Technology Solutions for Reducing GHG Emissions in the Canadian Energy Generation Sector

SREE 4001

Ashley Hooker: 100956091

Isabelle Kosteniuk: 100928252

Cassandra Wright: 100822330

Madison Green: 100933788

Alexander Wilson: 100969068

Executive Summary

This report outlines the feasibility study of a proposed offshore wind farm situated near the tri-provincial border of Newfoundland, Quebec, and Nova Scotia. The site experiences average wind speeds of 9-11 m/s at 80 m, and is located at an average depth of 50 m. The newly constructed Maritime link capable of transmitting 500 MW HVDC will provide infrastructure for inter-provincial transmission of wind power. The 1000MW HVDC Atlantic Link project will further support international wind energy infrastructure and may generate future business opportunities for the proposed offshore wind farm.

The project plans to install 40 6 MW Siemens turbines with OWEC Quattropod support structures that will be used to generate a maximum of 240 MW. Losses are estimated to be approximately 49% and an average capacity factor was calculated at 64%, resulting in annual output of 1093 GWh, enough to power 68 000 homes.

The project was determined to be economically infeasible with an NPV of -$161 million for best case scenario analysis. However, federal government subsidies for renewable energy totaled $11 billion in 2014, indicating that the project could be feasible for its social benefit. Additionally, as electricity prices in the region and total global installed capacity of offshore wind continue to increase the project will become more feasible. Environmental impact was determined to be negligible as compared to benefit due to carbon offset. Notably, the project would replace several high-emissions diesel plants in the nearby communities.

Overall the project has been determined to be a desirable addition to the Nova Scotian and Newfoundland energy grid, providing local benefits in the form of renewable tech jobs, decreased emissions, and reliable power. The feasibility of the project depends mainly on the availability of governmental subsidies. In light of the current subsidies available for the project, it is likely that the project will be able to attain the required funding, and therefore the proposed offshore wind farm project will likely be feasible in the new future.

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1. Background (Pre-feasibility Study) - Cassandra Wright

1.1 Wind Energy in Canada

With 11 898 MW of installed wind energy capacity in 2016, Canada became the 8th country in the world for installed capacity [1]. The average annual wind speeds across Canada at an 80m altitude are shown in Figure 18 shown in Appendix I; the higher wind speeds in the Maritimes, northern Quebec, southern Ontario & Alberta highlight the incentive in Canada for using wind as a renewable source of electricity.

Many wind farms were constructed across the country in the past 10 years, with Canada's installed wind capacity growing by an average of 24% each year from 2005 – 2015 [2]. Much of Canada's wind energy is currently generated in Ontario, Quebec, Alberta and the Maritimes [2] [3] (this is visually depicted in Figure 20, found in Appendix I of this Report). However, if the electricity generation mix of each province/territory is compared, (as shown in Figure 21 found in Appendix I of this Report), there is a very large proportion of wind generation for electricity in Atlantic Canada.

Wind power has been the largest source of new electricity generation in Canada for 11 years [1]. Since the resource is readily available, and wind technology is currently being invested in by the Canadian National Government, Atlantic Canada appeared to be a relevant and possibly feasible location for a new offshore wind farm.

1.2 Maritime Energy Economy, Reliability & Risk

1.2.1 Wind Power over the last decade

The Canadian Maritimes are abundant in wind energy, with consistently strong winds year-round it is an ideal location for a wind farm [4] [2]. The Pan-Canadian Framework outlines Canada's commitment to addressing greenhouse gas (GHG) emissions and has led to all provinces & territories to review their energy production methods [5]. However, the provinces of Nova Scotia, PEI, New Brunswick and Newfoundland (NFLD) had already begun to make use of the wind resources of Atlantic Canada with a combined total of 1150 MW of installed wind capacity by the end of 2016 [6]. (This is highlighted in Figure 22, in Appendix I of this report). PEI, Nova Scotia, and New Brunswick have 3 of the 4 highest per capita wind capacities in Canada [6] [7]. (This is shown in Table 6 found in Appendix I of this Report).

Over a decade ago, the Nova Scotian government put into legislation that Nova Scotia Power and the municipal electric utilities needed to have 25% renewables in their generation mix by 2015 and 40% by 2020" [8] [2] [9]. This goal was surpassed, with NS Power reaching 27% renewable generation in 2015 (when renewables were 7% of the mix in 2005) [10]. Between 2005 and

2015, Nova Scotia also managed to increase the share of wind in total generation capacity from 1% to 9% [11].

Although the Maritimes currently have many wind projects, (Figure 23, in Appendix I of this report), which have created a strong foundation for the industry in the region, there still is a significant amount of potential of wind energy left to be exploited in Atlantic Canada [6]. Compared to onshore, offshore wind speeds are higher and may produce up to 50% more electricity [2], and the speeds are more compatible with general demand curves, as offshore wind is generally stronger during the day when demand for electricity is high [2]. These facts combined with the ability to use larger, more efficient turbines offshore means that capacity factors for offshore wind are approximately 45%, whereas onshore wind has capacity factors closer to 30% [2]. Despite the many benefits of offshore wind, as of 2017 no complete offshore wind farms existed in Canada, but there has been 3.6 GW (3600MW) of proposed offshore wind projects; including five projects totaling 3.2 GW (3200 MW) in Atlantic Canada by Beothuk Energy [2].

1.2.2 The Maritime Link

The Maritime link project was the construction of a new 500 MW HVDC (High-Voltage Direct Current) transmission line, as well as a 230 kV HVAC (High-Voltage Alternating Current) transmission line between NFLD and Nova Scotia [9], which allowed NFLD to connect to the Atlantic electricity grid. A map of the maritime link may be seen in Figure 24, in Appendix I of this report. The link included 340 km of subsea cables across the Cabot Strait and 350 km of on land transmission cables [9], and upgraded the export total transfer capabilities (TTC) from New Brunswick to the Maritimes from 350 MW to 505MW [12] . The link also means that Nova Scotia's operator is better able to import electricity when it is needed, or more importantly with respect to the proposed offshore wind farm, may export electricity when it can be sold at a price that lowers costs for customers inside Nova Scotia [13].

1.2.3 The Atlantic Link

The Atlantic Link, (as shown in Figure 25, in Appendix I of this report), is a proposed 600 km long, 1000MW subsea HVDC transmission link that will allow Atlantic Canada to deliver approximately 5.69 TWh of "clean" energy annually to the state of Massachusetts [14]. The link is intended to have a supply mix of over 70% wind energy from new and existing wind farms in Nova Scotia and New Brunswick [14]. The Atlantic Link is currently 100% owned by Clean Power Northeast Development (a subsidiary of Nova Scotia's Emera Inc.), however New Brunswick Power has an option to become a minority investor [14].

1.3 The Proposed Location

1.3.1 Geographical Location

The latitude & longitude of the proposed wind farm site is 47.014 N, -61.3 W as shown in Figure 19 found in Appendix I. It is located in-between the Magdalen islands and Chéticamp, NS (where the onshore substation will connect to a 69 kV transmission line). In this location, the water is approximately 50m deep [15] [16] and at an 80m altitude, the average annual wind speed for the location is 9 – 11 m/s [4].

1.3.2 Local Energy Economy, Reliability & Risk

The southern end of NFLD, as well as the Cape Breton part of Nova Scotia, and the Quebec Magdalen Islands are areas where diesel generation is prevalent [12] [17]. The transmission maps of both Nova Scotia & NFLD may be found in Figure 26 and Figure 27 in Appendix I of this report. The proposed wind farm should generate more than enough clean energy to replace the thermal generation in the area, as well as create more energy capital for Nova Scotia to sell to the grid.

2.0 Technical Analysis and Design – Ashley Hooker and Madison Green

2.1 Wind Analysis

2.1.1 Wind Energy Availability

An important aspect of prospecting a wind farm is analyzing the area's available wind resource to accurately assess the effects of intermittent wind energy. Monthly and annual average are available for the chosen site, showing the 26-year annual average at 7.1 m/s (U_r), measured at 10 m (z_r) [18]. As the Siemens turbine has a hub height of 100 m[1] (z), the average wind speed must be scaled up using the following equation:

Equation 1 [19]

Where alpha, the coefficient representing the wind profile of the area, is assumed to be 0.11 for offshore conditions [19]. From where P(u) is the power output from the wind turbine's power curve, shown in Figure 5. Finally, the capacity factor was calculated by dividing E_{annual} (in MWh) by the maximum energy possible for this 240 MW array over a year, resulting in 64 percent. This

[1] While the turbine itself stands 100 m high, the base would add between 1 to 5 extra meters to the total height. For simplicity, 100 m total height has been assumed.

value is significantly higher than the value calculated by the RETScreen analysis of 51.9 percent; a discussion of this follows in later sections.

Table 1, this results in an annual average wind speed of 9.1 m/s. These conditions, paired with water shallow enough for a seabed foundational base, discussed in following sections, are sufficient for the requirements shown in the turbine's power curve; i.e. on average, a single turbine would be generating approximately 3 MW of power, or just over 26 000 GWh annually.

However, further analysis is needed for a more accurate assessment of the wind resource. This is found in hourly data logged by a nearby weather station on Saint Paul Island, Nova Scotia, which is approximately 50 km away from the chosen wind farm site. While there is a closer weather station, it is on the mainland, meaning that the wind data is more applicable for onshore conditions (i.e. much lower wind speeds). Saint Paul Island is far enough from the coast of Nova Scotia and small enough in size to experience offshore conditions comparable to the wind farm at the chosen site. Figure 1 shows the frequency at which wind speeds between 1 and 35 m/s occur based on 2016 data, discounting the less than one percent of the time that errors appeared or no data. Note that the hourly wind speeds were scaled up from their base measurement height of 27 m to reflect conditions at the turbine hub height. A sample of this data is provided below in Table 1.

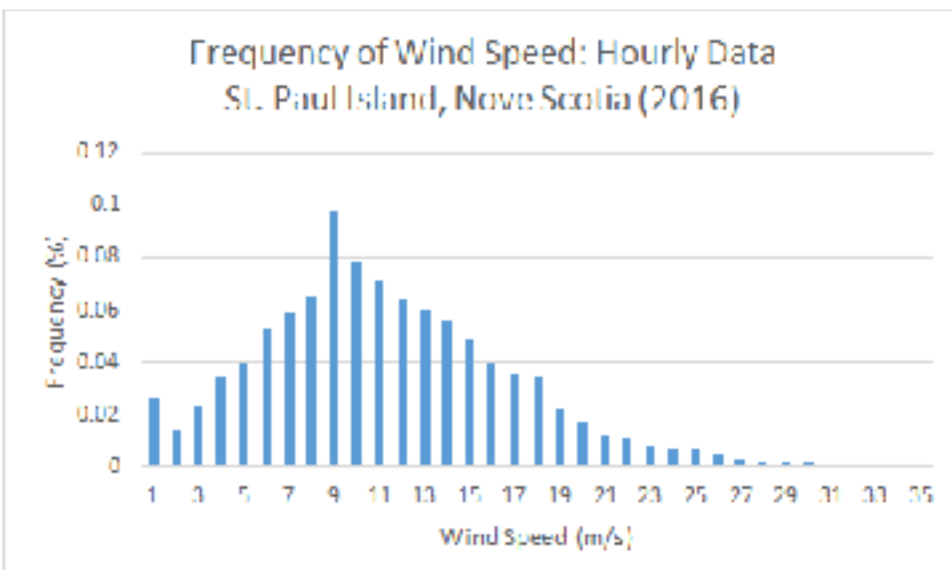

Figure 1 - Wind Speed Frequency

The average wind speed using the hourly data is 10.7 m/s, which is higher than the 22-year average from the Atmospheric Science Data Centre at 9.1 m/s [20]. Next, the standard deviation () was found to be 5.55, which allowed the Weibull shape parameter (k) to be calculated at 2.05 using Equation 2, as well as the scaling factor at 12.14 using Equation 3:

Equation 2 [19]

Equation 3 [19]

After finding these parameters, the probability of wind speed occurrence can be calculated through a Weibull distribution using Equation 4:

Equation 4 [19]

The results of this PDF can be graphed, shown in Figure 2.

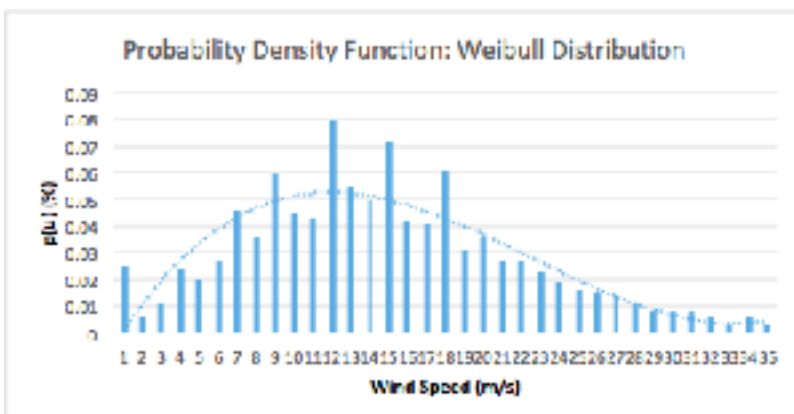

Figure 2 - Weibull Distribution

It should be noted that while there were some missing data points where the weather station went offline or otherwise failed to log data, but the total amount of missing data over the year amounted to less than one percent of the total (8760 hours). It was thereby treated as insignificant, and neglected. Next, the total annual energy was calculated using Equation 5:

Equation 5 [19]

where P(u) is the power output from the wind turbine's power curve, shown in Figure 5. Finally, the capacity factor was calculated by dividing E_{annual} (in MWh) by the maximum energy possible for this 240 MW array over a year, resulting in 64 percent. This value is significantly higher than the value calculated by the RETScreen analysis of 51.9 percent; a discussion of this follows in later sections.

