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ARTICLE

Perspectives on offshore wind farms development in Great Lakes

Soudeh Afsharian[1*] Bahareh Afsharian[2] Maryam Shiea[3]

1. Lassonde School of Engineering, York University, Toronto, Ontario, Canada
2. School of Engineering, Electronic Department, Azad University, Tehran, Iran
3. Captain climate Co., Mashhad, Iran

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ABSTRACT

Global warming emissions and carbon dioxide caused by human activities are overloading our atmosphere which cause web of significant and harmful impacts. There are little to no global warming emissions by renewable energy. To date, offshore wind farms generally have been installed in shallow ocean-coastal areas. The Great Lakes with freshwater have shown high potential for installing offshore wind farms, and significant advantages. There are more than 5 offshore windfarms in progress at the end of 2019 in Great Lakes. The object of this study is to present the capacity and prospects of offshore wind farms development in Great Lakes. Also, the power of wind farms, barriers, issues, wind vision, advantages and disadvantages, the criteria related to the location of the offshore wind farms in Great Lakes have been analyzed and presents statistics for decision-makers, interested communities, investors and academic researchers. This paper is among the rare works that have been done in aspect of statistical and data gathering for the wind offshore in Great Lakes as the moratorium in the Canadian side and the difficulties in obtaining permissions in the American side put the offshore wind sector on pause for a long time, and recently (since 2016) it started to get some momentum. The research has been conducted based on the analysis of acts, regulations, the subject's literature and information from websites.

1. Introduction

Today, many countries have publicly announced to significantly increase renewable energy production to replace conventional power plants in the next decades. This decision is challenging. One respect is the realization of an electrical power grid to be capable of distributing large electrical currents and over long distances. Also, suitable areas with good wind conditions for wind farms should be accessible while they are limited. Therefore, developing offshore wind farms is not straightforward. Canada is endowed with exceptional wind resources. In 2017, approximately 6 percent of Canada's electricity demand met by wind energy - and above this value in jurisdictions such as P.E.I. (28 percent), Nova Scotia (12 percent), Ontario (8 percent), Alberta (7 percent) and New Brunswick (7 percent). Wind-energy prices dropped by 70 percent in the U.S. in 10 years (between 2009-2019) [1] and the anticipated drop in world wind energy costs is 48 percent by 2050 [2]. Figure 1 shows the cost of different energy sectors without subsidies.

**Corresponding Author:*
Soudeh Afsharian,
Lassonde School of Engineering, York University, Toronto, Ontario, Canada;
Email: soudeh.afsharian@yahoo.com

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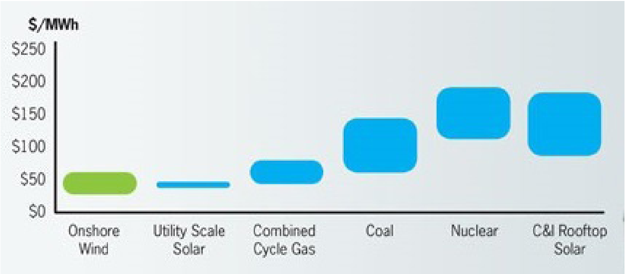

Figure 1. Wind energy has the lowest cost in the new electricity supply [1]

As demand for clean electricity ramps up, the reliance on wind energy increases as a key technology, contributing to affordable power and flexibility to the electricity grid modernization. Today, Canada's electricity grid is 80 percent non-emitting and the target of 90 percent increase by 2030 is adopted by the federal government. Larger wind turbines are now producing more energy because of the increased digitalization and size. The 2017 world leaders in wind energy integration are the European countries - Denmark, Uruguay, Ireland, Portugal, and Germany, respectively as illustrated in figure 2.

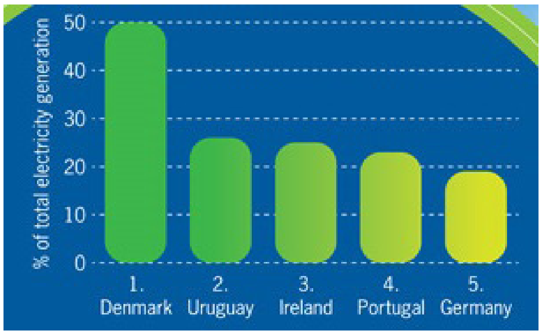

Figure 2. World leaders in wind energy

Canada has committed to reducing its greenhouse gas emissions by 30 percent below 2005 levels by the year 2030, (Figure 3).

