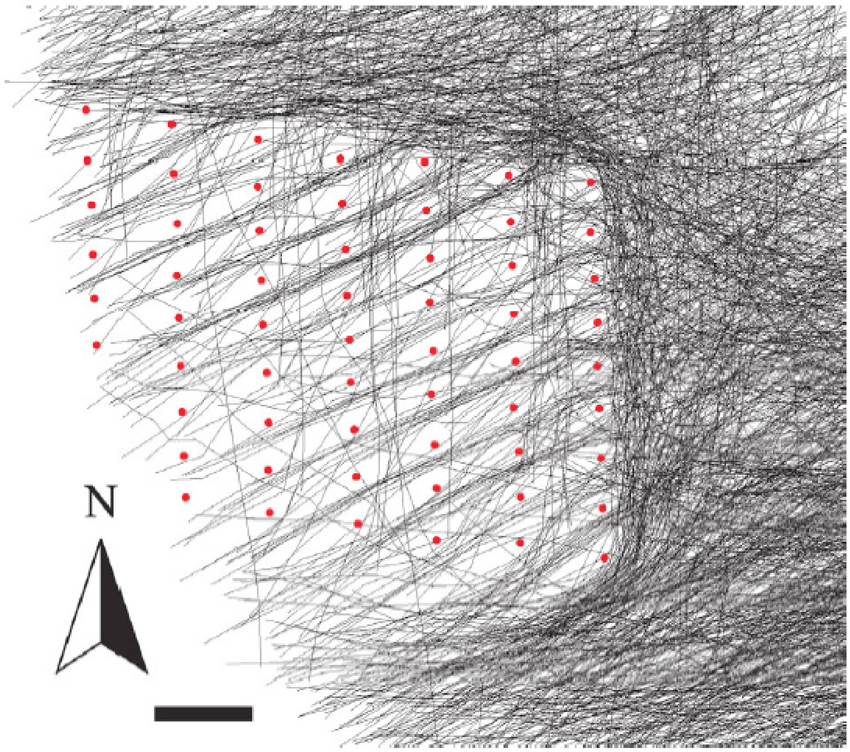

Figure 2: Waterfowl flight paths with respect to operating offshore wind turbines. Black lines indicate bird flight paths and red dots are wind turbines [19]. The thick black line represents 1000 meters to show scale.

Researchers involved in each of the bird studies concluded that they did not have enough data to generalize about how wind turbines could affect bird habitat.

Habitat Loss

A series of studies conducted off the coast of Denmark and Sweden looked at how wind farms affect the habitat available for seabirds. Waterfowl that once used the wind farm area for feeding or breeding dropped off substantially once construction of turbines began [20; 21; 22]. Some but not all birds returned once the wind turbines were operating normally. For example, some once-common species of loon avoided the wind development area [18].

The amount of time it takes for birds to re-inhabit the area is often dependent on how long it takes for the prey species to re-establish populations in habitats that may have been disturbed during the construction process [21]. This is particularly true for fish-eating birds. In contrast with loons, the presence of wind turbines actually increased the numbers of herring gulls and cormorants in the area; cormorants use the turbine foundations as a resting place while drying their wings [18; 23]. The researchers involved in each of these bird studies also concluded that they did not have enough data to generalize about how wind turbines could affect bird habitat more broadly.

Barrier Effect

Some birds will change their flight path to avoid a wind farm, which can increase the amount of energy they expend moving between habitats. As a result, a wind farm can act as a barrier that disrupts linkages between breeding, feeding, roosting or molting areas. This barrier effect will impact some species more than others [24]. For example, migrating songbirds that must cross the Great Lakes have limited reserves and a detour around a wind farm could be significant.

Avoidng a wind farm can increase energy expenditures as birds move between habitats. This can disrupt linkages between breeding, feeding, roosting or molting areas.

Species such as loons, cormorants and certain types of diving ducks are found to regularly detour around wind farms. However researchers have not yet been able to determine if this has a significant impact on these birds' reproductive fitness. This barrier effect is not unique to man-made structures. Studies have shown that weather patterns also force migrating birds to fly longer distances. A detour, whether around a storm system or a wind farm, should not be biologically significant unless it is dozens or hundreds of miles [18]. The distance a migrating or residential bird would have to fly to avoid a wind farm ranges from less than 1 mile to approximately 3 miles [19; 20].