Table 1 - Sample Data

Bin	Frequency	p(u) weighted	P(u) Power Curve kW	p(u)*P(u)	E_annual kWh
1	212	0.024605385	0	0	0
2	54	0.006267409	0	0	0
3	95	0.011025998	55	0.606429898	5225
4	205	0.023792943	175	4.163765088	35875
5	173	0.020078923	410	8.232358403	70930
6	231	0.026810585	760	20.37604457	175560
7	397	0.046077066	1250	57.5963324	496250
8	313	0.036327762	1900	69.02274838	594700
9	517	0.060004643	2700	162.0125348	1395900
10	382	0.044336119	3550	157.3932219	1356100
11	370	0.042943361	4300	184.6564531	1591000
12	684	0.079387187	5000	396.9359331	3420000
13	473	0.054897864	5500	301.9382544	2601500
14	428	0.049675023	5900	293.082637	2525200
15	619	0.071843083	6000	431.0584958	3714000
16	363	0.042130919	6000	252.7855153	2178000
17	352	0.040854225	6000	245.1253482	2112000
18	521	0.060468895	6000	362.8133705	3126000
19	265	0.030756732	6000	184.54039	1590000
20	309	0.03586351	6000	215.1810585	1854000
21	230	0.026694522	6000	160.1671309	1380000
22	232	0.026926648	6000	161.5598886	1392000
23	197	0.022864438	6000	137.1866295	1182000
24	165	0.019150418	6000	114.902507	990000
25	137	0.01590065	6000	0	0
26	126	0.014623955	6000	0	0
27	121	0.01404364	0	0	0
28	94	0.010909935	0	0	0
29	66	0.007660167	0	0	0
30	67	0.00777623	0	0	0

31	66	0.007660167	0	0	0
32	49	0.005687094	0	0	0
33	25	0.002901578	0	0	0
34	46	0.005338904	0	0	0
35	32	0.00371402	0	0	0
More	168				33786240
		E_annualMAX (kWh)	**E_annual (kWh)**	**Capacity Factor**	
		28856841.9	33786240	0.642812785	

2.2 Components and Overall System

2.2.1 Grid Connection

Figure 3 provides an overview of the proposed wind farm's grid-tied infrastructure. Each turbine in the array generates three phase alternating current at different amplitudes and frequencies, likely out-out-phase with one another. This three-phase power cannot be simply combined and sent to the grid, which has its own phase and frequency requirements; in fact, it must first go through an offshore substation where the AC inputs are rectified to output DC, and the voltage is boosted to HVDC conditions. High voltage transmission is crucial to keeping losses low, as power loss is proportional to the square of the current; ergo, voltage should be increased while current proportionally decreased [21]. In comparison to HVAC, HVDC transmission has lower electrical losses, provides superior power quality (i.e. more reactive power), and better-quality converter controllers, though cost analysis on similar projects reveals that the increased financial burden of HVDC lines does not outweigh the benefits[2] [22] [23].

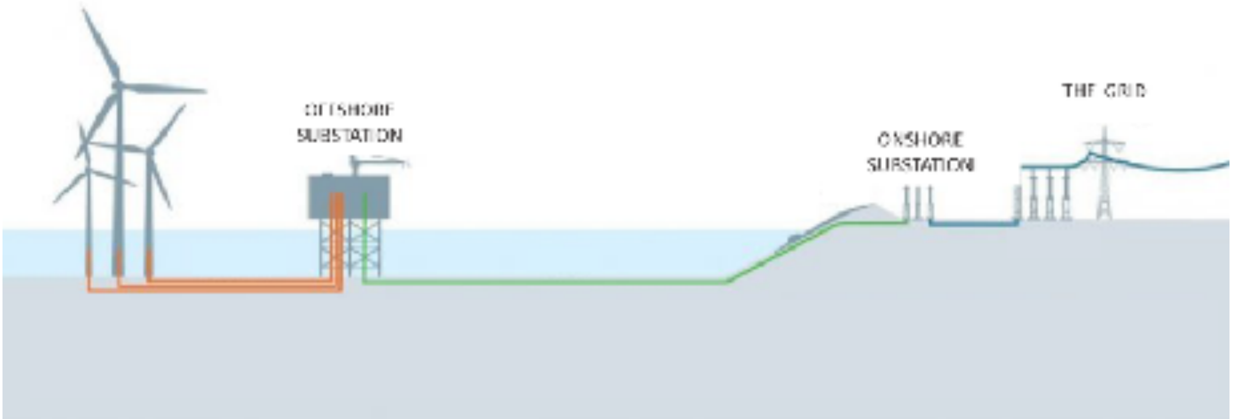

Figure 3 - Overview of grid connection [24]

From the offshore transmission line, the combined the high voltage DC reaches the onshore substation, where it is converted back into AC, where its frequency, amplitude and phase can be synchronized with the grid. From there, it can reach the combined 60, 000 people in northern Cape Breton and southwest Newfoundland that currently run heavily on coal and diesel, as discussed in earlier sections.

2.3 Turbine

The chosen turbine for our system is the Siemens 6 MW offshore turbine which can be seen below in Figure 4. This turbine is specifically made to be installed offshore as all its external surfaces and systems are coated with an off-shore grade corrosion protection [26]. The turbine offers maximum energy for offshore wind speeds, with three 75 m blades, a total rotor diameter of 154 m and a swept area of 18600 m^2 [26]. The turbines are also equipped with a yaw drive to ensure the turbines are facing into the wind, ensuring maximum energy production [26]. To reach the desired power output, forty of these 6 MW turbines will be installed, giving an installed capacity of 240 MW.

[2] Note that during the presentation, a question drew attention to the high-cost of the HVDC transmission lines, which, upon further research, is found to be accurate for farms with capacities of 100, 200 MW and 500 MW at distances of 60 km from the shore [25]. The decision was made to leave the original report with the choice of HVDC, but acknowledge that an economic analysis ought to be made to compare HVDC with HVAC.

Figure 4 - Siemens 6 MW Offshore Wind Turbine [27]

Below in Figure 5 the power for the Siemens 6 MW turbine which was used for our analysis can be seen. This power curve is an up scaled version of the Siemens 4 MW turbine as the data for the 6 MW turbine was not available for distribution.

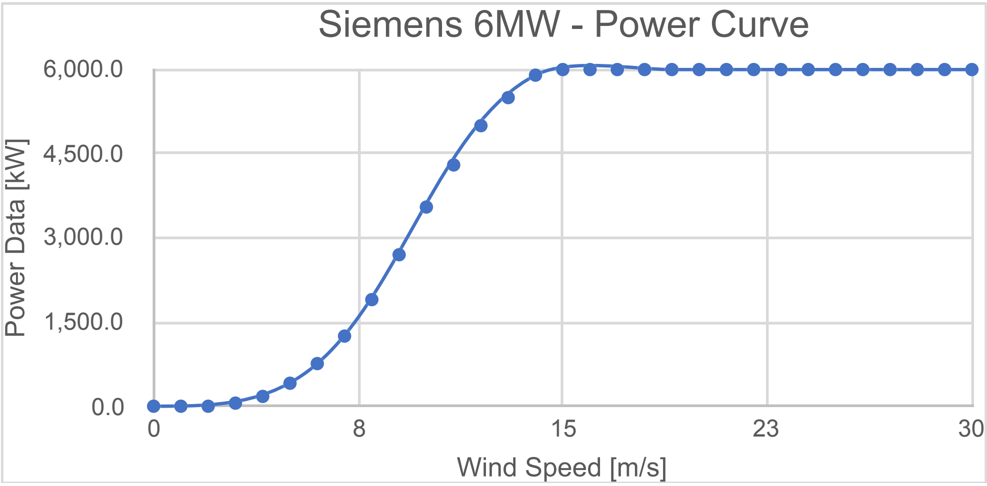

Figure 5 - Siemens 6 MW Power Curve. Modified from the Siemens 4 MW turbine.

The power curve is a useful tool when analyzing data, it gives important information such as cut in speed and cut out speeds. The cut in speed of the 6MW turbine is 3 m/s and the cutout speed is 30 m/s [27]. This curve was also used in the RETScreen analysis which is discussed further in section 2.6 of the report.

2.4 Turbine Foundation

Typical wind farms are installed at a water depth of approximately 20 meters deep using monopole foundations [28]. At the chosen location however, monopole instillation is impossible as a monopole can only be installed at water depths less than 20 meters [28]. To accommodate for the deeper than normal water levels of the chosen location, a jacket foundation was selected to support the turbines. Specifically, the OWEC Quattropod jacket foundation, which can be seen below in Figure 6 and Figure 7. These foundations are ideal for turbine support in deeper waters, a study was completed recently on behalf of a Japanese company proving that these foundations can withstand installations in waters up to 100 meters deep [29]. Although this has not yet been done, this still proves that these foundations are ideal for our project.

Figure 6 - OWEC Quattropod Before Installation [30]

Figure 7 - OWEC Quattropod After Installation [31]

In addition to the study OWEC completed for the Japanese company, these foundations have also been installed in four similar locations to the proposed power plant. The largest of these being Thornton Bank Wind Farm Phase II, with forty-eight installed units and one offshore transformer station situated in Belgian waters [31]. The most similar to our projects installation depth is the

Beatrice Wind Farm in Scotland with two units installed at a depth of approximately 45 meters deep.

2.5 Space and Building Requirements

An important aspect of wind farm planning, whether on or off-shore, is the spacing of the turbines. Since the turbine blades extract the kinetic energy in the oncoming wind, there is a corresponding velocity deficit (and dynamic pressure drop) in a vortical structure that forms behind the turbine's rotor [32]. In order to mitigate the effects of the rotor wake, sufficient distance must be allotted between the turbines so that the velocity and pressure can recover. Due to limitations in access to software that can optimize the spacing, a more creative approach was taken.

The Canadian Wind Energy Atlas offers an analysis of wind direction at 80 m in the form of a wind rose, pictured below in Figure 8.

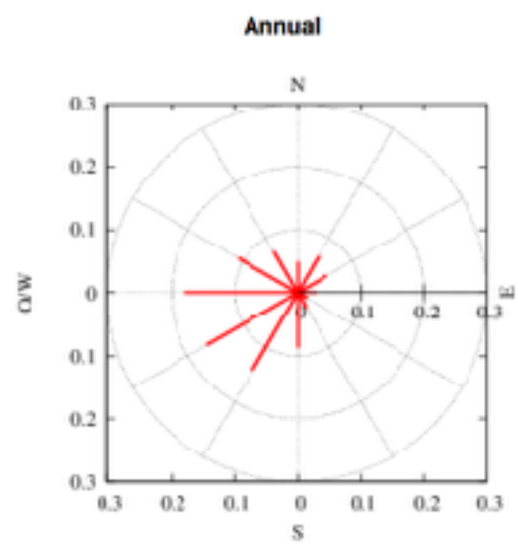

Figure 8 - 2016 Wind Rose for 47.014 N, -61.3 W [33]

This figure signifies that the direction of the wind most often comes from the southwest and blows towards the northeast. From this, it is ascertained that the turbines will be out of one another's wake if they are positioned in alignment with the average direction of the wind. Thus, Figure 9 demonstrates the idea of fitting the turbine array formation to the general pattern of curvature of the wind rose.

Figure 9 - Turbine Array Spacing [34]

This should ensure that the turbines are usually operating as if they're independent of one another; this translates to an infinite distance for wind recovery, whereas the standard is between 5 to 9 rotor diameters in the prevailing wind direction [35]. When the wind does come from a direction that puts the turbines in each other's wakes, they will be placed at a distance of 1 km apart and staggered slightly. This translates to about 6 rotor diameters apart in the direction perpendicular to the prevailing winds, while the industry standard is between 3 and 5 rotor diameters [35].

2.6 Energy Production Analysis

To fully analyze the amount of energy the proposed plant would produce RETScreen computer program was used. Data was taken from the St. Paul Island weather station, which is situated very near the proposed plant location. Having the weather station close to the proposed plant gives the most accurate offshore data possible. These values were then scaled from 10 meters up to the 100-meter hub height of the Siemens 6 MW turbine using Equation 1 above. The RETScreen inputs and outputs can be seen Appendix II. Data was input for losses which are discussed further in section 2.6.1 of the report. This gave an overall capacity factor of 51.9%. and 1,093,248 MWh of energy exported to the grid.