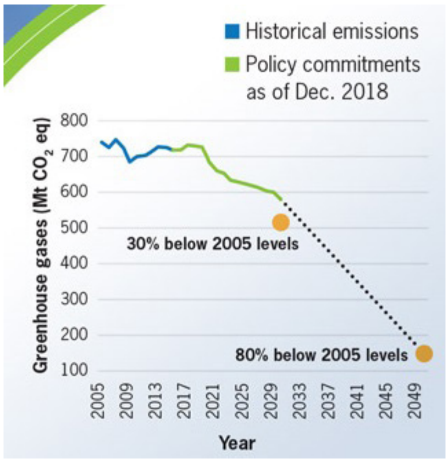

Figure 3. Greenhouse gas emissions by the year 2030

There are increasing concerns about the impact of electricity generation on the environment in Canada. Wind energy is among the best environmentally sustainable forms of electricity generation. Figure 4 reveals the annual average and total installed wind energy capacities are 510 and 12400 MW, respectively which share 27 percent of power generation in Canada's 2017-2040 energy forecast [3].

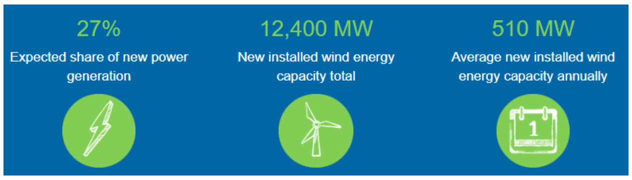

Figure 4. Role of wind energy in Canada's 2017-2040 energy forecast [3].

The Pan-Canadian Wind Integration Study demonstrates that more than 30 percent of electricity in Canada can be generated from wind energy without affecting grid reliability - with many economic and environmental advantages [4].

Offshore Wind Farm

Offshore wind energy generates from the wind over water. Wind farms are constructed in locations where wind speeds are higher and stronger. Compare to the onshore wind farms, there are many advantages of offshore wind projects [5]:

(1) The offshore wind speed tends to be faster

(2) The offshore wind speed tends to be steadier

(3) Coastal areas have high energy demand

(4) Windmills are larger and taller allowing for more energy collection

(5) Offshore wind farms are far from the coast so are less intrusive

Offshore wind energy rapidly grows and plays an important role in the current and near-future energy systems. Although only a tiny fraction of global energy supply provided by the offshore sector in 2018, in the coming decades it will set into a $1 trillion-business. Currently, just 0.3 percent of the global power generation is provided by offshore wind, while its potential is very high. There was an annual 30 percent growth in the global offshore wind market between 2010 and 2018, benefiting from rapid technology improvements. About 150 new offshore wind farms are developing around the world. The United Kingdom, Germany, and Denmark are the European leaders who fostered European technology's development. China is the world leader after Europe by adding the most capacity in 2018. Figure 5 illustrates the offshore wind technical potential and electricity demand, 2018 (Last updated 18 Nov 2019). While Europe has the smallest

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electricity demand but recorded the highest offshore wind potential. China has the opposite behavior; the highest electricity demand versus the lowest offshore wind potential. Offshore wind industry growth has been fostered in the borders of the North Seas, as it has high wind quality and relatively shallow water. By the end of 2018, the European Union reached nearly 20 GW of offshore wind capacity. The policy aims to multiply the capacity by 4 over the next decade. Figure 6, demonstrates the offshore wind capacity by country from 1991 to 2030. While there is almost no record for 1991, but in the 2018-2030 period, UK and Germany are the leaders in this section.

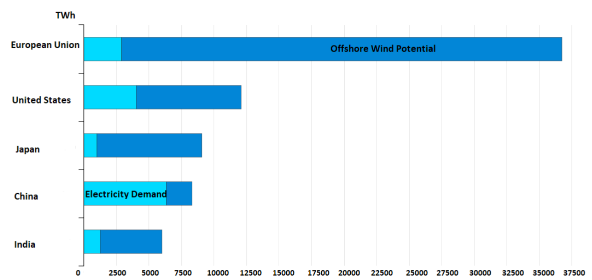

Figure 5. The offshore wind technical potential and electricity demand, 2018.

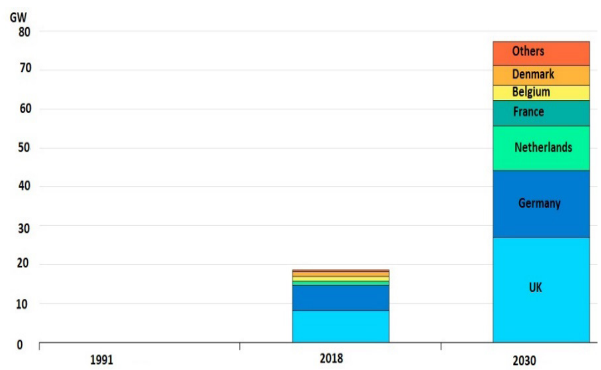

Figure 6. Offshore wind capacity by country, 1991-2030

Alongside Europe, China stands among the market leaders. It is aimed at the growing of 13 percent per year in the globe and is projected to increase fifteen-fold to 2040, accounting for 10 percent of investment in global renewable-based power plants. Figure 7 shows the installed offshore wind capacity, 2018 and 2040 in the Stated Policies Scenario. There is a clear comparison shown by the numbers. Use of natural gas for generating electricity releases 0.6 to 2 pounds of CO2E/kWh; coal 1.4 to 3.6, 0.02 to 0.04 for wind, solar 0.07 to 0.2, geothermal 0.1 to 0.2, and hydroelectric releases 0.1 to 0.5, (Figure 8). For example, analysis by UCS in 2009 showed that 25 percent renewable electricity reduces 277 million metric tons of CO2 annually by 2025- equals to annual output from seventy typical (600 MW) coal plants [6].