Potential Impacts for Bats

Land-based wind turbines have come under scrutiny for impacts on bats, but little is known about how offshore turbines could affect them. It is possible that foraging or migrating bats could collide with the turbines towers or blades. There are anecdotal reports of bats flying over Lake Michigan [25]. During times of migration most bats tend to follow features on the terrestrial landscape such as rivers and ridges and are not known to spend substantial time over large water bodies [26; 27; 28].

Most migrating bats tend to follow features on the terrestrial landscape and are not known to spend time over large water bodies.

The Cape Wind Report (FEIS) classified the expected operational impact of the turbines on bats as minor because though bats may fly over Nantucket Sound, they are not expected to forage in the project area [2]. It is reasonable to expect Michigan's bats, which are largely of the same species as those in Massachusetts, to behave similarly. Researchers from Grand Valley State University and Michigan Natural Features Inventory are investigating bird and bat activity over Lake Michigan as part of the Lake Michigan Offshore Wind Assessment Project, which should provide more local information (http://www.gvsu.edu/marec/lake-michigan-offshore-wind-assessment-project-62.htm).

Potential Impacts for Fish and Benthic Invertebrates

Some fish, including European eels, perch, pike and Chinook Salmon, may be sensitive to the electrical and magnetic fields created by buried electric cables.

The expected operational impact on fish of an offshore wind farm like Cape Wind is likely to be negligible to minor, including effects related to prey species, sound and vibration and habitat changes [2]. Research suggests that some fish may be sensitive to the electrical and magnetic fields from submarine electric transmission cables [4]. Other researchers have shown that certain species, including European eels, perch, pike and Chinook salmon, are sensitive to magnetic fields. However there is a lack of scientific information about whether underwater transmission cables actually affect fish physiology and behavior [29]. The Cape Wind Report classifies the impact of electrical and magnetic fields as negligible [2].

Operating offshore wind farms have a negligible to minor impact on the ecological aspect of commercial and recreational fisheries. The effect on fishing vessel traffic, however, may be minor to moderate. Increased operations and maintenance traffic in the project area could cause fish to avoid those areas. The distance between turbines is usually great enough as to not interfere with trawling gear. Navigation within the project area is expected to be moderately impacted, but the effects could be reduced through Coast Guard-approved actions, such as establishing directional traffic lanes [2]. Inclusive planning processes, like the Michigan GLOW Council process, can help identify important fishing resources during the planning phase so that turbine operation does not interfere with fishing activities [3].

The Coast Guard evaluates the navigational risks of specific offshore wind projects and cooperates with the lead permitting agency.

The U.S. Coast Guard evaluates the navigational risks of each proposed offshore wind farm and then cooperates with the lead permitting agency [30]. The Coast Guard's current policy does not include exclusion zones around offshore wind farms; however, Coast Guard officials have stated that "it is not possible to create a 'one-size-fits-all' policy" about navigation around offshore wind farms [30, p. 6]. The current plan for the Cape Wind project does not exclude fishing or vessel traffic inside the project area.

Once operational, the turbine foundation will be colonized by benthic (bottom-dwelling) organisms. The rocks and/or scour mats provide habitat for various aquatic creatures which in turn attract fish, just like other jetties, pier pilings and other underwater structures. A number of researchers have studied the aquatic life around wind turbines and found that:

Researchers found that the numbers of mussels, barnacles and fish increased around offshroe wind farms in Europe compared to references sites.

- Mussels, barnacles and other sedentary organisms increased in both species abundance and biomass at the Horns Rev wind farm in Denmark [10];
- Fish abundance and biomass was greater around Swedish wind farms compared to that of reference sites [31]; and
- Surrounding the foundation with boulders tends to provide more surface area, crevices, and habitat diversity than using gravel. More complex structures, including concrete jacks and "reef balls" (hollow, perforated concrete spheres that provide structure and habitat for sea creatures) could increase the available habitat while still providing scour protection [6].

Though the findings described above were drawn from studies of wind farms in saltwater seas, the Great Lakes have a number of artificial reefs and other comparable structures. In the Great Lakes, yellow perch often congregate around rock piles and artificial reefs. Deeper water artificial reefs attract benthic species like the deep water sculpin and its predator, the lake trout.

Though artificial reefs and wind turbine foundations draw individual animals to a particular location, it is unclear if these structures actually increase overall population numbers across a wide area.

Although underwater structures draw individual fish to a particular location it is unclear if artificial reefs actually increase overall population numbers across a wide area. The structures may make certain fish easier to catch without increasing the overall population.

