

Michigan's Offshore Wind Potential

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Table Of Contents

A. Background	1
B. Study Rationale and Objectives	3
C. Study Methods	6
D. Findings	12
E. Conclusions	13
F. References	15

Tables

Table 1: Wind Power Curve Values from Siemens SWT 3.6 Turbine Used for Simulation	7
Table 2: Full Build-out Results by Depth	12
Table 3: Resource Estimates by Depth and Distance from Shore Restrictions	13

Figures

Figure 1: NREL/AWS Truwind 2004 Onshore Wind Resource Map for Michigan	2
Figure 2: NREL/AWS Truwind 2008 Offshore Wind Speed Map for the Great Lakes Basin	4
Figure 3: Process Flow for Power Assessment	8
Figure 4: Examples of the Three Different Classes of Turbine Support Structures. Recreated From Dvorak, 2007	9
Figure 5: 30 m, and 60 m, Bathymetry Map	10
Figure 6: Shoreline Distance Restrictions Map	11

Summary

Based on the data released in 2008 by AWS Truewind on Great Lakes wind resources, this study projects Michigan's potential offshore wind energy resource capacity. The analysis used a geospatial framework to combine Great Lakes depth (bathymetry) information, with the wind resource information while considering selected possible shoreline restrictions. Wind turbine build-out scenarios were developed for the offshore areas within Michigan's Great Lakes boundaries, based on the assumption of the use of the Siemens STW 3.6 Wind Turbine. The projected number of turbines was used to project power output's under various depth scenarios. Our projections suggest the following offshore wind power potential for Michigan at various installation depth considerations:

- Assuming that wind towers can be located at all depths without restrictions, Michigan could potentially generate **321,936 Megawatts (Mw)** of electricity from offshore wind.
- Assuming that wind towers can be located up to a depth of **60 m** without restrictions, Michigan could potentially generate **102,592 Mw of electricity**.
- Assuming that wind towers can be located up to a depth of **30 m** without restrictions, Michigan could potentially generate **55,250 Mw of electricity**.

These represent significant electric power generation potential from offshore application of wind energy technology. The analysis further adjusts the above numbers for shoreline distance considerations. The adjusted projections for Michigan are as follows:

- At up to 60 m of depth, the projected generation capacity drops off from 102,592 Mw to 94,274 Mw if a shoreline distance of **1 km** is maintained, further drops to 62,205 Mw if a shoreline distance of **5 km** is maintained, further drops to 36,337 Mw if a shoreline distance of **10 km** is maintained, and further to 9,602 Mw if a shoreline distance of **15 km** is maintained.
- At up to 30 m of depth, the projected generation capacity drops off from 55,250 Mw to 47,360 Mw if a shoreline distance of **1 km** is maintained, further drops to 22,247 Mw if a shoreline distance of **5 km** is maintained, further drops to 9,481 Mw if a shoreline distance of **10 km** is maintained, and further drops to 926 Mw if a shoreline distance of **15 km** is maintained.

These results suggest significantly greater wind generation capacity for Michigan if Great Lakes wind assets offshore are taken into consideration along with previous estimates of wind assets onshore. These projections do not account for potential areas of concern such as shipping lanes, sensitive aquatic habitat, historic sites (such as shipwrecks and others), recreational fishing needs, commercial fishing needs, transportation corridors, migratory bird routes, and potential areas subject to tribal and other treaty concerns, and other natural resource management concerns. To account for these areas, much more significant data than is currently available will be needed. The authors are currently working to develop such data. A full accounting of Michigan's wind resources, onshore and offshore, could very well elevate the state's profile among U.S. states with wind potential.

A. Background

In the year 2004, the National Renewable Energy Laboratory (NREL) of the U.S. Department of Energy (DOE) published (in partnership with AWS Truewind) a state wind resource map and estimates of onshore wind resource capacity for the State of Michigan (see Figure 1). The NREL estimates spatially identified Michigan's onshore wind resources by wind intensity class. The report, which has served as the primary basis for much of the discussion about Michigan's wind energy potential, estimated a total onshore wind power potential of 16,560 megawatts (Mw) for the state (Flowers, 2007). That estimate was based on a series of assumptions about potential areas of exclusion.