2.6.1 Energy Diagram

Below in Figure 10 is a Sankey Energy Diagram, illustrating the amount of useful energy that our plant produces. The diagram also highlights all of the different losses that the wind farm occurs. Specifically, the system loses 49% of its available energy. Array losses are equal to 10%; these losses are caused by the interaction between the turbines wakes. Airfoil losses are equal to

3%, these losses are caused by things as bugs or ice build-up, as the turbine is operated these build up, causing a decrease in the aerodynamic performance of the blades. Miscellaneous losses are the highest, at 14%; these encompass all electrical losses as well as downtime losses, losses of energy production due to starts and stops, off-yaw operation, high wind and cut-outs from wind gusts. Lastly, substation and transmission losses are 6% and 9% respectively, which are losses incurred at the substation as well as the transportation of the energy to the grid. The values used for each of the losses were taken from expected average values in the RETScreen *Wind Energy Project Model [36]*.

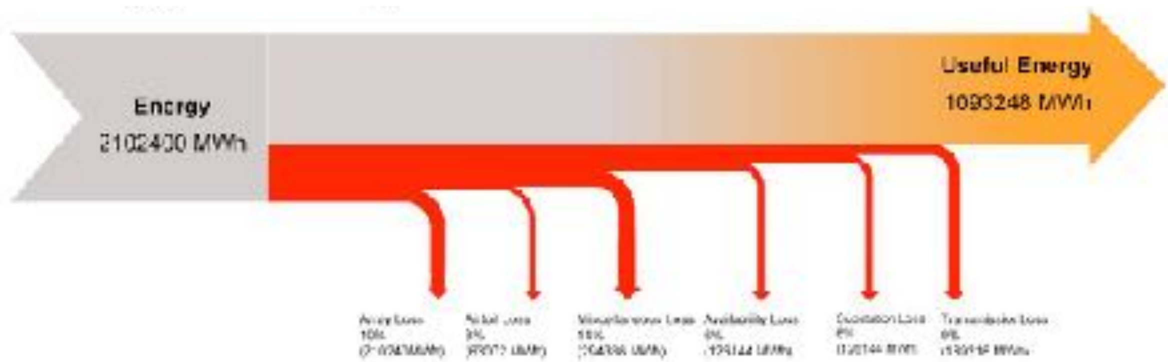

Figure 10 - Energy Flow Diagram

The losses the wind farm endures leaves 51% useful energy, which has the potential of powering approximately 68,000 homes.

3.0 Project Economics - Isabelle Kosteniuk

3.1 Methods of Economic Analysis

This section covers the economic analysis of the proposed offshore wind farm, which was largely based on research done regarding similar existing power plants, regional utility information, and SREE 4001 lectures. Initially, a brief market study was done to determine offshore wind farms average installed costs, generation costs, and other useful metrics.

Estimates of capital costs, operation and maintenance costs, and revenue were found from a variety of sources, reported on in section 3.2. Assumptions regarding analysis parameters such as discount rate, debt financing, and capacity factors are discussed in section 3.3. Section 3.3 also contains the results of best and worst-case analyses performed in Excel.

3.2 Cost Estimation

Table 2 contains a breakdown of capital cost estimates, including both minimum and maximum values. Graphical representations of the information in this table can be seen in Figure 11 and Figure 12. Major components of the capital expenditures include the transmission infrastructure, construction costs, and support structure costs. Section 3.3.4 contains a comparison between the fractional significance of each component cost of this project as compared to market reference.

Table 2 - Capital cost breakdown

Component	Minimum Cost	Maximum Cost
Meteorological system	2000 [37]	10 000 [37]
Support System	100 million [38]	400 million [38]
Wind Turbine	75.9 million [39]	75.9 million [39]
Electricity Collection and Transmission	178.1 million [40]	387.5 million [40]
Offshore Substation	3.2 million [41] [42]	10.5 million [41] [42]
Construction	300 million [43]	300 million [43]
Total	657.2 million	1.173 billion

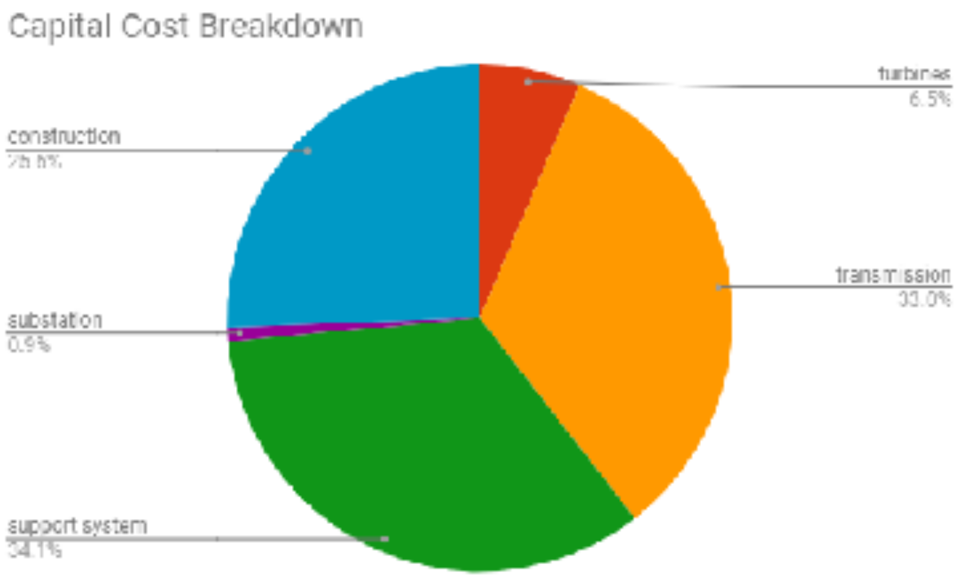

Figure 11 - Maximum capital cost breakdown

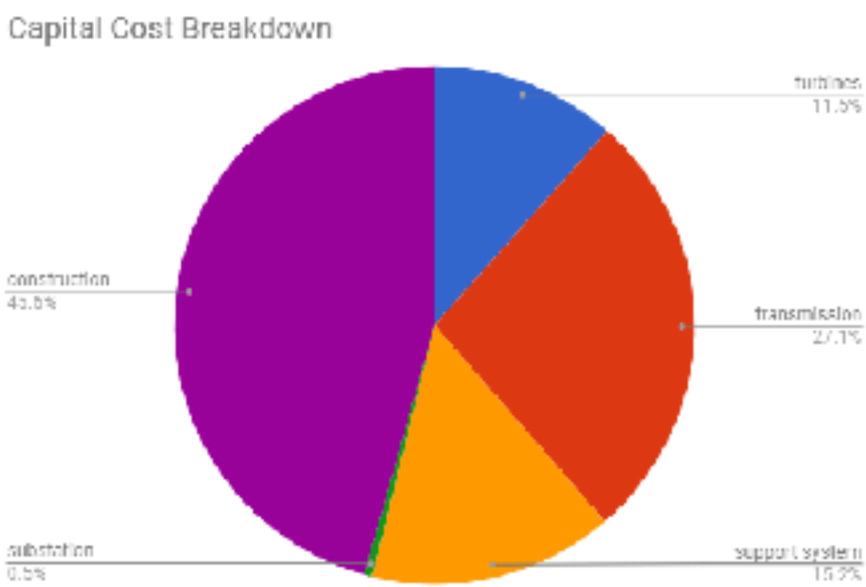

Figure 12 - Minimum capital cost breakdown

Operational costs were approximated as ranging from \$20 per MWh to \$40 per MWh. These values are backed by an analysis of seven different studies covering O&M costs for a range of offshore wind projects [44], as well as the reference offshore wind costs reported by NREL [45], resulting in annual cost of $17.9 million to $35.8 million, based off economic and technical parameters discussed in section 3.3. Decommissioning costs were neglected as research done by the National Offshore Wind Innovation Centre indicates that recycling returns generally cancel out costs. [46]

3.3 Analysis Results

The analyses reported on in this section represent the best/worst case scenarios for project feasibility, performed in Excel. For the best-case analysis, minimum capital and operational cost estimates are used, as well as the parameters shown in the ‘best case’ column of Table 3, which were determined to be the optimum values for maximizing returns. Table 4 contains values calculated based off of parameters in Table 3. Similarly, Table 3 and Table 4 contain parameters used for the worst-case analysis, which represent values determined to be least beneficial for the project within a reasonable range. Additionally, an installed capacity of 200 MW and constant capacity factor of 0.4 was assumed to simplify analysis.

Table 3 - Best and Worst-Case Financing Values

Parameter	Best case value	Worst case value
Debt financing fraction	0.5	0.2
Debt interest rate	8%	8%
Equity interest rate	12%	15%
Electricity price escalation rate	2.8% [47]	1.4%
Initial electricity price	$0.106 per kWh	$0.047 per kWh

Table 4 - Best and Worst Case Derivative Financing Parameters

Parameter	Best case value	Worst case value
Cash outlay	\$328.6 million	\$939.1 million
Annual debt payments	\$36.5 million	\$3.34 million
CRF	0.111	0.142
EIR	10%	13.6%

Figure 13 shows the best case cumulative cash flow of the project over a 20 year lifetime, plus 4 year lead time. Figure 14 shows a breakdown of project costs over the same period. The worst case scenario cumulative cash flow is illustrated in Figure 15. Refer to Appendix III for Excel spreadsheets used to perform the analyses.

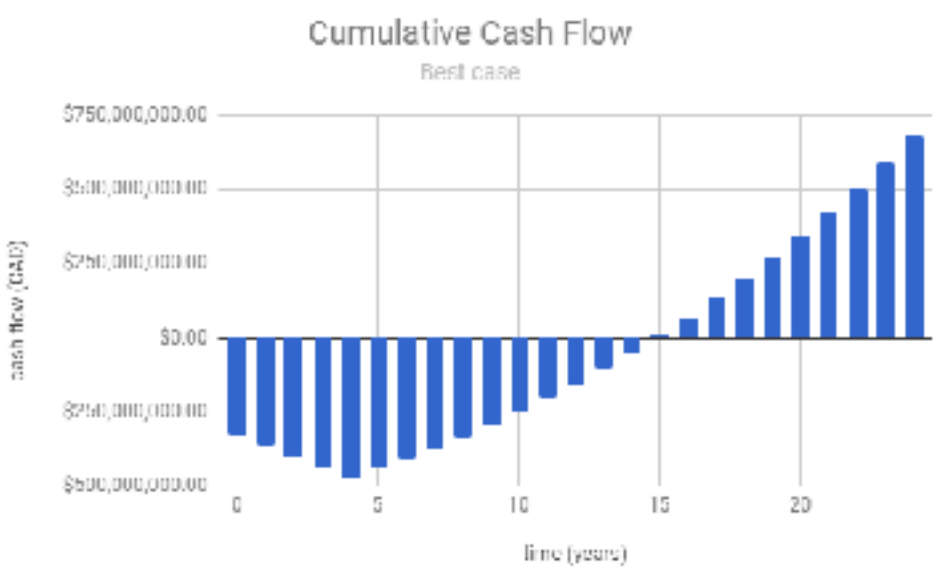

Figure 13 - Cumulative cash flow diagram for best case scenario

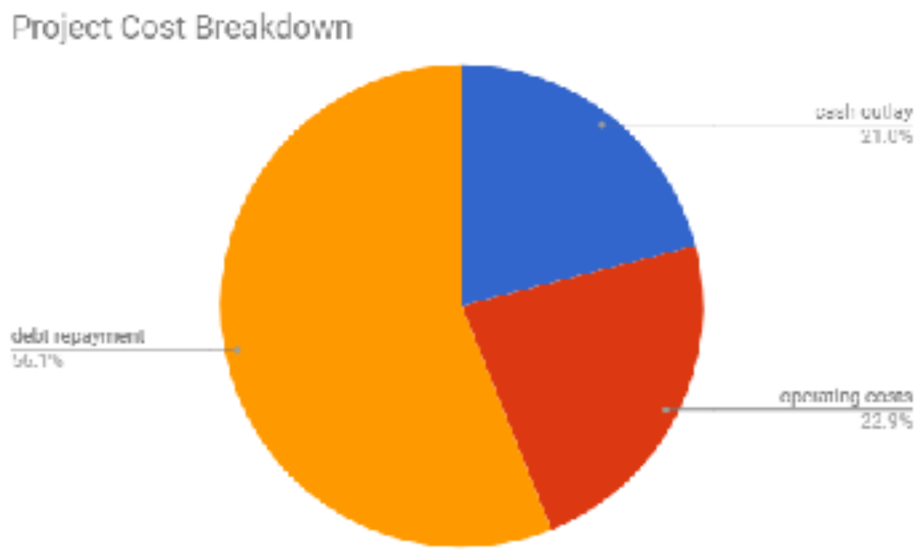

Figure 14 - Project costs breakdown for best case scenario

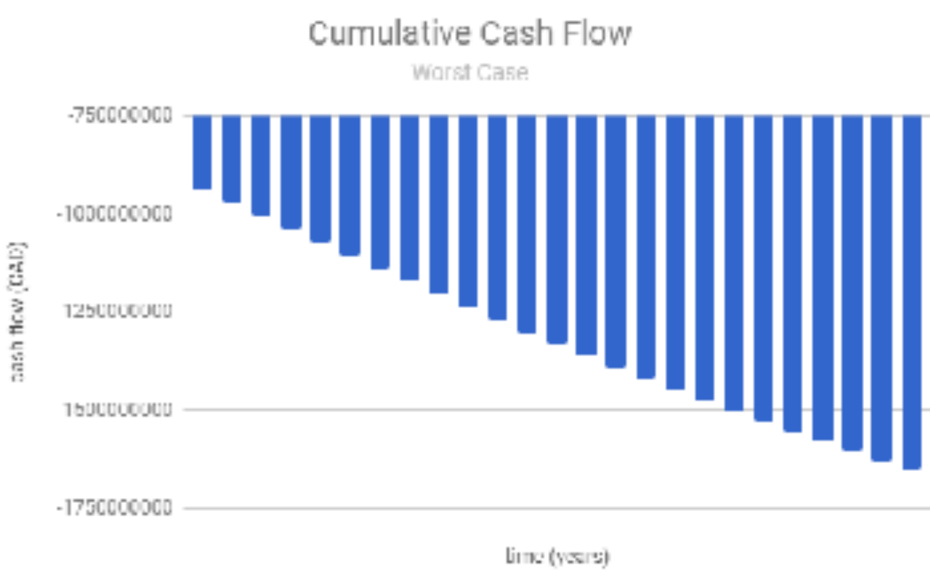

Figure 15 - Cumulative cash flow diagram for worst case scenario

Table 5 contains values calculated for each of the major metrics used to determine feasibility of the project. Appendix III contains diagrams of individual cash flows for each scenario, as well as the Excel spreadsheet used to create the figures in this section.