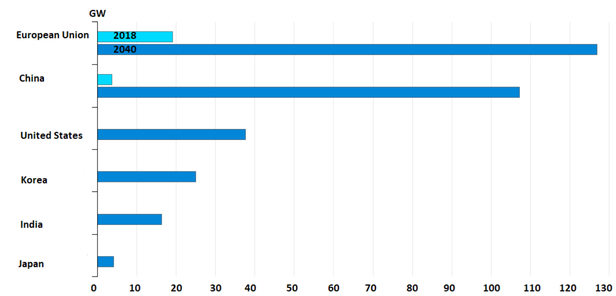

Figure 7. 2018 and 2040 installed offshore wind capacity [6]

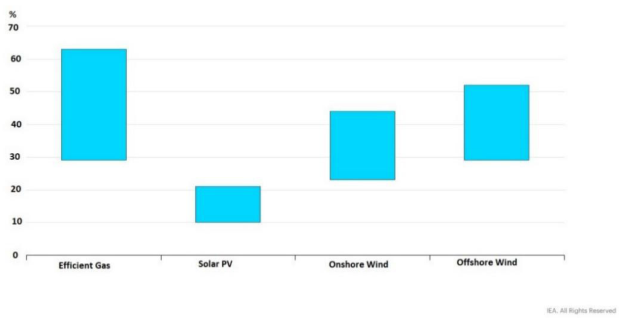

Figure 8. The comparison between different energy sectors for electricity releases [6]

2. Region of Study

The largest body of fresh water on Earth is called "Great Lakes" (Figure 9); Lakes Superior, Huron, Michigan, Ontario, and Erie, containing 1/5th of the freshwater (6 quadrillion gallons). The surface area is about 250000 km^2 and covers 1200 km from west to east [7]. They are on the border of the U.S. and Canada. More than 3500 plants and animal species inhabit there, and about 170$^+$ species of fish. Other important aspects of the Great Lakes are recreational activities, transportation, boating, fishing, tourism, and industrial hub. Many rivers and tributaries connect the Great Lakes. Lake Michigan and Lake Huron are connected with the Straits of Mackinac. Niagara River, including Niagara Falls, connects Lake Erie and Lake Ontario. The St. Lawrence River connects Lake Ontario to the Gulf of St. Lawrence, which leads out to the Atlantic Ocean. Because of the pollution and invasive species, the lakes have been changed considerably. According to EPA, currently, there are many (150 plus) programs designated for environmental restoration and management [7]. Lake Erie: which is the fourth largest of the Great Lakes with a surface area of 25700 km^2 has the smallest volume of 484 km^3. Lake Huron: the second-largest Great Lakes by the surface area of 59600 km^2 with the longest shoreline of about 6157 km, has many islands. Lake Michigan: the third largest of the Great Lakes (water surface of 57800 km^2), located entire-

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ly in the United States. Lake Ontario: the smallest of the Great Lakes (surface area of 18960 km^2), is much deeper than Lake Erie (despite the same size), about four times as volume as Lake Erie (1640 km^3). It is located downstream from Lake Erie and is at the base of Niagara Falls. Lake Superior: is the largest (surface area of 82100 km^2) and with a water volume of 12100 km^3 [8].

Figure 9. The Great Lakes map. (Retrieved from: http://adventureclubsa.com/ClubPortal/EventDetailPublic.cfm?clubID=204&EventID=216663&mo=5)

Great Lakes are showing their quality again to be considered as a source of renewable energy. The wind blows fast and frequent and has high potential to anchor wind turbines on the Great Lakes [9]. There are some advantages in Great Lakes wind energy over Atlantic:

(1) Depth is shallower
(2) Waves are smaller
(3) No hurricanes
(4) Electrical grids are close to the coast
(5) Fewer effects on commercial fishing
(6) Wind speed is competitive

However, the offshore wind farms in Great Lakes have been on hold for several years due to the concerns about birds killing by hitting the turning blades. After Ohio regulators finally determined there would be "minimum environmental impact", the first wind farm (LEEDCo) project was approved. However, LEEDCo must develop and install sophisticated radar- monitoring equipment in the lake before construction begins to determine how the wind turbines might affect birds and bats. By doing the migratory bird studies the company found the impact would be minimal. Another concern is that whether the tall turbine masts can survive ice sheets as Lake Erie - the shallowest of the Great Lakes - averages about 78 percent ice coverage each winter. However, as the water is fresh the ice challenge differs from that faced in the Baltic Sea. Frozen freshwater tends to hang less (and floats on top) below the waterline than does frozen saltwater. People are waiting to see what is possible in freshwater lakes by deploying this small project [10].