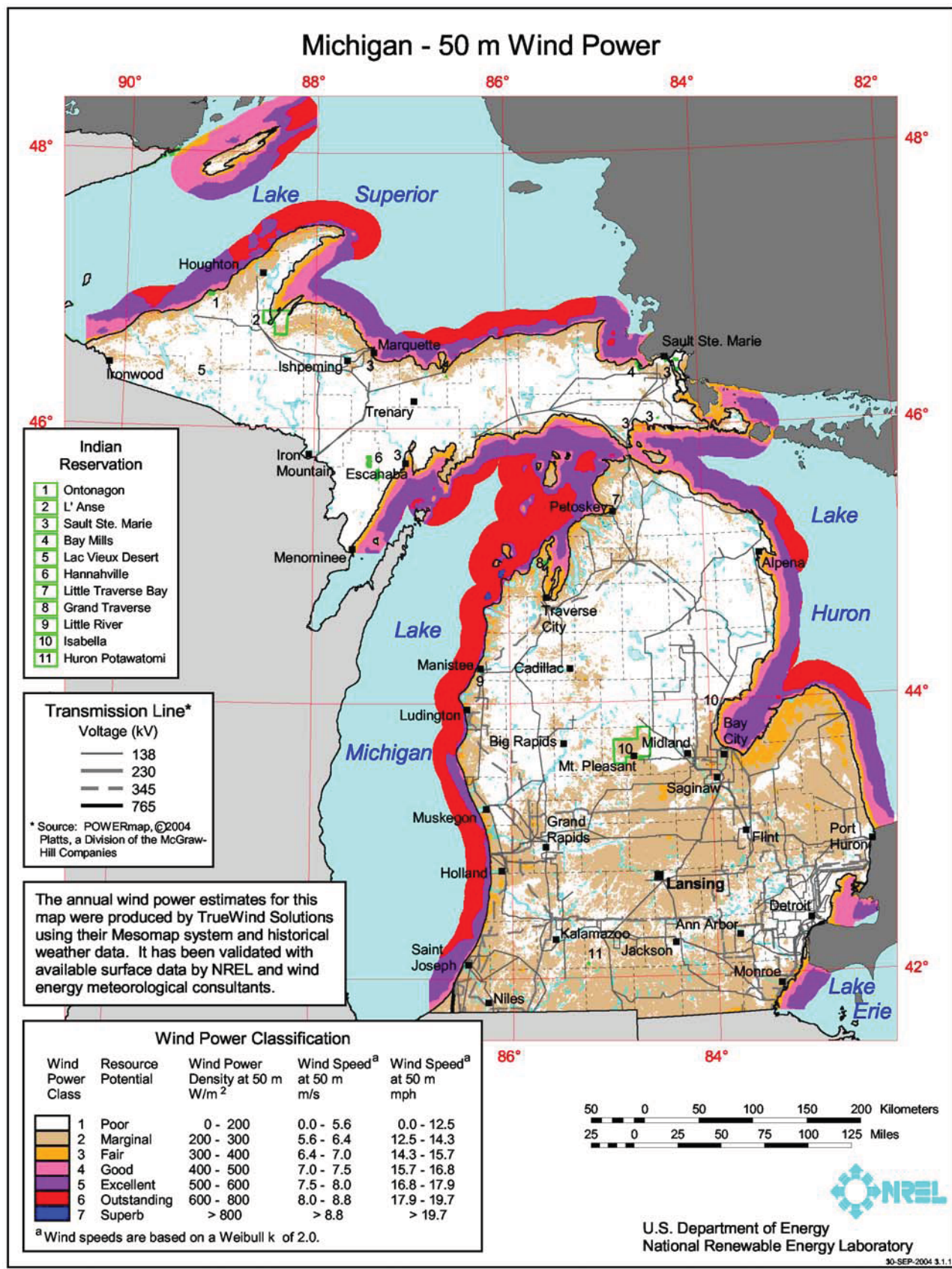
The estimated 16,560 Mw of wind generating capacity represents a substantial potential increase in Michigan's power generating capacity. Michigan currently consumes retail electricity in the amount of 108,018,000 Megawatt hours (equivalent to 12,331 Mw of continuous generating capacity) annually and is capable of generating 30,189 Mw at peak times (EIA, 2007). Since the release of the 2004 NREL report, under the leadership of the executive branch and the legislature, the State of Michigan has had significant discourse about optimal approaches for realizing Michigan's domestic energy production potential, especially via renewable energy. This debate has actively involved various interest groups within the private sector and the general public. The 21st Century Energy Plan, published in 2006 (Lark, 2006), also relied heavily on NREL's onshore wind estimates. So did the recently passed Clean, Renewable, and Efficient Energy Act of 2008 (Enrolled Senate Bill 213) which set a 2015 goal of 10% renewable energy. Michigan recently tested its offshore wind siting regulatory process in both shallow and deepwater settings (Klepinger, 2008).

While Michigan is well endowed in onshore wind resources, ranked 14th nationwide (Elliot, 1991), it is perhaps even better endowed in offshore wind. Offshore wind has several potential advantages over onshore wind, which are as follows:

1. Michigan is one of eight states and two provinces with Great Lakes resources under their control.
2. Michigan alone has, within its jurisdiction, approximately 40% of the Great Lakes water surface area.
3. Much of the Great Lakes bottomland that is within the jurisdiction of Michigan is essentially owned and operated by the state, in trust for the public (Illinois Central Railway Commission v. Illinois, 1892).
4. The degree of difficulty in implementing wind projects offshore in the Great Lakes is significantly less than in ocean or saltwater applications.
5. Project implementation costs for Great Lakes application will likely be lower than in marine applications.
6. State marine coastal management zones only extend 18 miles, while Great Lakes states zones are not subject to such restrictions.
7. Saltwater is much more corrosive than freshwater, making salt water offshore projects less durable.
8. Ocean floor topography makes it difficult to address viewshed issues, as ocean based projects involve greater depths closer to shore (Pryor, 2004).

The application of wind to freshwater areas, particularly in the Great Lakes, therefore, appears more feasible from some political, economic and social perspectives. However, the environmental implications are perhaps less clear, and icing conditions could present engineering challenges.

Figure 1: NREL/AWS Truewind 2004 Wind Resource Map for Michigan



B. Study Rationale and Objectives

The absence of data on Great Lakes offshore wind resource potential has been a major bottleneck to the quantification of Michigan's total renewable energy potential and the state's potential competitiveness in wind energy. The ability to quantify this resource was greatly enhanced when AWS Truewind (in partnership with the Michigan Energy Office, NREL, the Ontario Ministry of Natural Resources, New York State Energy Research and Development Authority, State of Indiana, the U.S. Department of Energy, the U.S. Department of Defense, and the Ohio Department of Development) released the first comprehensive wind resource results and maps for all of the Great Lakes. The 2008 AWS Truewind information and maps provide data at much greater heights than what was previously provided in 2004. The results suggest significant wind resources offshore (see Figure 2). Perhaps more importantly, it defines the availability of wind resources where each state, more than its local units of government and their constituents, is better positioned to define and implement a vision of what it can offer in renewable energy.

With this new data now in hand, one major bottleneck that remains is to identify what this resource translates into in terms of wind energy generating capacity. Given the unique resource of offshore wind power, it is possible for Michigan to uniquely define itself as a premier wind energy state. Most states have land based wind resources, the development of which faces a number of limitations. First, the acquisition of land for wind generation costs money, which may or may not be the case with offshore projects. Second, the assembly of land through leases and purchases with individual landowners is cumbersome at best. Third, "Not In My Backyard" (NIMBYism) offshore can perhaps be better mitigated through adequate distancing of installations from the viewshed of communities than onshore. To the extent to which energy self-sufficiency becomes a central vision and/or goal of a state, the state is likely better empowered to take leadership in implementing and facilitating wind projects offshore by using some of the same economic development tools and strategies that are used onshore. The current challenge for Michigan is to quantify this resource in relevant terms, such as potential power generation and potential economic impacts in Michigan.