Table 5 - Results of best/worst case analyses

Metric	Best Case	Worst Case
NPV	-$161.4 million	-$968.4 million
IRR	6%	-%5
NPEC	$0.04 per kWh	$0.08 per kWh
LEC	$0.17 per kWh	$0.43 per kWh
Payback period	15 years	N/A

For both scenarios, the project is unfeasible with zero subsidization. However, the best-case scenario requires only $6.5 million per year of subsidies to reach $0 NPV, which is entirely reasonable within the context of Canadian renewable subsidies [41]. The worst-case scenario results in net cash loss, extremely negative NPV, and no breakeven point. The project would require $40.35 million per year to reach $0 NPV in that case. Section 6 will discuss these results further.

4.0 Environmental Analysis – Alexander Wilson

4.1 Introduction

The 2010 Deepwater Horizon accident in the Gulf of Mexico produced a significant negative effect to the reputation of offshore industrial platforms. The Exxon Valdez oil spill and other oil tanker spills have affected offshore industrial transport similarly. These accidents and events have provided encouragement to move away from offshore energy production and transport. However, to abandon the oceans as a location of energy production is foolish and unattainable given the 71% of the earth's surface they cover. No matter what offshore energy production and transport is used, there will always be some environmental impact. The goal is to minimize this impact as much as possible.

4.2 Energy Production

The effects of ocean oil spills can exist for years after an event. Although the risk is much smaller, offshore wind turbines still pose a risk of oil spills. The gear boxes at the top of a turbine contain many gallons of lubricating oil. Given that fires occur in wind turbines multiple times a year (Figure 16), it is possible that some or all this lubricating oil can leak out.

Figure 16 - Wind Turbine Fire [48]

However, the amount of oil is small relative to historical oil spills. Additionally, fire safety and prevention improves every year.

The major risk of oil spills for offshore wind turbines comes not from the turbines themselves, but from the possibility of a collision with large ships. A report from the Hamburg University of Technology states that “Collisions of ships and offshore wind turbines (OWTs) constitute a considerable threat to the environment” [49]. The report considered collisions with mono-pile, jacket, and a tripod foundation wind turbine. The report found that a large 300 m ship, with a drift velocity of 4 knots is predicted to cause a structural collapse of a wind turbine it encounters. Additionally, there is significant risk of the impact causing the tanker ship to rupture.

When large ships become old and decrepit, sometimes they are sunk to create an artificial reef. In 2006, an old aircraft carrier was stripped down and sunk to create a vibrant environment for algae, sponges, and many species of fish [50]. The same thing could be done for wind turbines after they have worn out. The gearboxes and all other items containing oil and other pollutants could be removed. Then the turbines could be barged to a shallow location and sunk. This process works to assist the environment in two ways. First, it creates a safe environment for fish to hide in with a strong algae food source. Secondly, it reduces the amount of tourism to other reefs, thus reducing human impact in those locations [51].

4.3 Animal Safety

Although things certain politicians say are often exaggerated or false, many of their comments about the dangers of wind turbines to birds and aviary wildlife have been proven. An entry in the journal of biological conservation [52] sates that between 140,000 and 328,000 birds are killed by wind turbines every year. Some birds hurt by the turbines are injured through blunt force. The birds and bats collide with the high speed moving turbine blades which causes significant trauma. However, most of the injury experienced by the animals is due to a pressure difference. Wind turbines work to absorb the energy in the air, this creates areas of low pressure immediately after the turbine as opposed to the high pressure experienced at the front. A full lung of air taken in the high-pressure region wants to expand as the pressure decreases outside of the bird, behind the turbine. This causes the lungs to rupture, which causes a painful death for the animal. There is however, another valid argument to the issue. An article from the Huffington Post [53] states that 6.8 million birds die every year from collisions with cell towers, and a further 3.7 billion birds are slayed by cats every year. After considering these numbers, the number of birds killed by turbines is relatively small. The effect of wind turbines on birds could therefore be considered negligible.

It is well known that whales communicate and navigate to some extent through low frequency noise. Whales use low frequency noise to measure distances and send simple messages to each other. Many human activities have had a significant effect on the ability of whales to use this skill. Offshore wind turbines are no different. An article from the Huffington Post [53] states that offshore turbines produce as much as 120 decibels of sound. While attending a rock concert, people experience approximately 120 decibels of sound. However, underwater, sound travels four times as fast as it does in the air, this makes wind turbines equivalent to a rock concert you can hear many kilometers away. For whales this would seem to have a significant impact on their abilities to communicate and navigate. The problem with this analysis is that it does not consider that many boats already make a similar amount of noise. Additionally, whales only experience significant confusion causing injury, while close to the shores where they can occasionally become beached. Since the wind turbines will be situated far offshore, they may create an undesirable area for the whales to reside, but will not cause them any sort of harm.

4.4 Energy Transport

Although many of the technologies are the same, floating offshore wind platforms differ from offshore oil platforms in several ways. The most significant variance between them is the aspect of energy storage. Offshore oil platforms extract and store energy in the form of crude oil. Wind turbines have no natural method of energy storage and must constantly output into an electrical grid. This requires a constant connection to the shore through an underwater cable. Although safer than transporting crude oil, underwater cables have some environmental impact.

To lay an underwater cable, a specialized ship unspools a heavily shielded cable behind it as it slowly motors through the water. The cable passes out the back of the ship and travels down to the bottom of the ocean where it passes through a device called a plough. The plough works to dig a trench, lay the cable inside, then cover the cable back up. As can be seen in Figure 17, these plows can be very large. The “Elodie” plow [54] seen in Figure 17 can dig a trench up to 3m deep. After digging the trench, the cable is placed in the trench and covered back up. This means that after the cable is laid, the ocean floor is returned to a similar condition it was found in.

Figure 17 - Elodie Submarine Cable Plow [54]

However, ripping of the seafloor has a clear impact on the sea life in the path of the cable. The largest environmental impact would be seen in densely populated waters. The waters off Newfoundland lack the warm water and coral reefs of locations close to the equator and as such, do not have nearly the diversity or population of sea life. Laying cables through the seabed near Newfoundland would have very little affect, if any on the sea life in the area.

The other environmental aspect of underwater cables are the electromagnetic fields they generate when power is being transmitted through them. It is known that some sea creatures have an additional sense compared to humans called electroreception. Sharks use this sense to find prey to an extreme degree of accuracy. Some sources have stated that Sharks acute electroreceptive sense can discern voltage variations as little as 10 millionths of a volt [55]. Given the large max power load of 240 MW through the cables, significant electromagnetic fields would be created. It is known from Maxwell's equations that any moving electrical current generates a magnetic field. It can be seen in the equation below that the closed loop integral of the magnetic field is proportional to the sum of current and electrical field strength .

Equation 6

This means that a large current will have a proportionally large magnetic field generated around it. Although the specifics of the electroreceptive sense have yet to be fully documented and explored, any organism with the ability could become very confused and distressed when near underwater cables. Although it appears that this could be a problem, studies suggest otherwise. Considering that most sea organisms lack this electroreceptive sense, studies have concluded that undersea cables have negligible impact on sea life. A study from the "Monterey Bay Aquarium Research Institute" [56] found that the regions near and on top of an undersea cable near San Francisco had no discernable difference in sea life population from elsewhere. The largest environmental impact of the cable was found to be its movements from wave motion. In some areas, cable movement was found to erode and damage soft bedrock. This displaced bottom dwelling organisms in the area. However, wave motion only affects underwater cables in shallow environments of less than 20m which is a very small portion of the total cable length.

4.5 Emissions impact

While not immediately obvious, building wind turbines would have a significant impact on greenhouse gas emissions in the area. The turbines themselves emit no greenhouse gases, but they generate power which will replace power generated by diesel and gas generating stations in the area. Given the location of the wind turbines, many power plants in the Gulf of St Lawrence could be shut down.

On the Quebec island Magdalen, is the largest diesel generating power in the province. With a nameplate capacity of 66 MW [57], the Magdalen generating station has a huge environmental impact. From US Energy Administration data [58], an approximation of the annual CO2 production from the plant can be calculated. Given a value of 73.16 kg of CO2 per million Btu for diesel power, the annual CO2 emissions can be calculated. The annual CO2 emissions from the Magdalen plant are found to be 144,327 metric tons. Given that the average car produces about 5 metric tons of CO2 a year [59], construction of wind turbines in the area could have a significant impact on the environment.

However, it is important to consider the current motivation for having a Diesel plant on Magdalen island. The island is about 200 km from mainland Quebec and has a population of just under 13000 people. The reason for the construction of the plant is due to the cost of constructing and maintaining a transmission line between the island and the mainland. Therefore, the wind turbines would need to be situated near the island supply the required power. Alternatively, a new transmission line could be constructed to the island. It is important to note that a new transmission line to the island would have the same emissions reductions as the turbines on its own, as the diesel plant would no longer need to be used.

5.0 Implementation Issues - Cassandra Wright

5.1 Physical Environment & Accessibility

Traditionally offshore wind farms are more costly to build than onshore operations, since constructing a turbine array in deep water causes the construction phase of the project to take longer and be dependent on the weather [60]. Offshore wind turbines also experience an increased rate of wear due more extreme temperature changes and corrosion from the sea spray [60].

In the location of the proposed wind farm (47.14º N, -61.3º W), the coldest time of the year historically has been between December and March and temperatures may fall as low as approximately -13°C [61] [62]. If the temperature in the area is found to be low enough to cause icing problems with the blade, Siemens has developed both passive and active blade de-icing technologies [63].

The nacelle and rotor of the SWT-6.0-120 turbine together weigh less than 350 tons, which sets "a new low-weight standard for large offshore machines" according to Siemens [64]. Although the turbine is a massive machine, Siemens has installed over 600 offshore wind turbines over the last 20 years [64]. Siemens is a European company and therefore manufactures the turbines in England [65], which would add time and further expenses to deliver the turbines across the Atlantic Ocean.

Given the approximately 50m water depth [15], and the proximity to Chéticamp, NS (where roads and transmission lines are existing as seen in Figure 26*,* in Appendix I of this report), the construction of the proposed wind farm should be straightforward. Since the proposed location is in shallower waters (relative to the very deep Cabot Straight [16]), it is south of the major shipping routes in the Gulf of the St. Lawrence [66] as shown in Figure 33*,* in the Appendix V of this report. This means the risk of a ship physically hitting a turbine is very low. Also, the marine area has been protected from fishing industries as well as from oil or natural gas drilling and therefore the proposed wind farm would not impact any of these industries [67].

5.2 Local Benefits

In Nova Scotia's Dept. of Natural Resources 2017-2018 business plan includes spending about half of their estimated expenses on renewable resources [68]. The energy industries make up

0.9% of total employment in Nova Scotia, as well as 2.4% of employment in NFLD & Labrador [3]. In 2012 Nova Scotia's unemployment rate was 9%, whereas the national average was 7.2% [69]. There was an investment in local labor during the construction of the Maritime link, and the construction and implementation of the proposed wind farm would generate more local investment in labor, land leases, municipal taxes, site preparation, construction, and operations & maintenance [8]. Nova Scotia's Energy Training Program provides a wage subsidy to encourage private sector energy employers to hire students and recent graduates from Nova Scotia [70].

The proposed Atlantic Link project (as shown in Figure 25, in Appendix I of this report), is intended to create access to the New England and Massachusetts electrical grid [71]. The new transmission lines will allow Nalcor Energy (NFLD's major utility) to supply the states with a total of 1.09 TWh of energy (about 19% of the total 5.69 TWh committed to the transmission link) [71]. There is still approximately 35% of the link's capacity that is uncontracted to allow for additional energy in the future [14].

The Atlantic Link would also support local employment as it would directly and indirectly create more jobs in the energy industries of Atlantic Canada [14] [71]. The Atlantic Link project, which is currently owned by a Nova Scotia based company, is expected to create more than 200 jobs per year of construction [14], as well as an estimated 1,000 person years of employment related to wind farm construction [71], and more than $125 million in GDP growth in Nova Scotia [71]. In New Brunswick, it was estimated that the project will generate 7,500 person years of employment related primarily to wind farm construction, and an estimated $1.2 billion in GDP growth [71].