Artificial reefs and other underwater structures can also attract invasive species. There are over 180 invasive species in the Great Lakes. The boulders commonly used as scour protection can create complex habitat which is usually beneficial, but the boulders could also offer increased surface area for invasive zebra and quagga mussels and hiding spaces for the invasive round goby. Turbine foundations constructed in sandy areas will change the type of habitat available and could allow certain invasive species, such as mussels, to establish in new areas. For these reasons, using gravel rather than boulders as scour protection could be preferred in the Great Lakes if it reduces colonization by invasive species [5].

Michigan's coal and nuclear power plants withdraw water from the Great Lakes to cool their turbines. Cooling water intakes kill millions of fish annually in the Great

Lakes including 350,000 adult game fish [32]. Each MW of wind energy capacity reduces the need for 0.7-2.1 million gallons of cooling water and thus reducing the loss of game fish [33]. An offshore wind farm could avoid the intake of hundreds of millions of gallons of Great Lakes water. These effects are further explored in a companion brief, *Offshore Wind Energy in Michigan: Implications for the Great Lakes Environment.*

The maximum practical depth for a wind farm is dictated more by cost than by technological limits, but the economically feasible depth increases as technological advances bring costs down.

Physical Environment

Lake Michigan's physical environment presents several challenges to offshore wind energy development, including water depth, lake bed geology and ice.

Depth and Distance

All things being equal, it is less costly to construct an offshore wind turbine in shallow water than in deep water, which means the maximum practical depth for a wind farm is dictated more by cost than by technological limits. Technological advances are expected to continue to increase the economically feasible depth for offshore wind developments. In Europe, the average depth of new offshore wind farms in 2012 was 72 feet (22 meters), though projects in 131 feet (40 meters) are under construction and one in 164 feet (50 meters) has been approved[34]. Lake Michigan increases in depth rapidly moving west from the West Michigan shoreline (Figure 3).

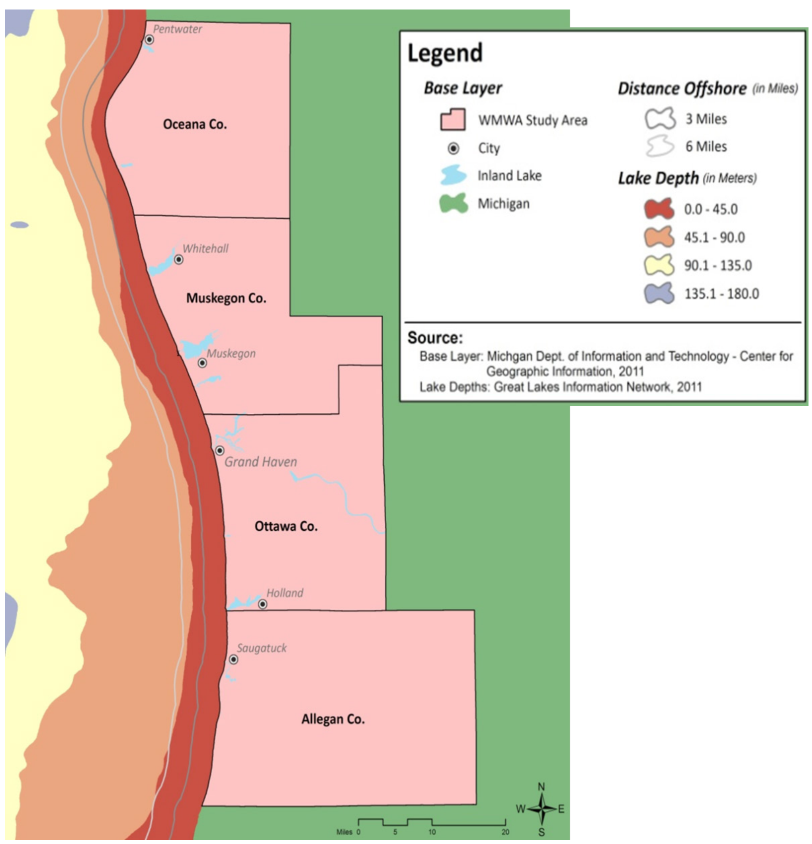

Figure 3: Water depths in Lake Michigan with lines showing the area three and six miles from shore.

Studies have shown that people are more accepting of the offshore wind farm's visual impact when it is six miles or greater from shore.