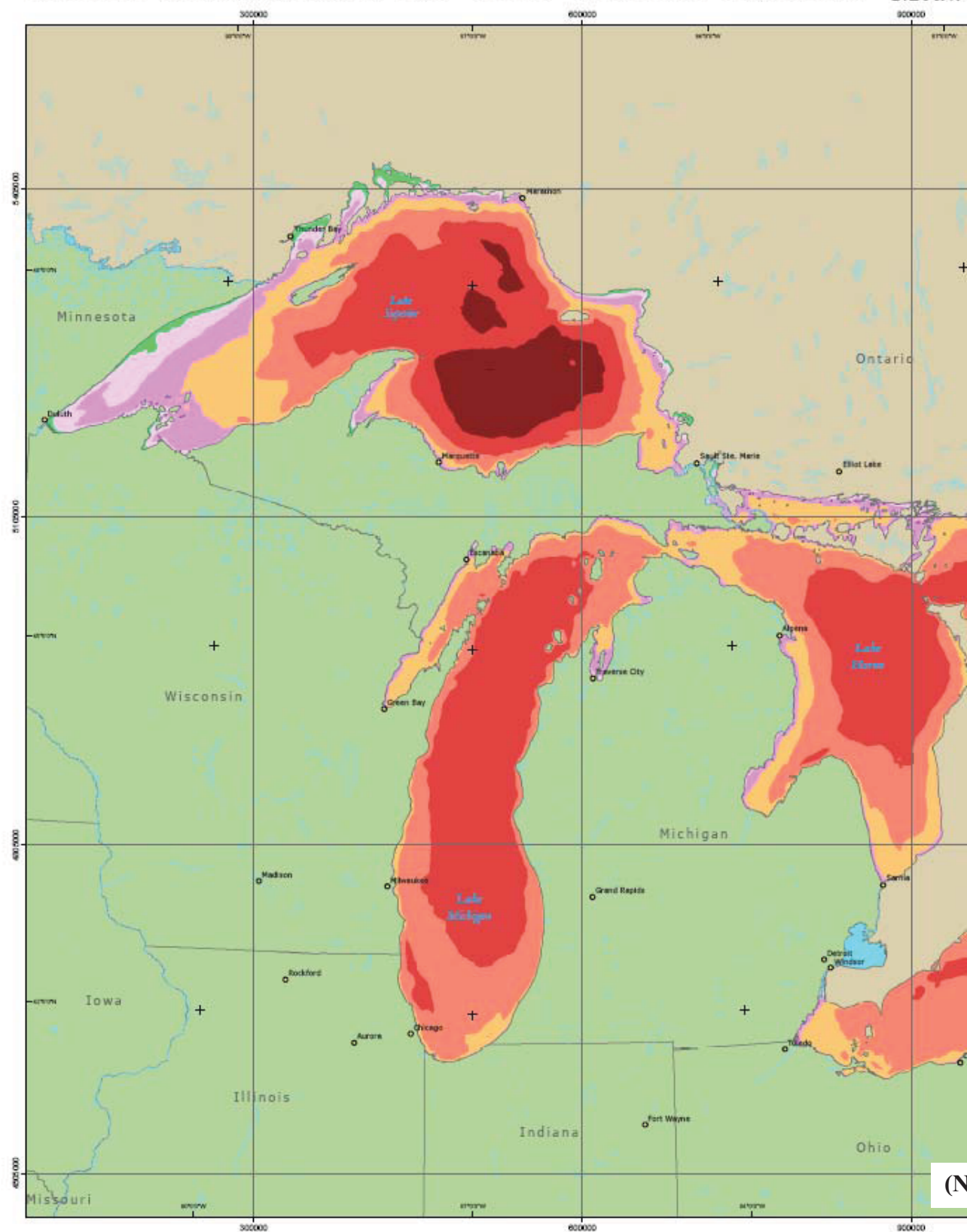
The overall objective of the study is to quantify Michigan's offshore wind generation potential. Specific objectives are as follows:

1. To determine the areas of the Great Lakes wind resource that are within the boundary and ownership of the State of Michigan.
2. To correlate wind speed data for areas within Michigan's boundary with depth (bathymetry) data to identify alternative scenarios with respect to feasible wind equipment applications.
3. To estimate the total offshore wind generating capacity of Michigan at various depths and shoreline distance restrictions by applying the parameters associated with optimal wind generating equipment and appropriate wind turbine spacing.
4. To present, in tabular and map form, the results in order to inform future policy decisions about Michigan's offshore wind potential.

In the event that Great Lakes deployment of wind farms are deemed to be politically, socially, and economically feasible, this study can be useful in arming Michigan policymakers with information to support their efforts to attract wind energy developers from in and out of the state to participate in building Michigan's renewable energy industry.

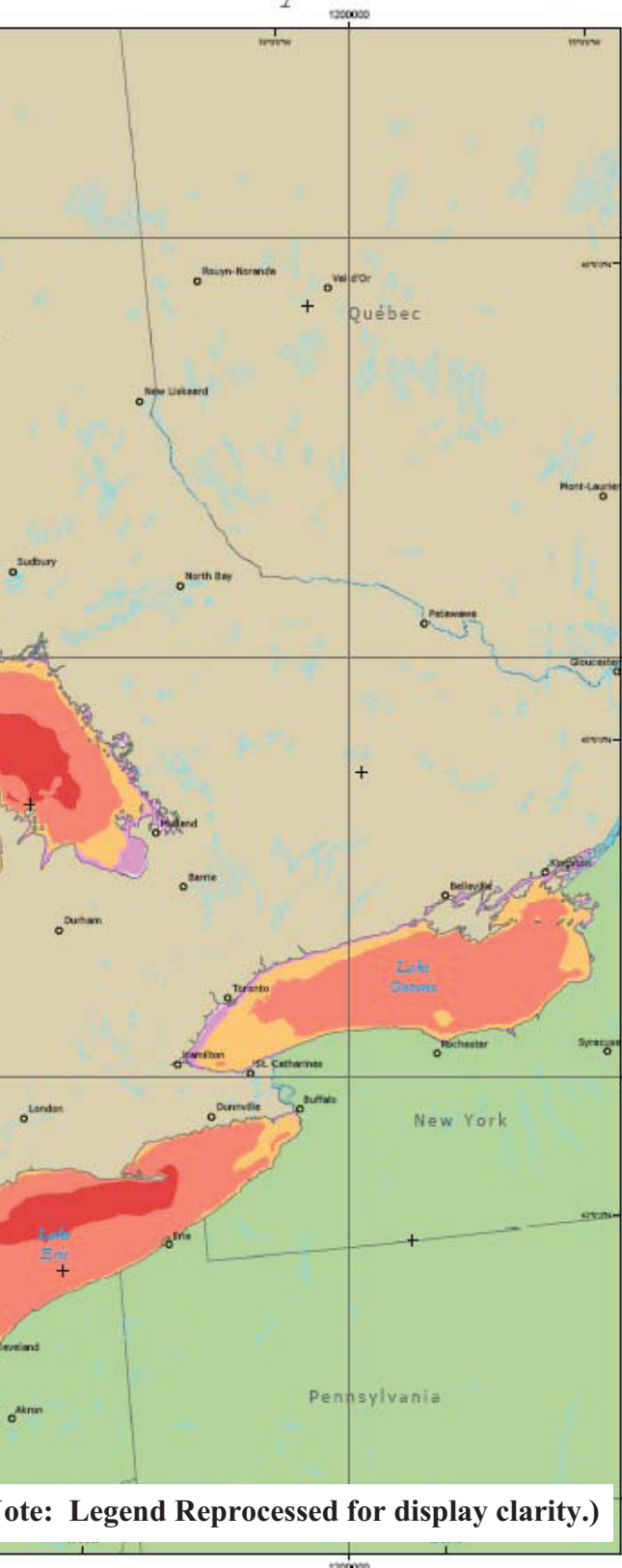
Figure 2: NREL/AWS Truewind 2008 Offshore