3. Literature Review

In 2020, Afsharian et al., focused on the potential impact of wind farms on Lake Erie's hydrodynamic and thermal structure, using 3-D COHERENS (a Coupled - Hydro-dynamical Ecological model for Regional and Shelf Seas) numerical software for the simulations. The study centered on Lake Erie which has a very high potential for installing offshore wind turbines due to its shallow depth and suitable wind pattern and speed [11]. In 2018, Afsharian and Taylor conducted a study to investigate the possible impact of Lake Erie wind farms on physical parameters of water such as thermal structure and mixed layer depths using 1-D modeling (COHERENS). They simulated three different water depths using observed meteorological data to run the model. The simulation was done twice, one without the wake effect and the other mode with 25 percent wake effect (wind speed reduction) [12]. In 2016, Sajadi et al. identified the transmission system upgrades facilitating the offshore wind projects and investigated the impacts of offshore operations on the regional transmission system in the Great Lakes region. 1000 MW-offshore wind farm in Lake Erie was modeled and simulated. Their research provided useful information on scenarios of integrating offshore wind, locating the interconnection points, simulating and modeling wind profile, quantify performance using computational methods, along with operating changes and upgrading equipment needed to mitigate the performance issues caused by offshore wind projects [13]. McCombs et al. in 2014, published a paper on the impacts of the offshore wind farms on the surface wave and eastern Lake Ontario circulation by a coupled wave and hydrodynamic model which applied to the Kingston Basin. In the simulation, they added semi-permeable structures in the surface wave model to represent the turbine monopoles, and to show the drag of monopoles' influence on the flow in the fluid momentum equations they added an energy loss term [14]. In 2014, the U.S. Department of Energy (NREL) issued a report on the economic effects of offshore wind in the Great Lakes region using the JEDI (offshore wind Jobs and Economic Development Impact) model [15]. Loomis, 2013, has analyzed the potential economic effects of offshore wind energy (using 6 offshore wind project scenarios) in the Great Lakes using the offshore wind Jobs and Economic Development Impact (JEDI) model. The model is developed by the National Renewable Energy Laboratory (NREL) to estimate the jobs and economic development impacts [16]. Norouzi et al., in 2013, studied the importance of ice impact

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on the wind turbines in offshore wind farms in the Great Lakes. They demonstrated the importance of ice impact in cold climate. The simulated 5 MW-wind project was deployed in a water depth of 15m. They used the FAST model, which developed by NREL. The study presented how turbines respond to different load cases and conditions [17]. An assessment was done on offshore wind energy in west Michigan in 2011. The West Michigan Wind Assessment is a Michigan Sea Grant-funded project analyzing the benefits and challenges of utility-scale wind energy development in coastal west Michigan [18]. In another research in 2011, Ewert et al. published a guideline on wind energy for Great Lakes regions. They developed the guideline because of the broad interest in the placement and operation of wind turbines. The report helped to minimize the impacts on species, communities and ecological systems, provided useful points and information for wind energy projects such as sites, birds and bats concern, and communities through peer-reviewed literature and printed reports [19]. A feasibility study has been done by AWS Truewind on behalf of the New York State Energy Research and Development Authority (NYSERDA), in 2010 on New York's offshore wind energy development in the Great Lakes. It assessed the technical and economic feasibility to investigate the parameters affecting offshore wind development such as the global offshore wind development activity and technology, (wind turbine and foundation types), lake geophysical conditions, wildlife, lake uses such as vessel traffic, industrial, commercial, recreational and fishing, adjacent land uses and infrastructure availability to support offshore wind development, siting assessment, legal jurisdictions, including a summary of federal and state approvals, reviews, permits, and economics [20]. In 2010, the conference board of Canada issued a report on the "insights you can count on" about the job and economic impacts of the offshore wind industry in Ontario [21]. In 2005, Pryor et al. studied the offshore wind energy development in the Great Lakes for the Michigan renewable energy program [22].

4. Materials

The research has been conducted based on the analysis of acts, regulations, the subject's literature and information from websites. The basis for the selection of the analysis method has been the type of gathered information.

5. Results and Discussion

Great Lakes offshore wind projects

Canadian side:

Although there is a moratorium in Ontario-Canada since 2011, on the US side of Lake Erie the largest offshore wind farm project is launching. There are some concerns about the offshore project such as concern about the drinking water quality as Lake Erie produces drinking water to 11 million people and there is uncertainty about the environmental impacts and the fragile ecosystem. Another main concern is that Lake Erie is a critical migration route for millions of birds, including endangered and threatened species.