The visual impact of an offshore wind farm must also be taken into consideration. Studies have shown that people are more accepting of the wind farm's visual impact when it is 6 miles or greater from shore [35]. Considering both depth and distance from shore, West Michigan has few sites that are both 6 miles from shore and less than 45 meters in depth (the current practical limit of conventional technology) (Figure 3). There is a small area off the coast of Allegan County but it may be too small for large-scale offshore wind development. One company has proposed an offshore wind farm 6 miles offshore from Muskegon and Ottawa counties in water greater than 45 meters, but that project has not been granted a permit or bottomland lease [36].

Ice

Rings of ice can form in the relatively calm waters immediately around the turbine foundation, requiring maintenace workers to use ice boats or ice breakers to access the turbines.

Constructing offshore wind turbines in a cold weather environment like Michigan requires special preparations for icy conditions. The potential for ice to form on the lake around turbine towers and on the turbine blades will influence the design, safety and cost effectiveness of a project. Engineers must consider the temperature of the ice, its speed and thickness when evaluating the impact of ice on the turbine bases, floats and mooring lines [9].

Lake Michigan's freshwater environment is more prone to freezing than saltwater, though offshore wind farms in northern European waters do experience sea ice. Rings of ice can form in the relatively calm waters immediately around the turbine foundation. During periods of heavy ice build up, maintenance workers may have to use ice boats or in extreme cases ice breakers to access the turbines.

European engineers have designed mitigation methods to prevent the pressure of large ice sheets from damaging the turbine foundations. Many of the farms located in these colder regions have ice breaking cones or barriers that push ice up and break it into smaller pieces (Figure 4). Studies have shown that the ice loads were greatly reduced when using an ice cone structure rather than a cylindrical-type device [37]. These special foundations might be appropriate if offshore wind turbines were to be deployed in Lake Michigan.

Ice can form on the turbines themselves, reducing the aerodynamic efficiency of the blades and/or potentially breaking free and sliding off or being thrown off the turbine by the moving blades.

Ice can also form on the turbines. Ice buildup is both a safety concern and a performance challenge as the ice reduces the aerodynamic efficiency of the blades. Ice builds up on the turbine blades only under certain weather conditions: high relative humidity, freezing temperatures and overcast or nighttime skies [2]. Spray from waves is not expected to reach hundreds of feet into the air to coat the blades, but could cause ice to form around the turbine base.

Ice buildup can break free and slide off the turbine nacelle or tower, and ice on the blades can be thrown a distance by the moving blades. Simulations suggest that under rarely encountered worst case conditions, the rotating blades could throw a two-pound plate-shaped ice fragment as far as 1,100 feet from the turbine base [38]. Modern wind turbines, however, have sensors to reduce the risk of ice throw. Ice buildup on the blades causes the blades to vibrate which risks damage to the turbine rotor and can lead to ice throw. Vibration sensors would shut down the turbine until weather conditions warmed sufficiently or the blades were inspected by remote camera and declared safe. The actual risk of ice throw to boaters is low because few vessels would be expected to be operating during the winter months when the particular conditions for ice buildup are favorable. The Cape Wind Report classifies the expected impact of ice throw as negligible [2].

Figure 4. The foundations at the Nysted offshore wind farms are equipped with inverted ice-breaking cones.

Case Study: Vindpark Vänern, Sweden

Michigan's freshwater Great Lakes present challenges not faced by offshore wind farms in saltwater environments. The world's first and only freshwater offshore wind farm, Vindpark Vänern, has been operating in Sweden's Lake Vänern since 2009. This wind farm operates in an environment that is similar to Michigan's Great Lakes and offers a learning opportunity. Much of the information summarized here comes from a presentation at the Great Lakes Commission's workshop *Offshore Wind Energy – Understanding Impacts on Great Lakes Fishery and Other Aquatic Resources* [39].

The world's first and only freshwater offshore wind farm, Vindpark Vänern, has been operating in Sweden's Lake Vänern since 2009.

Figure 5: Lake Vänern in central Sweden is Europe's largest lake.

The Lake Vänern wind farm includes 10 turbines about 4 miles from the lakeshore in water 10-43 feet deep, with turbines mounted on concrete gravity foundations.