WIND RESOURCE OF THE GREAT LAKES *Mean*



Wind Speed Map for the Great Lakes Basin

Annual Wind Speed at 150 Meters



MESOMAP

Inset



Reference



Wind Data Resolution: 200m
Coordinate System: UTM 16N
Datum: WGS84



Disclaimer

This map was created by AWS Truewind using the Mesomap system and historical weather data. Although it is believed to represent an accurate overall picture of the wind energy resource, estimates at any location should be confirmed by measurement.

Originator

Date: April 16, 2008
Department/Originator: GIS / JCT
File Path: GreatLakes_final_SPD_PWR_16Apr08
Map Class: Final; Public
Client: NREL

AWS Truewind

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- City
- Water Body
- States
- Provinces

Mean Speed at 150 m

	mph	m/s
	< 12.3	< 5.5
	12.3 - 13.4	5.5 - 6.0
	13.4 - 14.5	6.0 - 6.5
	14.5 - 15.7	6.5 - 7.0
	15.7 - 16.8	7.0 - 7.5
	16.8 - 17.9	7.5 - 8.0
	17.9 - 19.0	8.0 - 8.5
	19.0 - 20.1	8.5 - 9.0
	20.1 - 21.3	9.0 - 9.5
	21.3 - 22.4	9.5 - 10.0
	> 22.4	> 10.5

(Note: Legend Reprocessed for display clarity.)

Renewable energy will receive significant attention in the U.S. in coming years. With the expected gradual growth in energy demand, the growing global competition for conventional energy and the raw materials and fuel to produce such energy, energy costs are expected to increase dramatically (Mobil Oil Co, 2007). The implications are likely to be significant, with the potential outcomes of changing the way Americans use energy and the industrial dominance that the U.S. has enjoyed globally (Shell, 2008). A number of national initiatives have highlighted the importance of managing this problem intelligently. The Energy Independence and Security Act (110th Congress, 2007), the recently unveiled renewable energy plan by the T. Boone Pickens group, the recent plan revealed by Nobel Laureate and former U.S. Vice President Al Gore (We Can Solve It, 2008), and recent moves by traditional energy companies to redefine themselves in the renewable energy space illustrate the challenges and complications that U.S. states and the nation will face in attempting to internalize their energy sources in the face of rising global demand, potentially shrinking global supply and the limited short-term options to address possible gaps.

This initial assessment was conducted as the first estimate of the power production potential for Michigan's offshore management area.

C. Study Methodology

The strategy in this study was to keep the analysis simple, tractable and expeditious. We see development of estimates of offshore wind power production potential to be an ongoing process that will be informed with new data. Supplementary analysis will be released, in due course, as more detailed information is available on optimal exclusionary zones, such as shipping lanes, sensitive aquatic habitat, historic sites (such as shipwrecks and others), recreational fishing needs, commercial fishing needs, transportation corridors, migratory bird routes and potential areas subject to tribal and other treaty concerns.

The Basic AWS Truwind Wind Information

The starting point in our analysis was to acquire the AWS Truwind sampling data for the Great Lakes. AWS Truwind sampling data was obtained using satellite based downward looking light detection and ranging (LiDAR). A summary of this information is provided in Figure 2. It shows mean wind speed for one year at 150m above the lake surface in miles per hour (Mph) and meters per second (m/s). This data was provided in tabular form to the Land Policy Institute by AWS Truwind, in cooperation with the Michigan State Energy Office and the Michigan Department of Labor and Economic Growth.

As shown in Figure 2, the vast majority of the Great Lakes exhibit wind speeds of over 19 Mph or 8.4 m/s. Even the near shore locations, which represent a very small proportion of Great Lakes surface area, typically exhibit wind speeds between 17.9 and 19.0 Mph or 8.0 to 8.5 m/s. The resource offshore is generally much greater and is more broadly distributed offshore than onshore.

Translating the AWS Truwind Data into Resource Maps

The tabular sampling data for wind speed, direction and density were used to construct a 200 m grid of wind speed at a height of 150 m in the Great Lakes region. The wind speed map was resampled to 1 km cells in an Earth Science Research Institute (ESRI) Grid format to simulate a tower in the center of each cell, giving a simulated inter-tower spacing of 1 km or 0.62 mi. To model only Michigan's potential, the Great Lakes grids were then truncated to the

boundaries of Michigan's coastal management area. Given the resolution of the sampling grid, there is a ± 100 m error along the boundary, resulting in a total area error rate of 0.68%. This provided an estimate of Michigan's offshore average wind speed.

Converting Wind Speed into Power Estimates

It was assumed that turbines similar to the Siemens STW 3.6 turbine would be used. This is the most common offshore turbine configuration in use at the moment (DELTA, 2007). The power curve parameters used are shown in Table 1. These parameters represent actual power generation from this specific turbine as deployed in a similar offshore environment (DELTA, 2007), obviating the need to worry about capacity factor considerations. For this analysis, inter-turbine spacing of 1 km was assumed. This yielded a 100% build-out map of Michigan's potential number of turbines offshore. The power production of each turbine was calculated by multiplying its output power in Kilowatts (Kw) by the wind speed at its location. The methods are summarized in Figure 3.

Possible Exclusions to Consider

While 100% build-out estimates might be useful for discussion purposes, it is clear that placing power turbines everywhere in Michigan's Great Lakes surface is not practical or desirable due to several considerations. These considerations include depth; distance to shore; and possible exclusions due to competing uses, environmental concerns and other factors. These exclusions are discussed next.