Icebreaker Offshore wind Project (LEEDCo):

8 miles off the coast of Cleveland in Lake Erie, there will be 20.7 MW wind farm which will provide power to 7000 homes and be the largest offshore wind farm in North America. Table 1 shows the details of this project [23]. The investors and developers intend to build 1400 to 1600 wind turbines across Lake Erie by the year 2030. This project will lead to more construction of offshore wind turbines in the Great Lakes. Figure 10 shows the map of this project [24].

Table 1. Icebreaker LEEDCo

Location	Lake Erie United States
Name	Icebreaker
Other names	Great Lakes Wind Energy Center, LEEDCo, Cleveland Pilot Wind Project
Type	Organization
Capacity (MW)	20.7
Latitude	41.612
Number of turbines	6
Wind turbine capacity (MW)	3.45
Cost	$ 128 Million`

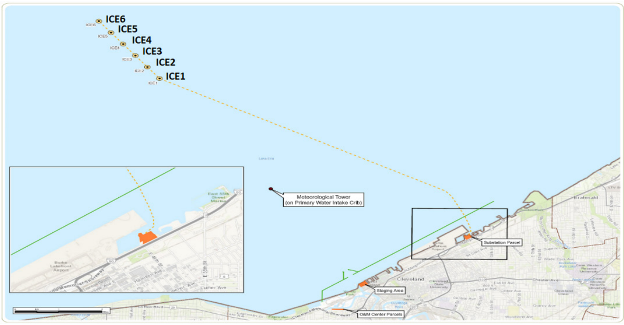

Figure 10. Icebreaker Wind Farm

Naikun Wind Farm:

In August 2019, it was announced that the Canadian offshore wind project moves forward and Naikun Wind Energy Group has signed an offer with an offshore wind developer to develop a project in British Columbia, Canada, (Figure 11). The project is located in Hecate Strait, between Haida Gwaii and Prince Rupert on the British Columbia mainland. The 400 MW offshore wind farm will cover 550 km^2 area [25].

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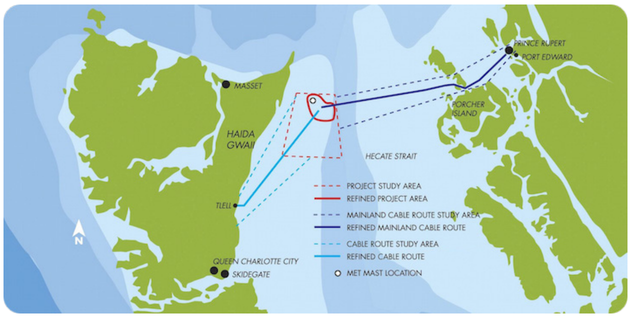

Figure 11. Naikun Wind Farm

Beothuk Wind Project:

Beothuk Energy Inc. is developing a $1-billion offshore wind farm in western Newfoundland to respond to the demand for clean energy in Atlantic Canada and the eastern United States. Because of the constant wind and shallow water depth and existing infrastructure, western Newfoundland has a great opportunity to start offshore wind projects. With many states in the U.S. like Massachusetts, pushing to move toward a green economy, Newfoundland could be a major provider and helping their economy [26]. Offshore start-up Beothuk Energy is partnering with Copenhagen Infrastructure Partners (CIP) to develop wind farms off the east coast of Canada, starting with 180 MW St. George's Bay project in Newfoundland, (figure 12). The St. George's site is 18 km offshore in a water depth of 25 m. The plan is generating first power in 2021. The plans worth C$4 billion, with a capacity of 1GW and off the south-west coast of Nova Scotia. Other projects are developing in New Brunswick and Prince Edward Island [27].

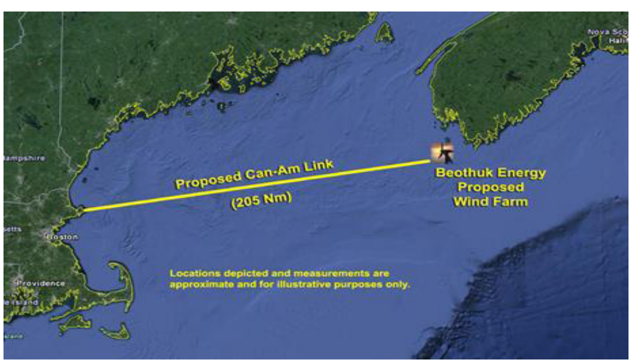

Figure 12. Beothuk offshore wind project in Nova Scotia

American Side:

Block Island Wind Farm: The eastern United States expects approximately 86 GW in offshore wind by 2050 and Atlantic Canada is well-positioned to deliver it [26]. The $300 Million-Block Island Wind Farm (2016), in Rhode Island, is the only operational offshore wind farm in the United States and is built by Deepwater Wind in 4 miles off the coast of Block Island, RI, (Figure 13). The capacity is 30 MW with a total of five 6-MW turbines. It can potentially power up to 17000 homes [28]. According to the U.S. Department of Energy (DOE), the Block Island project is a tiny fraction of more than 2000 MW that could be developed with current technology around the country. Based partly on the success of the Block Island Windfarm, there are now over 20 offshore wind farms in development stages in the United States, mostly in the northeastern coastal Atlantic offshore region. This includes the 816 MW Empire Wind offshore wind farm project off the coast of Long Island, planned to start operations in 2025, and the 880 MW Sunrise Wind project, also in Long Island, with a planned completion date in 2024. The 800 MW Vineyard Wind project in Massachusetts, near Martha's Vineyard, plans to be operational by 2022 [29].

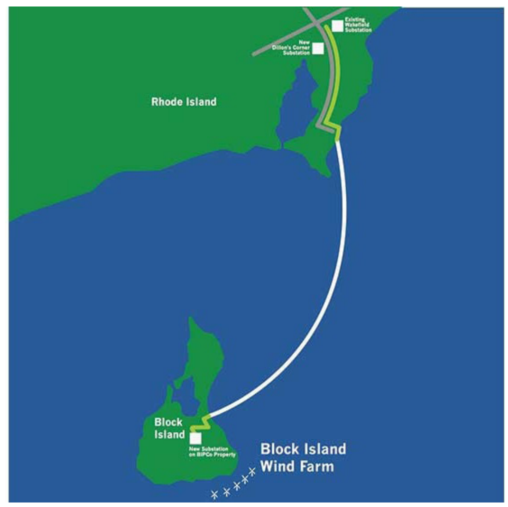

Figure 13. The Block Island Wind Farm

In 2016, the office of Energy Efficiency and Renewable Energy has conducted several different levels of resource assessment. In the first step, wind speed at 100 meters from the surface (the height where wind turbines operate) was analyzed across the coastlines and Great Lakes, (Figure 14). Western, eastern and a portion of southeastern U.S. in addition to the Great Lakes region have winds above 7 m/s. highest wind speed (above 10 m/s) is recorded for the east and some parts of the western U.S.

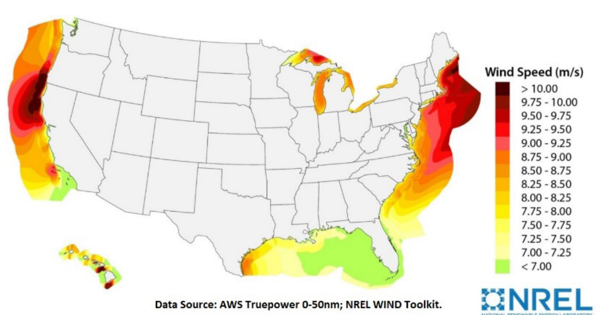

Figure 14. Offshore wind speeds (at 100 meters), 2016 U.S. Offshore Wind Resource Assessment (OSWRA)

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The next step was the calculation of the gross resource potential by evaluating the portion of wind that can be used by wind turbines with specific size and space between them. It assessed the projected technology development of trends for U.S. offshore wind turbines until 2021. By combining the assumptions with estimates of the amount of power that each wind turbine can capture the gross resource potential of 10800 GW of capacity or more than 44000 TWh of electricity generation per year was estimated. Different levels of resource assessment including deployment, economic potential, technical resource potential, gross resource potential, and total offshore wind resource potential illustrate in Figure 15. The deployment contains the installed capacity and the generated electricity; costs, prices, and values are calculated in the economic section; technology resource includes the land use, environment, and technology exclusions; while in the gross resource section different factors such as politics, power density, wind, and energy capacity, gross and net capacity must be considered.

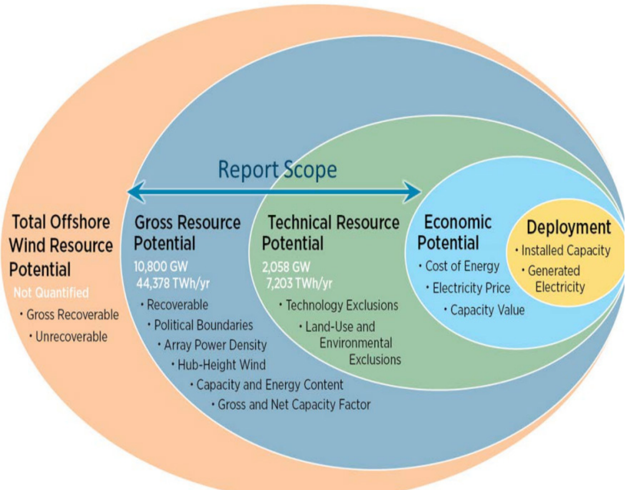

Figure 15. Different levels of resource assessment

However, by applying some exclusions, such as a restricted depth of 60 meters in the Great Lakes for the platform and removing areas with low or no energy potential such as shipping lanes, wildlife refuges, and marine protected areas, the U.S. offshore wind has more than 2000 GW potential capacity. Which is nearly double the nation's current electricity use. As illustrated in figure 16 a and b, the technical potential of 7200 TWh/year is distributed among the coastal and Great Lakes states. Deepwater areas and low wind zones (lower than 7 m/s) are excluded, [29]. Massachusetts and Minnesota have the highest and lowest energy potential, respectively.