5.3 Legislation & Subsidies

Nova Scotia's Provincial & Municipal Governments have some requirements that must be met to be built legally [8]. The proposed wind farm is offshore, so it is assumed that the municipal requirements are void but the wind farm must comply with all the provincial and federal regulations in place. The following list are the regulatory environmental requirements for the offshore wind farm project [8]:

1) Undertake a provincial Environmental Assessment (EA), administered by the Department of Environment

2) The EA requires proponents to register required information on the environmental effects of any proposed project. EA registration information submitted by the proponent is made available for public review, and all stakeholders have the opportunity to submit comments on the project. Registration information is then reviewed by experts within the provincial and federal government

3) Evaluation by these experts, along with issues raised by the public, is considered by the Minister when making a decision. Decision options of the Minister include: granting approval with conditions, request for more details/analysis, or rejection

4) Any projects that receive funds from the federal government, are on federal lands, or require a federal permit or authorization may be required to undergo to the federal Environmental Assessment process in addition to the provincial EA.

As Nova Scotia has embraced renewable energy generation and set a goal of achieve 40% renewable energy sources by 2020, the province introduced a Community Feed-in Tariff (COMFIT) program [72]. The program subsidized community-based renewable energy projects by guaranteeing a rate per kilowatt-hour for the energy that fed into the province's electrical grid [72]. From 2011 – 2016, the COMFIT program was massively popular; using over 100 community partnerships the program collectively generated 150 MW of renewable, community owned power [72]. In this time, more than 45 million dollars was raised by the general population to develop COMFIT projects, and in turn led to a $135 million investment in Nova Scotian communities" [72]. By the end of the summer in 2015, the COMFIT program was no longer accepting applications [72] [73]. According to the COMFIT Project Status Report [72], the program has, or is currently helping, in 92 wind projects in the province [72].

To help achieve Canada's Greenhouse Gas (GHG) Reduction Targets, the federal budget has a few different strategies for aiding in a transition to renewable power generation. A few of these strategies include Regulatory Targets or Standards that mandate how much electricity generation should come from renewable sources, carbon-taxing, or direct revenue support policies for renewable generation (such as Feed-In Tariffs, Standing Offer Programs, Requests for Proposals specifically for renewable power projects, and Renewable Energy Credits) [74]. In the Federal 2017 budget, the *Energy Innovation Program* received $24 million in funding [75], which could be a consideration for subsidizing the large capital costs of the proposed wind farm.

Natural Resources Canada (NRCan) has proposed to authorize $79 million in funding to the *Next Generation Clean Energy Infrastructure Program* which will support investments in renewable & sustainable infrastructure [76]. The funding deadline for this particular program was Sept. 25th, 2017 [76], however this was not the first iteration of this program and will likely be available again in the future. Under the current terms of the program, the maximum funding amount for a project is $20 million (or 50% of project cost) for demonstration projects, and the maximum funding for R&D is $1.5 million (or 75% of project cost) [76]. This program is more focused on Buildings research & electric Vehicle development, but still could apply to an offshore wind farm [76].

Additionally, the *Clean Growth Program* (CGP) provides $155 million for clean technology research & development, as well as demonstration projects in Canada's energy, mining and forestry sectors [77]. This program is still active and has an application deadline set for Feb. 7th 2018 [77].

5.4 Future Business Opportunities – The Maritime & Atlantic Transmission Links

In 2015, Canada exported 9% of the generated electricity to the United States, which met 2% of U.S. consumption [3]. Of the total 68 TWh exported to the States in 2015 [3], almost 60% (close to 35 TWh) were sold to the northeastern US, with most of the exports going to the New England and New York markets [78]. These markets are very dependent on Natural Gas generation via pipelines, however the constraints of the pipeline often cause price spikes to the natural gas in the winter months which could incentivize further imports from Canada [78].

Currently the proposed Atlantic link is intended to have a supply mix of over 70% wind energy from Atlantic Canada, which will be sold to the States at a 20-year fixed-price for the electricity transmission [14]. The combination of the Maritime link, the Atlantic link, the electricity infrastructure upgrades throughout Nova Scotia and NFLD, and the benefits of the geographic location indicate that securing the $6.5 million per year in subsidies or funding to reach a NPV of $0 for the project seems to be reasonable.

6.0 Discussion

An integral aspect of the analysis of a wind farm's technical feasibility is the capacity factor. It was found in two ways: through calculation of hourly annual data for 2016, and through RETScreen. The capacity factor was calculated to be just under 65 percent for the 2016 data, while the capacity factor that RETScreen resulted in was closer to 52 percent; this is a major discrepancy worth discussing. First, the calculated capacity factor is alarmingly high; while offshore wind farms can achieve a capacity factor higher than that, it is usually instantaneous (specific to a particularly windy time of the day) as opposed to on 12-month rolling average, which is closer to 45 percent [79]. Second, the calculated analysis does not account for any losses beyond those already factored into the turbine's power curve (Betz's Limit, etc.), though when the same percentage of losses are applied to the calculated annual energy production, the capacity factor approaches 52 percent.

Another point of discussion that affects the technical analysis is the average annual wind speed. Once corrected for measurement height Equation 1, the data taken from the 22-year average from the Atmospheric Science Data Center was considerably lower than that extracted from the annual hourly wind data for 2016: the former presented an average of 9.1 m/s, while the 2016 data revealed an average of 10.7 m/s. This suggests that perhaps 2016 was a windier year than usual, which means that the calculated analysis -based on the 2016 data - likely overestimated the amount of energy that would be produced annually. To further complicate the matter, RETScreen analysis was also conducted using St. Paul Island weather station measurements, which gave an average wind speed of 12.9 m/s. In future, this could be rectified by taking multiple years of hourly data and finding a more accurate mechanism to deal with missing data points.

Results of the technical analysis in Section 2 of the report indicate that the proposed power plant has potential. The chosen turbine, Siemens 6 MW wind turbine, gives an advantage as it is a large turbine specifically designed to optimize offshore wind speeds. Installation of forty turbines gives an installed capacity of 240 MW and the potential to power 68000 homes after taking all losses into account. This value meets as well as exceeds the project goal of providing power to the homes currently dependent on diesel and coal power in Nova Scotia and Newfoundland. This also indicates that further expansion of the project to the Magdalen Islands would be beneficial to further reduce the production of greenhouse gases.

Results of the economic analysis reported in section 3.3 show that NPV is negative for both best and worst-case scenarios, IRR is less than EIR, and LEC is larger than the present cost of electricity. However, economically, the project approaches feasibility. Considering the analyses reported on in section 3.3, subsidization between \$6 and \$40 million annually is required to reach a zero-dollar NPV. The Financial Post reports that in total, Ontario wind subsidies could hit \$13 billion over the next 20 years [80], and CBC reports that Canada spent a total of \$11 billion on renewables in 2014 alone [81]. As well, Canada paid \$3.3 billion in fossil fuel subsidies [82]. Given these figures, it is reasonable to assume some level of subsidization could be achieved, and therefore attain project feasibility.

Additionally, there are several opportunities for reduction in capital expenditure and operational costs, which would reduce the level of subsidization required for feasibility. For instance, transmission infrastructure costs represent approximately one third of capital costs. As energy infrastructure in Newfoundland continues to grow, this value would decrease as distance to provincial grid lines decreases. Construction costs also represent a large fraction of project costs, ranging from 25 to 45 percent of capital costs. This large range exists due to the highly variable cost of construction based on location, material availability, and local economy.

Apart from expenditures, the assumed electricity price and its escalation rate play a significant role in project economics. The price of electricity sold to consumers in Newfoundland is expected to increase for the foreseeable future, benefiting power producers in the region. As well, as the installed capacity of renewable power increases, the price of technologies decreases and the workforce of skilled laborers grows, reducing turbine and support structure costs as well as operational costs.

This project has good potential for achieving feasibility assuming the continued trends of government subsidization of renewable energy and price decreases in renewable tech. Given the availability of the wind resource in Atlantic Canada, as well as the minimized environmental and economic drawbacks of the proposed location, the proposed wind farm was intended to be scaled-up to be a large generator. Ideally, the wind farm's generation will result in stimulating international energy trade in the Maritimes.

When considering any power plant in terms of its environmental impact, it is important to consider its effect on climate change. Canada currently has a goal to reduce carbon emissions to 30% below 2005 levels by the year 2030. To meet this goal, the largest producers of carbon emissions will need to be tackled first. Canada has a great system of hydroelectric power generating stations, but about 25% of Canada's electricity is still produced through fossil fuels. Many fossil fuel power plants exist in remote regions where a connection to the provincial power system would be too expensive to justify.

Although wind turbines do not directly remove greenhouse gases from the air, they work to offset emissions from other fossil fuel power generation sources. Covered in this report was a consideration of the Magdalen island diesel generating plant. The plant currently provides 66 MW of power to the Quebec islands. Producing this much power through diesel generators produces approximately 150,000 metric tons of CO2 annually. The wind turbines proposed in this report have the potential to offset most of these emissions. However, given the high variability in wind speed, the turbines do not always operate at peak capacity. The output of the entire array of wind turbines at optimal wind speeds will be 240 MW. If the Magdalen islands were given priority in terms of power distribution, the turbines would be able to cover the 66 MW required at lower wind speeds. Also, if the project was unable to achieve sufficient funding from the Maritime provinces, Quebec may provide some financial incentives to eliminate the diesel generation on the Magdalen islands.

While 150,000 metric tons of CO2 sounds like a considerable number, it is important to consider the emissions output on the global scale. Globally, the CO2 emissions from fossil fuel use in 2014 was 9.795 billion tons [83]. Relative to that number, the emissions from the Magdalen plant are just a drop in the bucket. However, it is important to make every attempt to reduce emissions as climate change can only be avoided by effort from billions of people around the world.

In conclusion, adding this power plant to the Newfoundland energy grid would be desirable for the province. It provides renewable tech jobs, decreased emissions, as well as reliable power. The feasibility of the project depends mainly on the availability of governmental subsidies, however, with government subsidies the project has great potential.

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Appendix I – Background Extra Figures and Tables

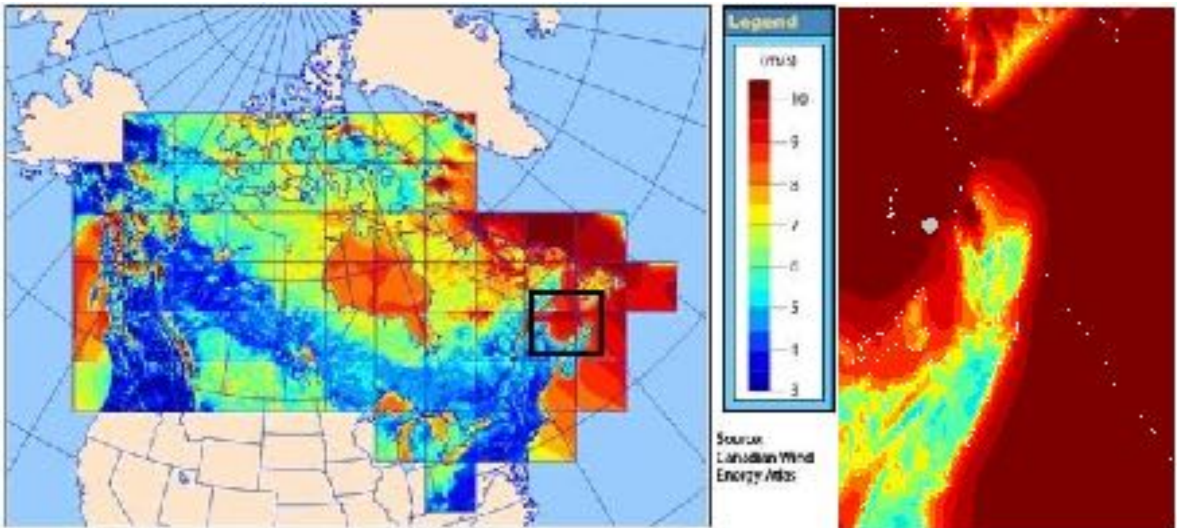


Figure 18 - Average Annual Wind speeds across Canada at an 80m altitude (Close-up of proposed location with Cape Breton & Magdalen Islands on right) [4]

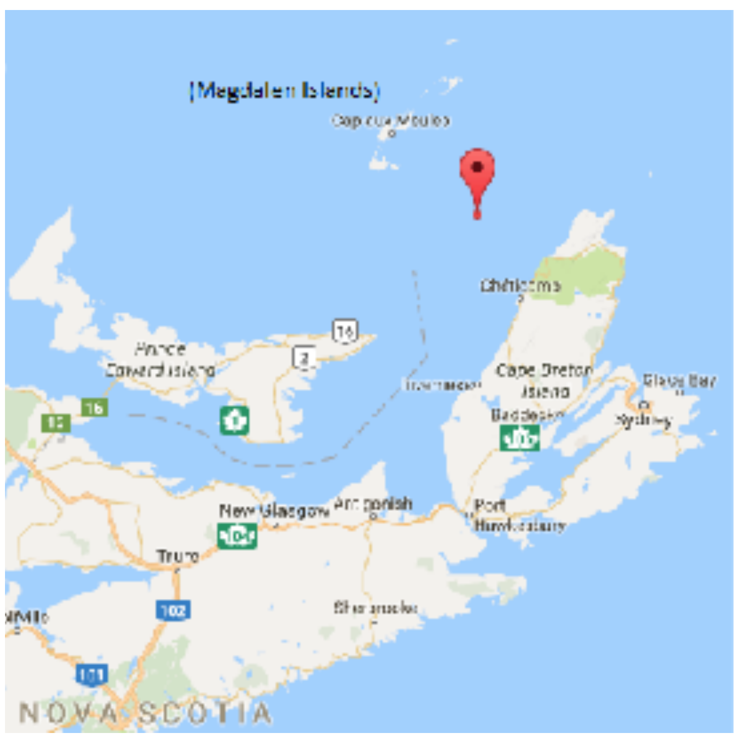


Figure 19 - Location of proposed wind farm (modified) [Google Maps]