Depth - Existing offshore wind turbines have been limited to 60 m or less, with under 30 m preferable and more economical (Henderson, 2003). While many areas with such depths are close to shore, within the Great Lakes, many shallow areas are also found well offshore. The tower technologies currently applied at different depths are shown in Figure 4. As shown in Figure 4, foundation and anchoring considerations become more complicated as depth increases (Dvorak, 2007).

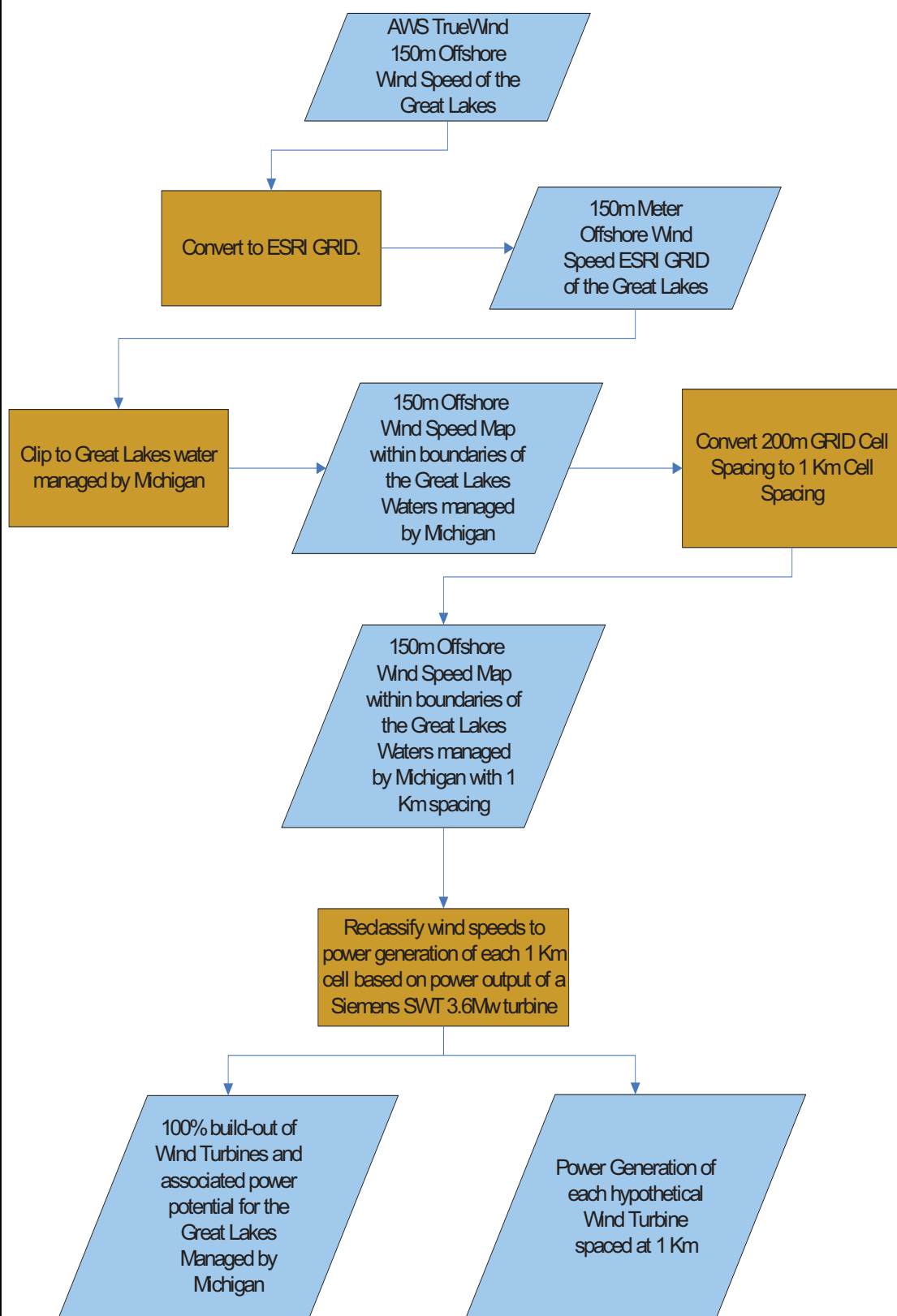
Distance to Shore - One of the critical hurdles in offshore wind deployment is public concern about view infringement. These concerns are generally mitigated by locating wind turbines at significant distances from shore, rendering them less visible from shore (Musial, 2005).

Table 1: Wind Power Curve Values from Siemens SWT 3.6 Turbine Used for Simulation.

Wind Speed m/s	Power Generation Kw
6.25 - 7	1,500
7-8	2,325
8-9	3,075
9-10	3,470
10 and up	3,600

Environmental Considerations and Other Exclusions - For offshore wind application to receive optimal public support, there are clear areas of exclusion that must be considered. Future research, new public policy, and site-specific discoveries during offshore wind field development will likely result in a significant reduction in the total number of wind systems installed on the Great Lakes due to these concerns. To account for all these exclusions, much more significant data than is currently available will be needed. In the Dvorak study for California by Dvorak et al. for Stanford University they assumed a 33% area reduction for these type of exclusions. For NREL's analysis, in a U.S. National deepwater applications assessment, they assume a 67% exclusion reduction (Musial, 2005). For the purpose of this study we accounted only for distance to shore and depth.

Figure 3: Process Flow for Power Assessment (Methods)

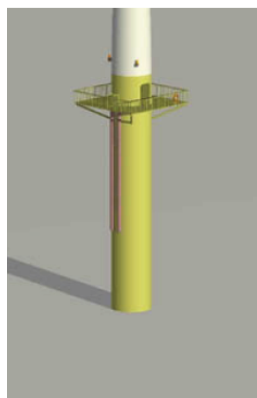


Shallow Water Adjustment

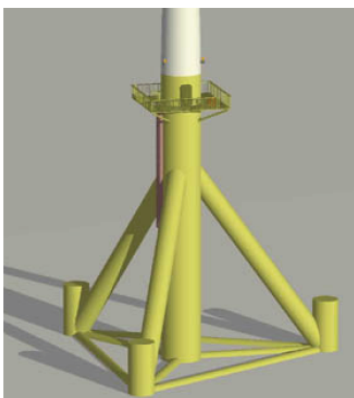
For the shallow water adjustment, we restricted the potential application of wind to lake areas with 30 m or less in depth. Since this depth in the Great Lakes is largely close to shore depth restrictions are clearly related to shoreline restrictions. Figure 5 presents a map of Michigan's Great Lakes areas at different depths. Most of the shallow areas being so close to shore, this adjustment reduces the total area available by about 90%.