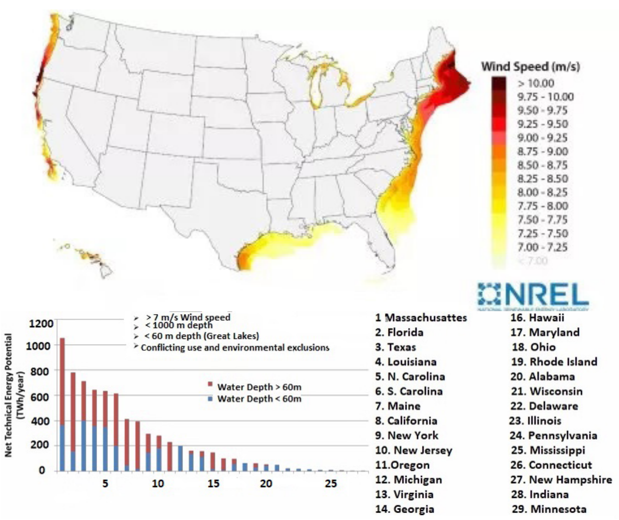

Figure 16. Offshore wind speeds at 100-m heights as narrowed down for calculating the technical resource potential, top) the map, bottom) the chart

In summer 2018, Statoil company planned to construct a 1.5 GW Empire Wind project about 15 miles south of Long Island in the U.S. this amount of electricity is enough for roughly 1 million homes and is across 79000 acres of leased federal waters and the anticipated start date is 2023 and will complete in 2025. Avangrid Renewables has planned a major wind farm in 122000 acres of federal waters with the capacity of 1.5 GW of electricity 27 miles off the coast of Kitty Hawk, North Carolina. Another major wind farm (1 GW) is going to install by Orsted 10 miles off the New Jersey coast, between Atlantic City and Cape May on 160000-acre site. The plan is that the wind farm comes online between 2020 and 2025.

After years of false start and delays, it seems that the U.S offshore wind industry finally gains some momentum. U.S. and Europe wind energy developers pursue a slate of projects along the U.S. coast. According to the U.S. Department of Energy, more than 25 offshore wind projects with a generating capacity of 24 GW are now being planned, mainly off the U.S. Northeast and mid-Atlantic coasts. Several key factors are driving the long-awaited take-off U.S. offshore wind, [30]:

(1) Driven down costs due to the sophisticated turbine technologies and economies of scale.

(2) Wind farms in deeper water due to the advances in construction.

(3) Less public's concern when seeing wind farms farther offshore.

(4) The government support.

<u>Canadian and American Wind Atlas</u>

The Wind Atlas, unveiled in October 2004, generated

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by Environment and Climate Change Canada (RPN) and initiated in the year 2000. WEST (Wind Energy Simulation Toolkit) has generated the results [31]. 5-year mean (1996-2000) of Wind Energy Potential (Watt/m^2) based on the Canadian Meteorological Center (CMC) daily 24-hour forecasts (25 km resolution). Figure 17, is Wind Energy flow, (50 meters above ground), unit is Watts/m^2 (not of land but of turbine cross-section area). Red-brown is the highest value, occurring mostly over open (non-coastal) waters [32].

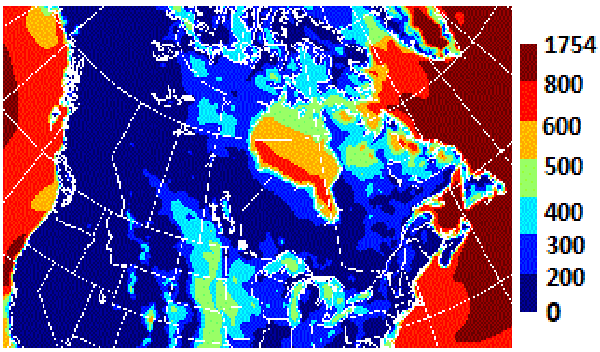

Figure 17. Canada Wind Energy flow, at 50 meters above ground (Watts/m^2)

Figures 18 and 19 respectively show the U.S. land-based and offshore annual wind speed at 80 m according to the NREL and the U.S. wind speed anomaly map 2010-2019. From the vortex website. The data source is ERA5 and the wind mean speed is averaged at 100 m height [33]. From figure 18, most areas have the wind speed of less than 6 m/s, while the east and western parts as confirmed in figure 16 and some central regions recorded the wind speeds above 7m/s and even more, in some regions the wind blows faster than 10.5 m/s at 80 m height.