Figure 20 - Wind Farm locations across Canada [2]

Table 6 - Wind Capacity and Populations Across Canada's Provinces and Territories [6] [7]

Province or Territory	Installed Capacity [MW]	Population (thousands)	Per Capita Installed Wind Capacity (Watts/thousand people)	Notes
PEI	204	152	1342	Over 30% of demand
Nova Scotia	597	953.9	625.8	Approx. 3.7% of demand, 40 MW in 2016
Quebec	3510	8394	418.1	
New Brunswick	294	759.7	387	Approx. 3.7% of demand
Alberta	1479	4286.1	345.1	
Ontario	4718	14 193.4	332.4	
Northwest Territories	9.2	38	242.1	
Manitoba	258	1338.1	192.8	
Saskatchewan	221	1163.9	189.9	
NFLD & Lab	55	528.8	104	Approx. 3% of demand

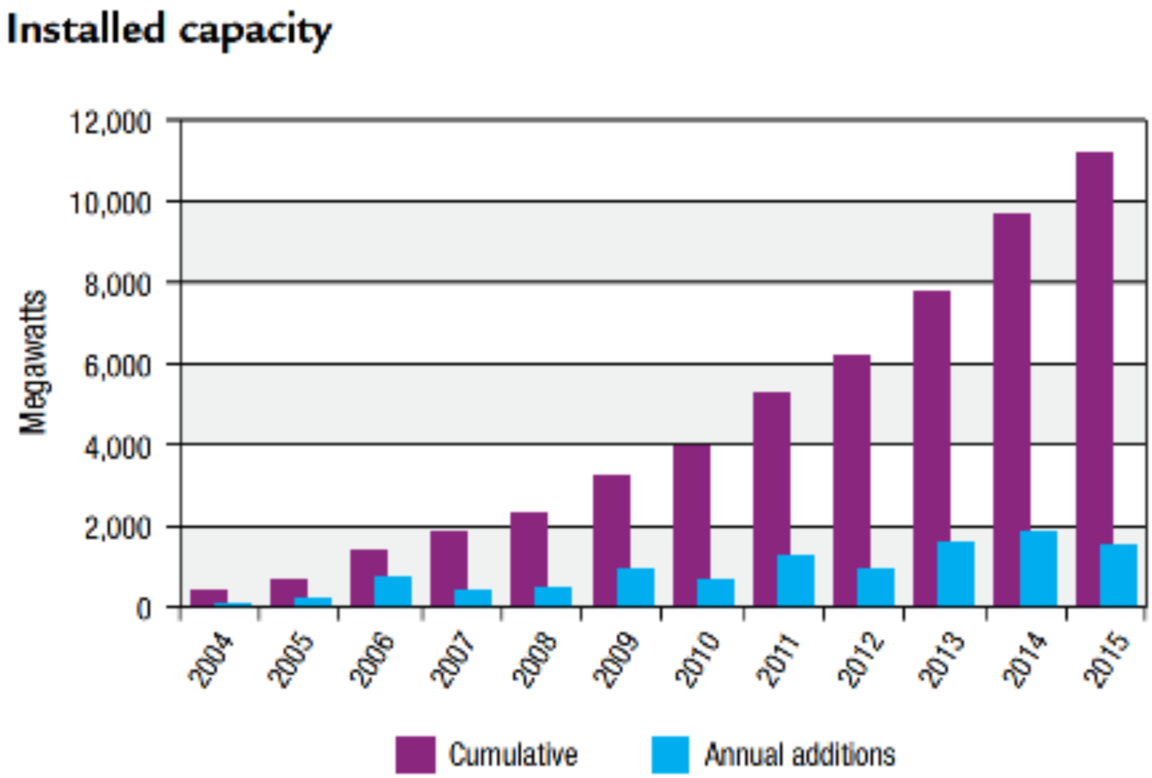


Figure 21 - Wind Power in Canada (11,205 MW of wind generation capacity at the end of 2015)

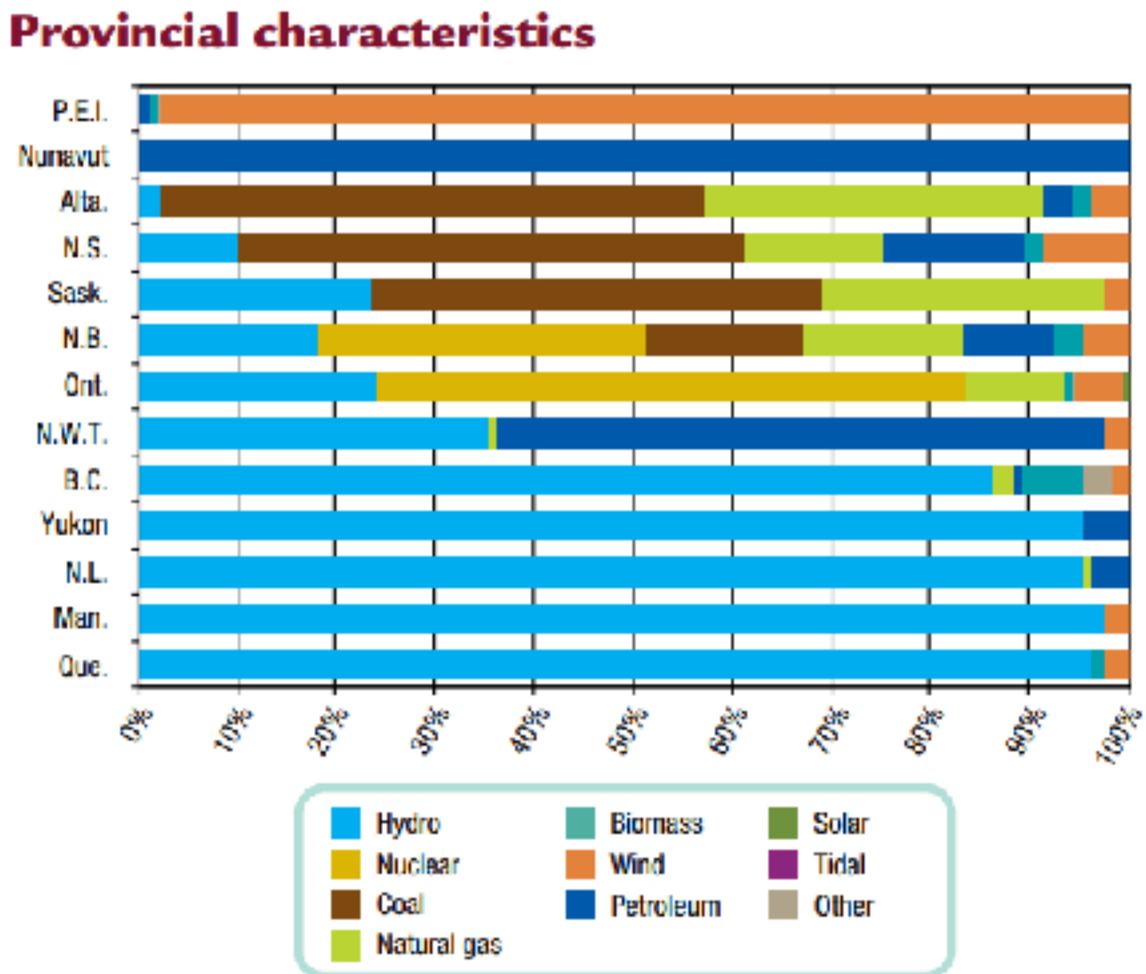


Figure 22 - 2014 Provincial Generation Sources [3]

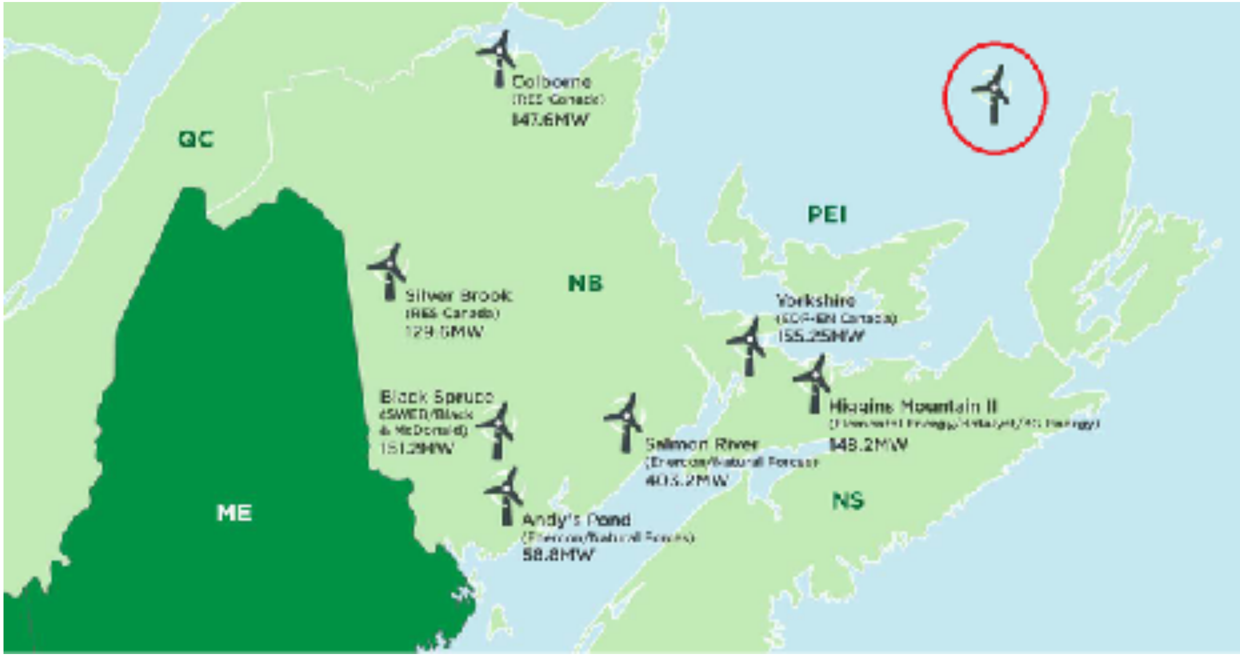


Figure 23 - Existing Wind Power in Nova Scotia (modified) [84]

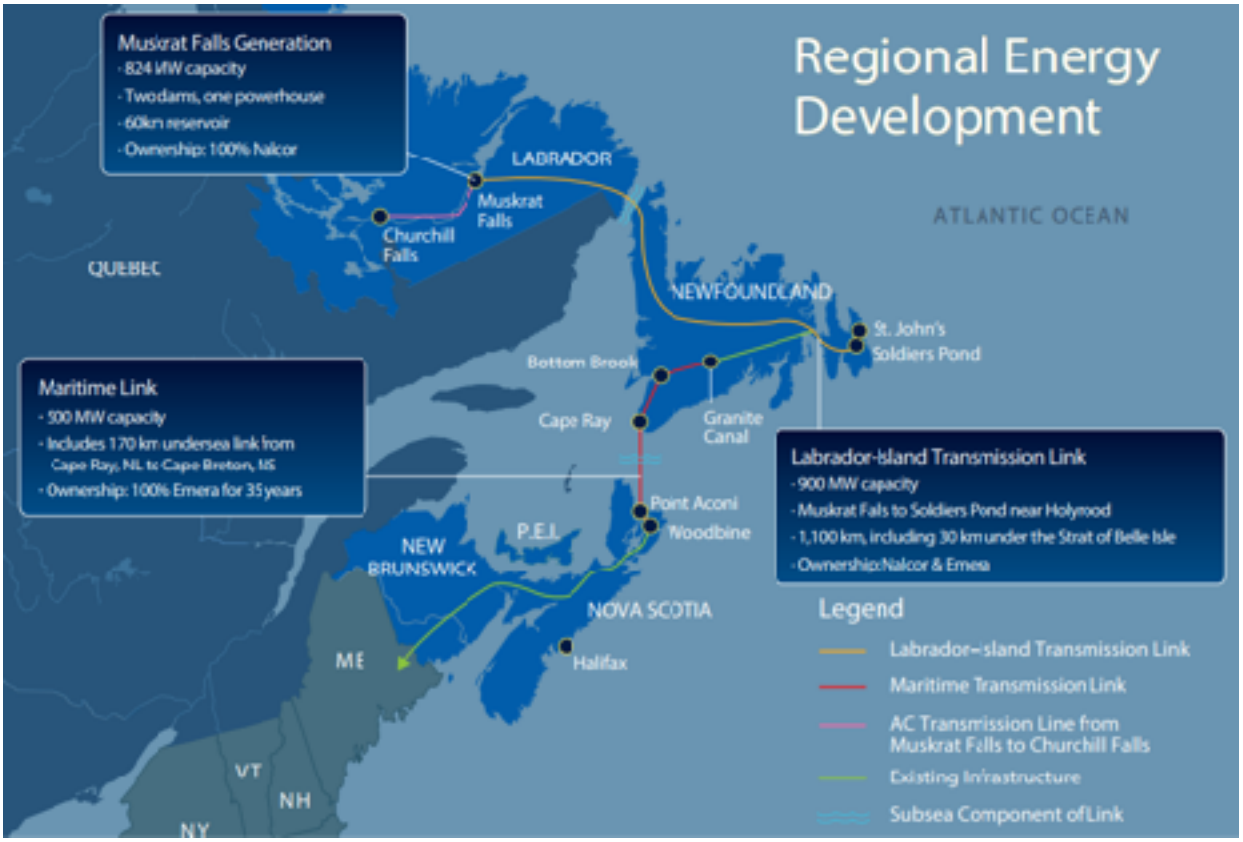


Figure 24 - The Maritime Link [9]