Lake Vänern, Europe's largest lake, is about one-third the size of Lake Ontario (Figure 5). The 10-turbine, 30 MW project lies about 4 miles from the lake shore in water 10-43 feet (3-13 meters) deep (Figure 6). The turbines are mounted using a unique rock adaptor foundation that uses vertical wires to attach the foundation to solid rock. The active construction period lasted just over two years, although it took nearly 10 years to become fully operational [39]. The project developers report three advantages of its freshwater lake location compared to saltwater settings in the region: less corrosion in freshwater; lower wave heights and maximum wind speeds reduce loads; and lower installation costs[40]. The lake freezes in the winter subjecting it to ice loads that may be similar to those experienced in the Great Lakes (Figure 7).

Figure 6: Vindpark Vänern lies about 4 miles from the shore in Lake Vänern.

Lake Vänern includes important environmental resources such as nature reserves, bird protection areas and Natura 2000 areas (an EU-wide network of protected habitats). The lake also has designated "national interest" areas for resource use including fisheries, shipping, recreation and wind power.

Vindpark Vänern was sited within the wind resource zone to minimize conflict with other uses of the lake, including nature reserves and other protected areas, fisheries, shipping, and recreation.

Vindpark Vänern was sited within the wind resource zone to minimize conflict with other uses of the lake. Most of the protected nature reserves, including the Natura 2000 areas, are within about 2 miles of shore including the islands that dot the lake. The wind farm is within the lake's designated recreation area but outside the main shipping lanes. A second wind farm is planned for Lake Vänern several kilometers from the existing project. The new project would feature 16-20 turbines and is further from shore than Vindpark Vänern.

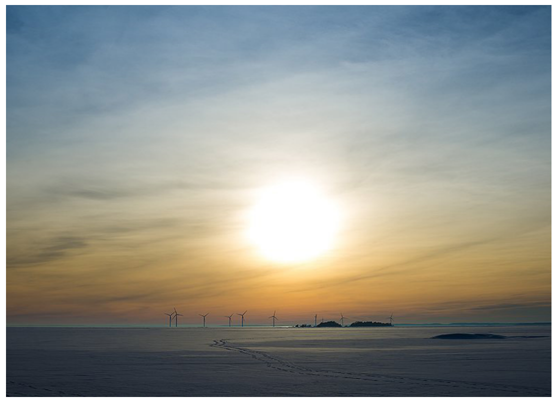

Figure 7: Winter sunrise over the Vindpark Vänern (photo courtesy of Vindpark Vänern).

A second wind farm is planned for Lake Vänern several kilometers from the existing project and would feature 16-20 turbines further from shore than Vindpark Vänern.

Commercial fishers operate in Lake Vänern catching salmon, whitefish and other fish. Commercial fishermen were involved in the siting process for the proposed wind farm. Their input led to the project footprint being modified to avoid interference with the important vendace fishery (a fish similar to whitefish). Access to the wind farm project area will be restricted during summer construction season which is outside the vendace fishing season. The restricted area includes a buffer around the turbine under construction and along the cabling route. Anchoring is prohibited within the same buffer during the operation phase to protect the cables [40]. Ultimately, the permitting authorities determined that the expansion of the wind project would not substantially affect the fishery [40].

Observations of bats around Lake Vänern indicate that bat activity is mostly confined to areas close to shore and not in the areas of the wind farms. Birds do migrate over the lake and typically fly on a southwest route from the peninsula northeast of the Vindpark Vänern and toward the large peninsula to the southwest. The route does not cross the Vindpark Vänern, but about three percent of migrating birds take a route that crosses the proposed wind farm area. However, observations of bird impacts at this project in Sweden are not directly applicable to the Great Lakes. Unlike Sweden, the Great Lakes is an important flyway for large and small birds, some of which are likely to be more sensitive to offshore wind turbines than the birds that use Lake Vänern.

The Vindpark Vänern case study suggests that some of the environmental challenges of offshore wind energy in a freshwater environment can be overcome. The wind farm has operated without significant impacts to either the natural environment or other resource users, and the proposed expansion has been approved. The turbines from both the existing and planned projects are relatively close to land and would be visible on clear days. The project developers estimate that the new phase could avoid the emission of 200 tons of SO_2 per year and avoid human health damages [40].

Technical problems, however, have plagued the project. It took nearly 10 years for the initial 10-turbine project to become fully operational. At least three of the turbines have suffered mechanical problems and have not functioned properly [39]. The offshore environment adds to the difficulties of servicing the turbines in a safe and timely manner. The Vindpark Vänern experience shows that offshore wind energy may be feasible in the Great Lakes from an environmental perspective, but operations and maintenance issues must be carefully addressed.

Studies from operational projects in Europe and pre-construction assessments in Cape Cod show that the impacts on coastal environments from offshore wind energy are mostly minor.