Figure 4: Examples of the Three Different Classes of Turbine Support Structures. Recreated From Dvorak, 2007.

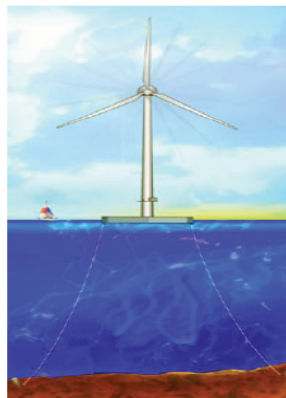
Turbine Tower Support Structures



Monopile: 0-20m
Image Owen, 2007



Water Jacket Tripod: 20m-60m
Image Owen, 2007



Floating: 50m-200m (future)
Image NREL, 2007

Shallow and Mid Depth Adjustment

This analysis is identical to the shallow water scenario, with the exception that the maximum depth was increased to 60 m reflecting more advanced wind turbine tower support structures (Dvorak, 2007). As shown in Figure 5, extending wind turbines to areas up to 60 m in depth increases Michigan's potential by almost double. Although this depth may present cost challenges due to more complicated foundation technologies, it can be implemented with current technology.

Deep Advanced Technology Adjustment

This scenario applies no depth restriction. Advances in floating platform technology in the future will allow placement in almost all depths. Currently this is largely untested in practical applications, so turbine placement at these depth will be a future application.

Shoreline Distance Adjustments

Future research, new public policy, and site-specific discoveries during offshore wind field development will likely result in a significant reduction in the total number of wind systems installed on the Great Lakes. Michigan recently tested its offshore wind siting regulatory process in both shallow and deepwater settings, but the scope of potential regulatory and other exclusion areas is presently unknown (Klepinger, 2008). Therefore, a review of offshore distances allowed elsewhere and used in previous analysis was conducted. Based on this review, distances of: 1 km (Finfacts, 2007), 5 km (Owen, 2004), and 10 km offshore (Musial, 2005), and 15 km were selected to illustrate the impact these adjustments have on available wind power generation. These adjustments are shown in Figure 6.

Figure 5: 30 m, 60 m, Bathymetry Map Within Michigan's Management Boundaries

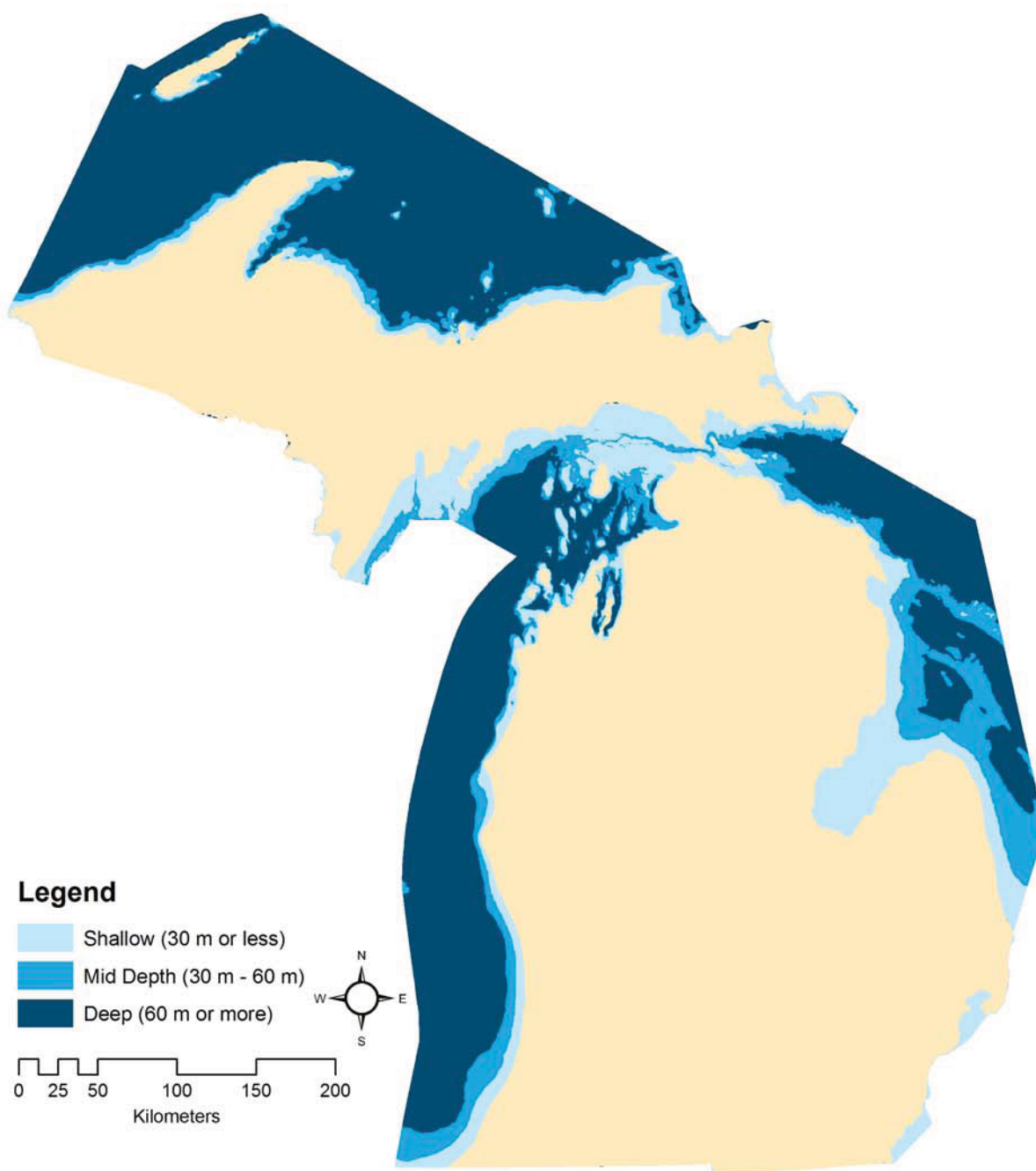
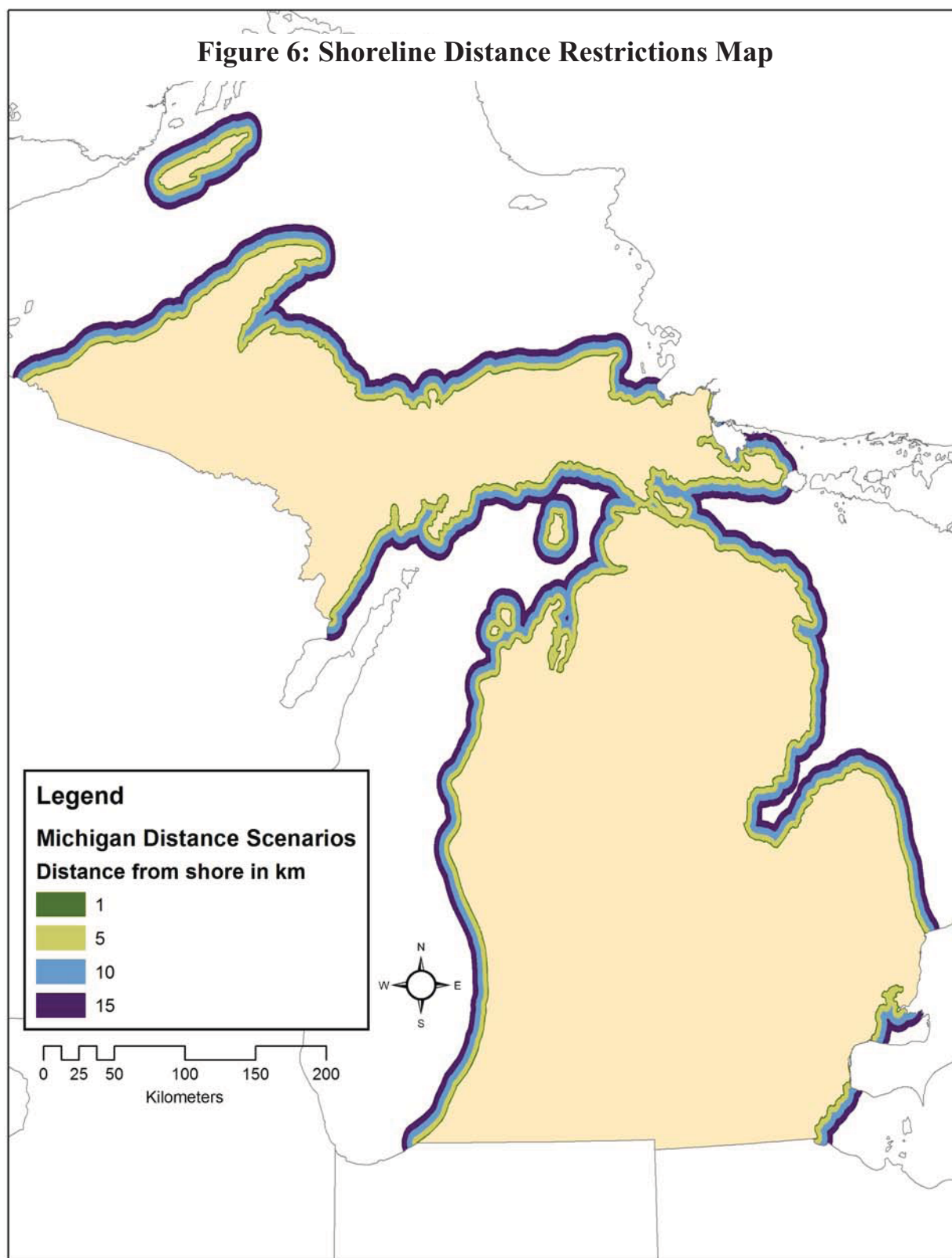