Figure 25 - The Atlantic Link [14]

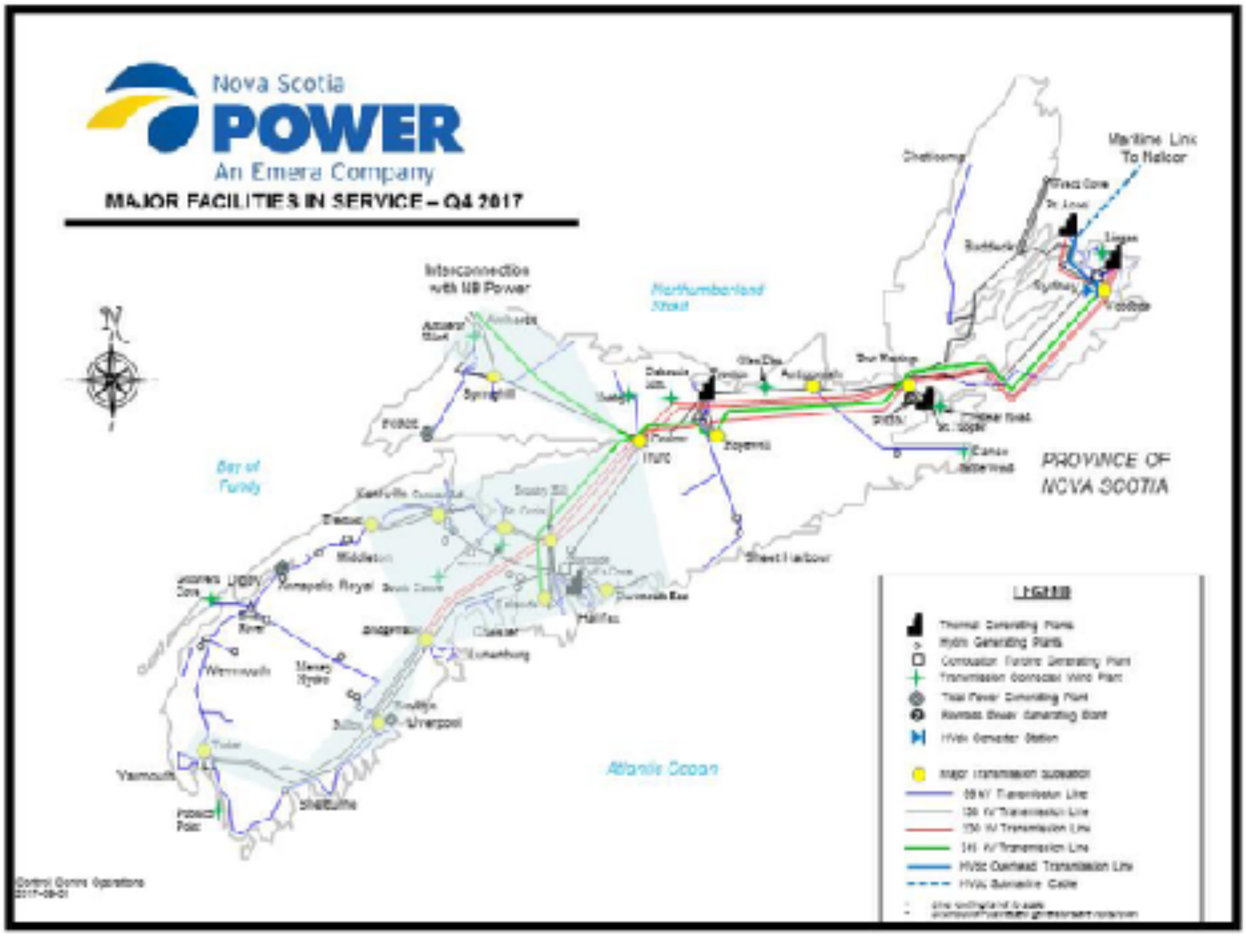
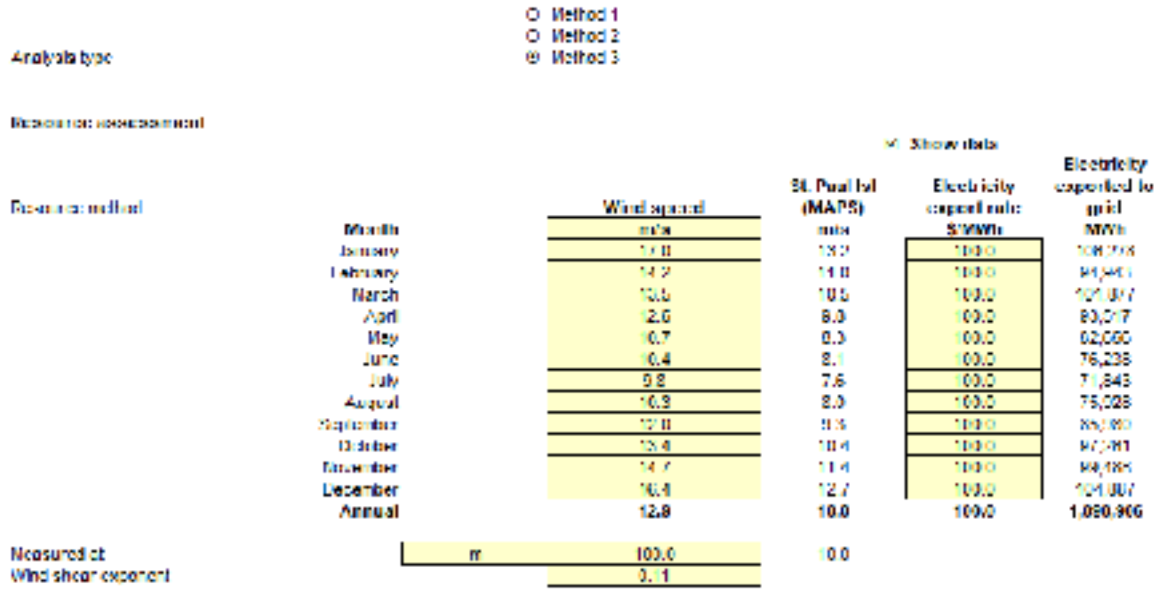


Figure 26 - Nova Scotia Transmission Grid [12]


LEGEND
Labrador
Quebec
Gulf of St. Lawrence
Atlantic Ocean
Newfoundland
Provincial Generation and Transmission Grid

Figure 27 - Newfoundland Transmission Grid [17]

Appendix II – Technical Analysis Extra Figures and Tables



Analysis type: ○ Method 1 ○ Method 2 ◉ Method 3

Resource assessment

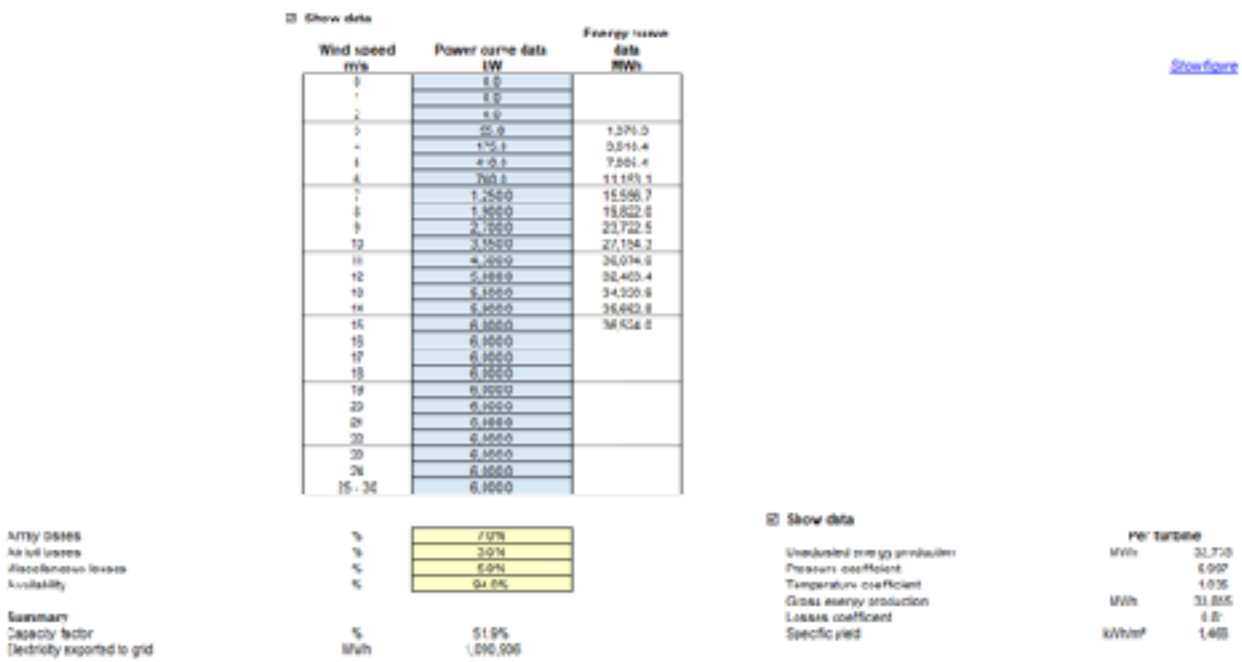
Resource method

☑ Show data

Month	Wind speed m/s	St. Paul Isl (MAPS) m/s	Electricity export rate $/MWh	Electricity exported to grid MWh
January	[illegible]	[illegible]	100.0	[illegible]
February	14.2	11.0	100.0	[illegible]
March	13.5	10.5	100.0	[illegible]
April	12.6	9.0	100.0	89,517
May	10.7	8.3	100.0	82,060
June	10.4	8.1	100.0	76,236
July	9.8	7.6	100.0	71,843
August	10.9	8.0	100.0	75,028
September	12.0	[illegible]	100.0	[illegible]
October	13.4	10.4	100.0	[illegible]
November	14.7	11.4	100.0	[illegible]
December	16.4	12.7	100.0	[illegible]
Annual	12.8	10.0	100.0	1,090,906

Measured at	m	100.0	10.0
Wind shear exponent		0.11	

Figure 28 - RETScreen Data Input #1



☑ Show data

Wind speed m/s	Power curve data kW	Energy curve data MWh
0	0.0	
1	0.0	
2	0.0	
3	55.0	1,376.5
4	175.0	3,810.4
5	410.0	7,881.4
6	760.0	11,153.1
7	1,250.0	15,556.7
8	1,900.0	19,822.0
9	2,700.0	23,722.5
10	3,550.0	27,194.3
11	4,300.0	30,074.6
12	5,100.0	32,403.4
13	5,600.0	34,200.6
14	5,900.0	35,662.8
15	6,000.0	36,634.0
16	6,000.0	
17	6,000.0	
18	6,000.0	
19	6,000.0	
20	6,000.0	
21	6,000.0	
22	6,000.0	
23	6,000.0	
24	6,000.0	
25 - 30	6,000.0	

Show figure

Array losses	%	7.0%
Airfoil losses	%	3.0%
Miscellaneous losses	%	6.0%
Availability	%	94.0%
Summary		
Capacity factor	%	51.9%
Electricity exported to grid	MWh	1,090,906

☑ Show data

		Per turbine
Unadjusted energy production	MWh	32,738
Pressure coefficient		0.997
Temperature coefficient		1.035
Gross energy production	MWh	31,855
Losses coefficient		[illegible]
Specific yield	kWh/m²	1,468