Conclusion

Every kind of development in and along the Great Lakes has an environmental impact, and offshore wind energy development is no exception. Compared to land-based wind farms, offshore projects (in fresh or saltwater) offer greater wind resources, less turbulent winds and reduce impact on neighbors, but come with higher installation and operations and maintenance costs. Studies from operational projects in Europe and pre-construction assessments in Cape Cod show that the impacts on the coastal environments from offshore wind energy are mostly minor and include beneficial impacts on air quality.

Construction and decommissioning phase impacts are mostly minor, local in scale and limited to the duration of the construction/decommissioning activity. Noise and activity may drive fish from the area but they are likely to return when the activities cease. Vessel access to the project area may be restricted for safety reasons during the construction and decommissioning phases.

Birds face the greatest risk from offshore wind farms, particularly in the operational phase.

Offshore wind energy, like other clean energy sources, will improve air quality and human health as it displaces more polluting forms. Studies show that wind energy can displace coal-fired electricity and avoid emissions of SO_2, CO_2, and other pollutants. The emissions savings from a single wind energy project is small compared to the total amount of pollution generated by Michigan's energy portfolio, but such savings are an incremental step with measurable benefits.

Birds face the greatest risk from offshore wind farms particularly in the operational phase. The degree of impact depends on the project location, particular bird species, whether they use the open water resource for feeding, breeding or as a migration route. For some species, the impact may be negligible, others major. The risk of collision is greatest for birds which use the open water resource for much of the year. Migrating geese and ducks have demonstrated an ability to maneuver around operating wind farms, but the behavior of other birds is unclear.

The unique geology and geography of the Great Lakes, and Michigan's cold winters present challenges.

Offshore wind farm operation is generally seen as having a minor impact on fisheries. In Cape Cod, the proposed wind farm is expected to have a minimal impact on the commercial fishery. The Coast Guard has not issued an exclusion zone in the project area — vessels of all kinds should be able to access the area between turbines. Abundance of certain kinds of fish may increase in the area around the wind farm as the foundation adds three-dimensional structure to the environment. In Lake Michigan, the structures may benefit perch, but probably not open water species like salmon.

The unique geology and geography of the Great Lakes presents challenges for offshore wind development. Lake Michigan, in particular, increases in depth rapidly with distance from shore. Deep water foundations are technically feasible but generally cost-prohibitive. There are few locations along West Michigan that are outside the 6-mile threshold for visual impact and of suitable depth. Some of these locations may become feasible as technological improvements bring down construction costs.

Michigan's cold winters also present challenges. Ice on the blades is a technical challenge that must be dealt with by both onshore and offshore wind farms wherever freezing temperature are experienced. Lake ice, however, can be more vexing and will make turbine maintenance more challenging in the winter. Freshwater freezes more readily than saltwater where most offshore turbines are currently located. Careful planning and technological innovations can protect turbine foundations from damage during ice events.

The experience of the world's only freshwater offshore wind farm, Vindpark Vänern in Sweden, offers lessons for Michigan. The technical challenges of winter lake ice are not insurmountable. Lake Vänern freezes over each winter yet the turbines are still able to function. An inclusive planning process enabled the wind resource zones to be designated without impeding the lake's important commercial fishery or its natural environment. On the other hand, the offshore location and tough winter weather have made maintenance difficult and several turbines have experienced ongoing mechanical problems. The technical challenges have not dissuaded the community, however, and a second offshore wind farm in Lake Vänern is being planned.

The science suggests that carefully planned offshore wind energy development is environmentally feasible in Michigan's Great Lakes.

Offshore wind farms around the world have operated with minimal environmental impact. The science suggests that carefully planned offshore wind energy development is environmentally feasible in Michigan's Great Lakes. The economic and social dimensions are more likely to determine whether offshore wind energy becomes a reality in West Michigan.

Acknowledgements

The West Michigan Wind Assessment is funded by a grant from Michigan Sea Grant. The project staff gratefully acknowledges the guidance of the project steering committee and the suggestions from outside reviewers. The authors of this issue brief would like to thank Aaron Ferguson, an undergraduate student at Grand Valley State University, for his contribution to the foundation section.

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This publication is a result of work sponsored by Michigan Sea Grant College Program, R/CCD-11, under: NA10OAR4170071 from National Sea Grant, NOAA, U.S. Department of Commerce, and funds from the State of Michigan.

MICHU-14-205