Figure 6: Shoreline Distance Restrictions Map



D. Findings

Initial estimates of Michigan's offshore wind potential are shown in Table 2. The results suggest that the offshore wind potential dwarfs that of Michigan's onshore potential of 16,560 Mw, as calculated by NREL in their 2004 analysis. The map of projected wind power generation is presented in Figure 7. It shows the projected output from each Siemens SWT 3.6 (or similar) turbine if placed within different zones within the Great Lakes. In essence, if the Great Lakes surface area is built out, without restrictions, to maximum depth, the total power output is projected to be 321,936 Mw, or 99,932 Siemens SWT 3.6 turbines. As can be seen from Figure 7, the majority of the surface area in Michigan's portion of the Great Lakes has outstanding or superb wind power generation capacity, according to NREL's designation (see Figure 1).

Total Offshore Wind Power Potential

Total offshore power potential at a maximum depth is estimated to be 321,936 Mw. This translates into 99,932 potential high power Siemens STW 3.6 wind turbines. This is over almost 20 times the estimated power onshore. If maximum depth is reduced to 200 m, an estimated 269,562 Mw is possible. This is over 16 times the wind power potential onshore. This translates into 84,500 potential high power Siemens STW 3.6 wind turbines. At a maximum depth of 60 m, which is currently feasible and has been done elsewhere, the offshore power generation potential is 102,592 Mw, which translates into 33,861 high power

Table 2: Full Build-out Power Estimates by Depth.

Maximum Depth Projections		60m Depth Projections		30m Depth Projections	
Power (Mw)	Towers	Power (Mw)	Towers	Power (Mw)	Towers
321,936	99,932	102,592	33,861	55,250	18,782

turbines. At a maximum depth of 30 m, the most feasible and common deployment depth worldwide, the potential is estimated at 55,250 Mw, or 18,782 turbines.