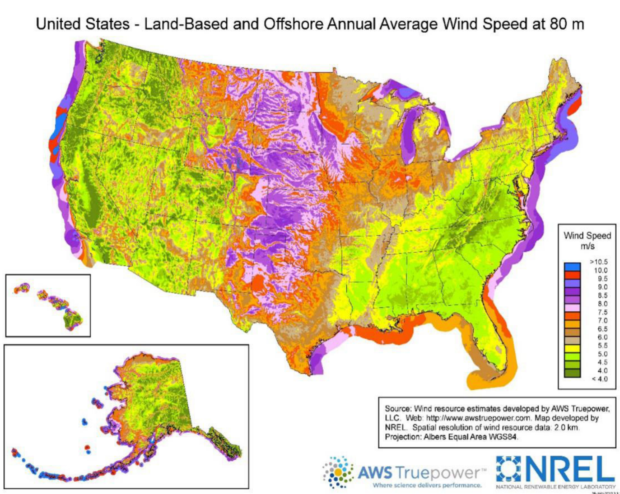

Figure 18. The U.S. land-based and offshore annual wind speed at 80 m, (NREL)

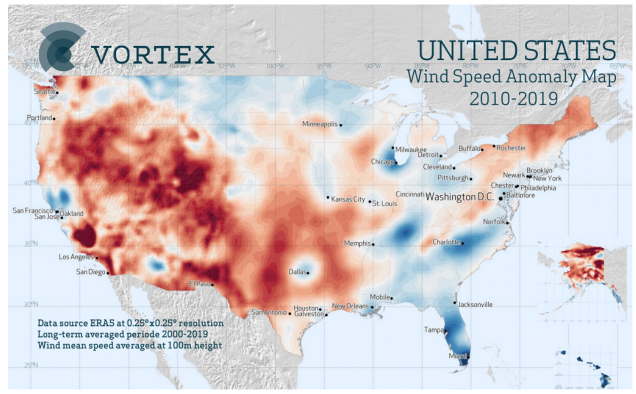

Figure 19. The U.S. wind speed anomaly map 2010-2019 [34]

6. Conclusion

To kick-start a construction boom and make the costs affordable to make offshore wind attractive to corporate energy buyers and power companies, significant technical improvement is needed and the issues on hurdles for installing the wind turbines in water must be solved. However, the offshore wind farms are coming to the Great Lakes and the governors are preparing draft model legislation for permitting, leasing and siting potential projects. Canada is signing agreements with developers to pursue projects. Although series of events had led to chase the investors out and drop the interest in offshore wind projects in Great Lakes, (Michigan policy momentum halt or Ontario moratorium in 2011), today the tide is turning again. Advocates hope Icebreaker catalyzes further offshore wind projects by settling economic, environmental and regulatory concerns, while opponents concerns about aesthetics, or potential impacts on wildlife. However, it seems the Great Lakes become a focal point for offshore wind in the future due to its high potential and suitable environmental condition such as shallow depth, strong and steady wind and freshwater. The principal barrier to offshore wind is economics. In addition to economics, other challenges are the Great Lakes port infrastructure in some areas, equipment issues such as large vessels to service the turbines, and the high-voltage transmission. So far, the total capacity of the wind projects in the Great Lakes-the approved ones are about 3127 MW which can provide power for more than one million homes. To summarize, Icebreaker with 20.7 MW (planned for 5520 MW), Naikun with 400 MW, Beothuk with 180 MW (planned for 1GW), Block Island with 30 MW (planned for 2000 MW), Empire with 816 MW (planned for 1.5 GW), Sunrise with 880 MW, Vineyard with 800 MW, Avangrid with 1.5 GW, and Orsted with 1 GW of capacity are the projects which are in progress or under construction. The U.S.

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offshore wind has more than 2000 GW technical resource potential capacity or 7200 TWh of generation per year. Approximately, every 1 TWh/year powers 90000 homes. So, nearly 6.5 million homes could be powered by only 1 percent of the offshore wind energy. According to wind vision released by Energy Department in 2015, just 86 GW development (about 4 percent) of the U.S offshore wind technical resource potential by 2050 would support 160000 jobs, reduce power sector water consumption by 5 percent and reduce America's greenhouse gas emission by 1.8 percent. Although offshore wind power in Canada and U.S. is not very impressive today, there are signs that the sleepy industry is finally waking up. The statistical information in this paper will help the investors and policy makers to have a better perspective of the situation in this industry as it is anticipated that most of the offshore wind projects come on line by mid 2020s and investors must begin preparing for this renewable energy opportunity.

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