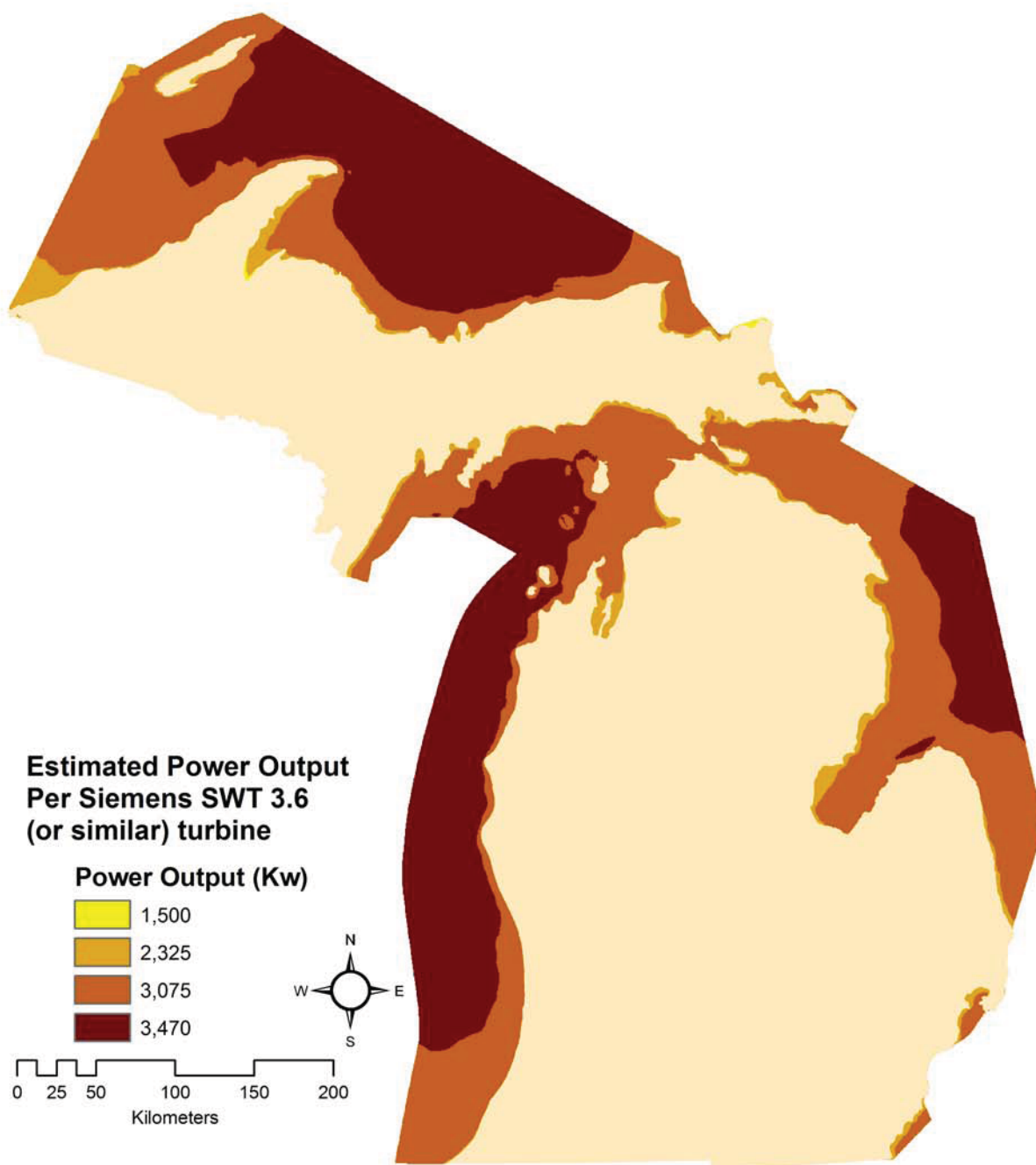
At the 30 m depth the total power available offshore in Michigan is over 3 times that available on land. As the technology for anchoring and installing wind turbines offshore matures, the move to deeper depths will allow Michigan to take advantage of even larger potential; with over 6 times the onshore power estimate available at 60 m.

Adjusted Offshore Wind Potential Based on Depth and Shoreline Distance

Separate power production potentials were calculated based on scenario modifications for depth and shoreline adjustments. The shoreline distances used are mapped in Figure 6. The resulting intersections of adequate distance from shore and desired depth are presented in Table 3.

As shown in Table 3, at Maximum Depth, Michigan's potential drops off from 321,936 Mw zero distance to shore to 312,546 Mw at 1 km to shore then to 257,250 Mw at 5 km to shore,

Figure 7: Projected Power Output per Turbine in Michigan's Great Lakes Waters (No Depth or Shoreline Restrictions Applied)



then to 234,175 Mw 10 km from shore, then to 197,278 Mw 15 km from shore. These numbers translate into 99,932 turbines with no shoreline restriction, 96,371 turbines (1 km minimum distance from shore), 83,748 turbines (5 km minimum distance from shore), 70,630 turbines (10 km minimum distance from shore), and 58,992 turbines (15 km minimum distance to shore).

As shown in Table 3, at 60 m depth or less, Michigan's potential drops off from 102,592 Mw at zero distance to shore to 94,274 Mw at 1 km distance, then to 62,205 Mw at 5 km distance, then to 36,337 Mw 10 km distance, then to 9,602 Mw at 15 km distance. These numbers translate into 33,861 turbines with no shoreline restriction, 30,714 turbines (1 km minimum distance from shore), 19,813 turbines (5 km minimum distance from shore), 11,469 turbines (10 km minimum distance from shore), and 2,880 turbines (15 km minimum distance to shore).

Finally at 30 m depth or less, Michigan's potential drops off from 55,250 Mw zero distance to shore, to 47,360 Mw at 1 km to shore, then to 22,247 Mw at 5 km to shore, then to 9,481 Mw 10 km to shore, then to 926 Mw at 15 km distance to shore. These numbers translate into 18,782 turbines with no shoreline restriction, 15,795 turbines (1 km minimum distance from shore), 7,177 turbines (5 km minimum distance from shore), 9,034 turbines (10 km minimum distance from shore), and 275 turbines (15 km minimum distance to shore).

E. Conclusions

The estimates presented in this report provide a framework for preliminary examination of Michigan's offshore wind potential. With the exception of 30 m depth and a minimum distance of 10 km and 15 km from shore, and the 60m depth 15 km from shore, these estimates exceed previous estimates of Michigan's onshore wind potential. Given the unique management framework in the Great Lakes, the potential to mitigate some of the issues that typically arise with onshore application and the potential for Michigan to be a bigger player in the national wind generation space, we recommend that greater consideration be given to state policies to guide offshore wind development.

Table 3: Resource Estimates by Depth and Distance From Shore Restrictions.

<i>Distance From Shore</i>	Maximum Depth Projections		60m Depth Projections		30m Depth Projections	
	<i>Power (Mw)</i>	<i>Towers</i>	<i>Power (Mw)</i>	<i>Towers</i>	<i>Power (Mw)</i>	<i>Towers</i>
0 km	321,936	99,932	102,592	33,861	55,250	18,782
1 km	312,546	96,371	94,274	30,714	47,360	15,795
5 km	275,250	83,748	62,205	19,813	22,247	7,177
10 km	234,175	70,630	36,337	11,469	9,481	3,034
15 km	197,278	58,992	9,602	2,880	926	275

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