Figure 29 - RETScreen Data Input #2

Appendix III – Economic Analysis Extra Figures and Tables

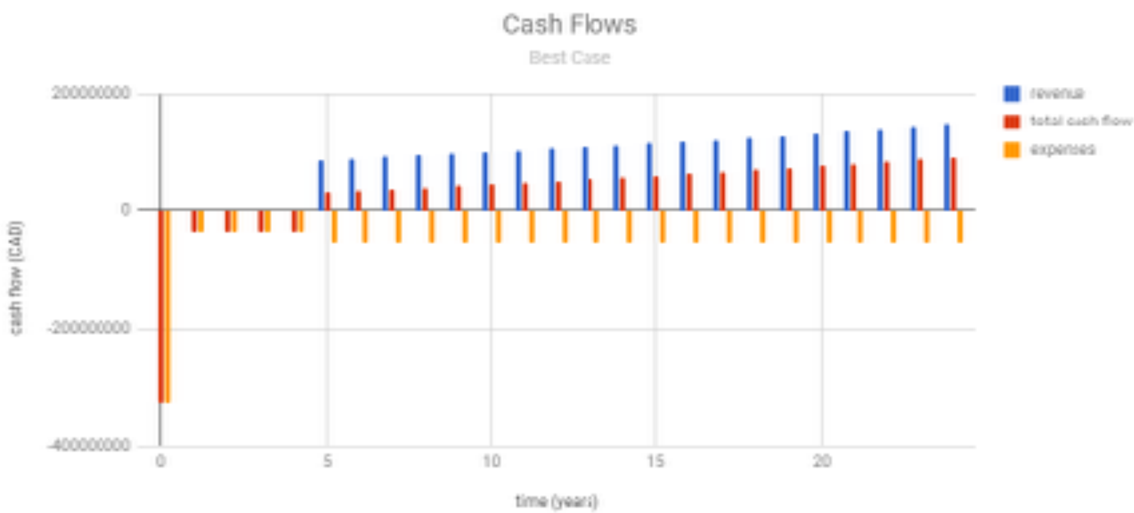


Figure 30 - Best Case Scenario Cash Flows

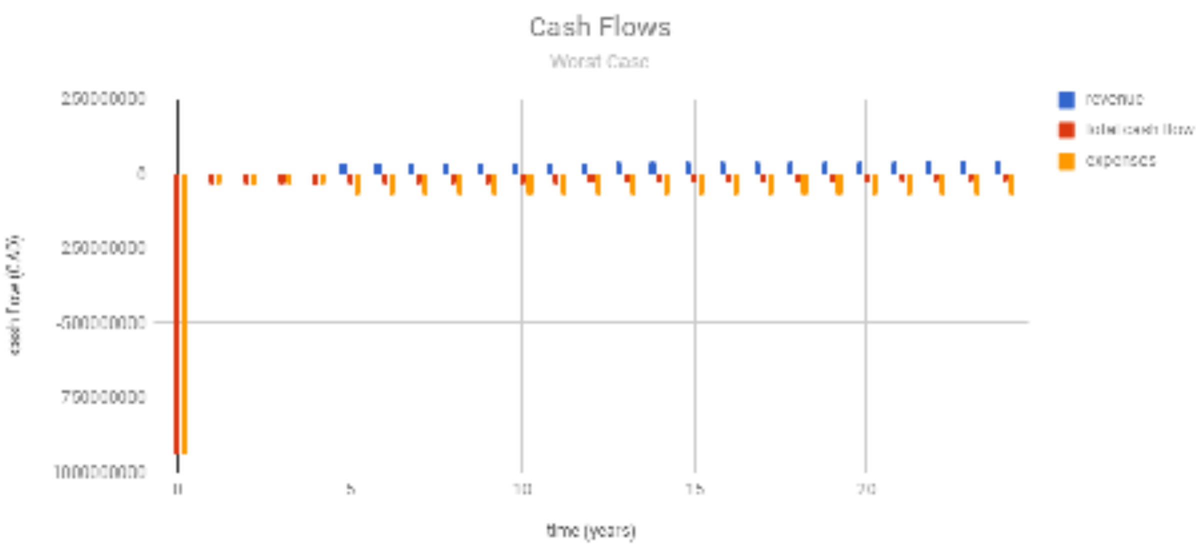


Figure 31 - Worst Case Scenario Cash Flows

Table 7 - Capital costs spreadsheet

	currency	CAD	reference
transmission	max	min	
cost per mile - underwater	8000000	5000000	19
kms to shore	40	30	
cost per mile - above ground	1500000	900000	19
kms to substation	200	150	
mile to km	1.6		
under water cost	200000000	93750000	
above gnd cost	187500000	84375000	
total cost	387500000	178125000	
offshore substation	max	min	
transformer	7000000	2000000	21
building	500000	200000	22
other equip	3000000	1000000	22
	$/kW	$	
turbine assembly	1200	240000000	24
construction	300	60000000	24
substructure	700	140000000	24
total installation/ construction		300000000	

Table 8 - Operational costs spreadsheet

OM	currency	max	min
cost per MWh	CAD	20	40
annual cost	CAD	17940480	35880960
installed capacity {MW}		# turbines	
200		66.66666667	
capacity factor			
0.4			
annual energy (MWh)			
700800			
support structure	min	max	
$/MW	500000	2000000	23
total	100000000	400000000	

Table 9 - Best case analysis spreadsheet

EXPENSES		capital costs		
		component	costmin	reference
		met station	2000	17
		per 200 MW turbines	75877500	18
		transmission	178125000	19
		support system	100000000	23
		substation	3200000	21,22
		construction	300000000	
		TOTAL CAPITAL	657204500	
REVENUE		annual revenue	74284800	
fd(%)		fe		i - effective interest rate
8	0.08	12	0.12	0.1
0.5		0.5		
AEO [MWh]	700800			
lifetime [yrs]	24			
CRF	0.1112997764			
escalation rate	0.028			
debt payment	36573356.93			

cash outlay	328602250			

year	capital cost	operational costs	revenue	total cash flow	cumulative cash flow	electricity price ($/kWh)
0	328602250	0	0	-$328,602,250.00	-$328,602,250.00	0.106
1	0	36573356.93	0	-$36,573,356.93	-$365,175,606.93	0.108968
2	0	36573356.93	0	-$36,573,356.93	-$401,748,963.87	0.112019104
3	0	36573356.93	0	-$36,573,356.93	-$438,322,320.80	0.1151556389
4	0	36573356.93	0	-$36,573,356.93	-$474,895,677.73	0.1183799968
5	0	54513836.93	85283601.41	$30,769,764.47	-$444,125,913.26	0.1216946367
6	0	54513836.93	87671542.25	$33,157,705.31	-$410,968,207.95	0.1251020865
7	0	54513836.93	90126345.43	$35,612,508.50	-$375,355,699.45	0.128604945
8	0	54513836.93	92649883.1	$38,136,046.17	-$337,219,653.28	0.1322058834
9	0	54513836.93	95244079.83	$40,730,242.90	-$296,489,410.38	0.1359076482
10	0	54513836.93	97910914.06	$43,397,077.13	-$253,092,333.25	0.1397130623
11	0	54513836.93	100652419.7	$46,138,582.72	-$206,953,750.53	0.1436250281
12	0	54513836.93	103470687.4	$48,956,850.48	-$157,996,900.05	0.1476465288

13	0	54513836.93	106367866.7	$51,854,029.72	-$106,142,870.33	0.1517806316
14	0	54513836.93	109346166.9	$54,832,329.99	-$51,310,540.34	0.1560304893
15	0	54513836.93	112407859.6	$57,894,022.66	$6,583,482.32	0.160399343
16	0	54513836.93	115555279.7	$61,041,442.73	$67,624,925.05	0.1648905246
17	0	54513836.93	118790827.5	$64,276,990.56	$131,901,915.61	0.1695074593
18	0	54513836.93	122116970.7	$67,603,133.73	$199,505,049.35	0.1742536682
19	0	54513836.93	125536245.8	$71,022,408.91	$270,527,458.26	0.1791327709
20	0	54513836.93	129051260.7	$74,537,423.79	$345,064,882.05	0.1841484885
21	0	54513836.93	132664696	$78,150,859.09	$423,215,741.15	0.1893046462
22	0	54513836.93	136379307.5	$81,865,470.58	$505,081,211.73	0.1946051763
23	0	54513836.93	140197928.1	$85,684,091.19	$590,765,302.92	0.2000541212
24	0	54513836.93	144123470.1	$89,609,633.18	$680,374,936.10	0.2056556366
		NPV of expenses	$722,169,488.87			89821894.1
		NPV	-$161,416,162.85			
		IRR	6%			
		NPEC	$0.04			
		LEC	$0.17			

Table 10 - Worst Case analysis spreadsheet

EXPENSES		capital costs		
		component	costmax	reference
		met station	10000	17
		per 200 MW turbines	75877500	18
		transmission	387500000	19
		support system	400000000	23
		substation	10500000	21,22
		construction	300000000	
		TOTAL CAPITAL	1173887500	
REVENUE		annual revenue	74284800	
fd(%)		fe		i - effective interest rate
8	0.08	15	0.15	0.136
0.2		0.8		
AEO [MWh]	700800			
lifetime [yrs]	24			
CRF	0.1426881815			
escalation rate	0.014			
debt payment	33499974.53			
cash outlay	939110000			

year	capital cost	operational costs	revenue	total cash flow	cumulative cash flow	electricity price ($/kWh)
0	939110000	0	0	-$939,110,000.00	-939110000	0.047
1	0	33499974.53	0	-$33,499,974.53	-$972,609,974.53	0.047658
2	0	33499974.53	0	-$33,499,974.53	-$1,006,109,949.06	0.048325212
3	0	33499974.53	0	-$33,499,974.53	-$1,039,609,923.59	0.04900176497
4	0	33499974.53	0	-$33,499,974.53	-$1,073,109,898.13	0.04968778968
5	0	69380934.53	35308699.85	-$34,072,234.68	-$1,107,182,132.81	0.05038341873
6	0	69380934.53	35803021.65	-$33,577,912.89	-$1,140,760,045.70	0.0510887866
7	0	69380934.53	36304263.95	-$33,076,670.58	-$1,173,836,716.28	0.05180402961
8	0	69380934.53	36812523.64	-$32,568,410.89	-$1,206,405,127.17	0.05252928602
9	0	69380934.53	37327898.98	-$32,053,035.56	-$1,238,458,162.72	0.05326469603
10	0	69380934.53	37850489.56	-$31,530,444.97	-$1,269,988,607.69	0.05401040177
11	0	69380934.53	38380396.41	-$31,000,538.12	-$1,300,989,145.81	0.0547665474
12	0	69380934.53	38917721.96	-$30,463,212.57	-$1,331,452,358.38	0.05553327906
13	0	69380934.53	39462570.07	-$29,918,364.46	-$1,361,370,722.84	0.05631074497

14	0	69380934.53	40015046.05	-$29,365,888.48	-$1,390,736,611.31	0.0570990954
15	0	69380934.53	40575256.7	-$28,805,677.83	-$1,419,542,289.15	0.05789848273
16	0	69380934.53	41143310.29	-$28,237,624.24	-$1,447,779,913.39	0.05870906149
17	0	69380934.53	41719316.64	-$27,661,617.90	-$1,475,441,531.28	0.05953098835
18	0	69380934.53	42303387.07	-$27,077,547.46	-$1,502,519,078.75	0.06036442219
19	0	69380934.53	42895634.49	-$26,485,300.04	-$1,529,004,378.79	0.0612095241
20	0	69380934.53	43496173.37	-$25,884,761.16	-$1,554,889,139.95	0.06206645744
21	0	69380934.53	44105119.8	-$25,275,814.73	-$1,580,164,954.69	0.06293538784
22	0	69380934.53	44722591.47	-$24,658,343.06	-$1,604,823,297.74	0.06381648327
23	0	69380934.53	45348707.76	-$24,032,226.78	-$1,628,855,524.52	0.06470991403
24	0	69380934.53	45983589.66	-$23,397,344.87	-$1,652,252,869.39	0.06561585283
		NPV of expenses	$1,274,349,178.29			
		NPV	-$1,164,072,543.92			
		IRR	#NUM!			
		NPEC	$0.08			
		LEC	$0.43			

Appendix IV – Environmental Analysis Extra Figures and Tables

AREPAs reference list of tasks regarding wind turbines

Equipment	Year	Location	Damage	AREPA's effort
Control panel in wind turbine, WV2007	2012	Tim, Denmark	Fire	Analyses, advising, and restoration
Transformer platform (under construction) for offshore wind farm	2012	Rotterdam, Holland	Fire	Analyses, advising, and restoration
Keenan RM Converter	2012	Keenan II, Oklahoma, USA	Fire	Analyses, advising, and restoration
Turbine T108	2012	Clyde Wind Farm, Biggar, Scotland	Humidity	Analyses and advising
A1 wind turbine, Nysted Havmøllepark	2011	Offshore, Gedser, Denmark	Fire	Analyses, advising, and restoration
TIM-1 wind turbine nacelle	2011	Tim, Denmark	Brake dust	Restoration
Wind turbine nacelle	2011	Vallata Sito, Italy	Fire	Analyses and advising
Wind turbine NL5	2011	Risø Test Centre, Bovlingbjerg, Denmark	Fire	Analyses, advising, and restoration
Wind turbine 79 in The Blacklaw Wind Farm	2011	Lanarkshire, Scotland	Fire	Analyses, advising, and restoration
Wind turbine ID 43818	2011	Jelling, Denmark	Fire	Analyses, advising, and restoration
2 tower sections	2011	Washington, USA	Salt water	Advising
Power units for wind turbines	2011	Duluth and Iowa, USA	Humidity	Analyses, advising, and restoration
Control panel in wind turbine E9755	2011	Aastrup, Denmark	Fire	Restoration
Control panel in wind turbine	2011	Bjerringbro, Denmark	Fire	Restoration
Wind turbine	2011	Risø Test Centre, Bovlingbjerg, Denmark	Explosion/water	Restoration
Wind turbine no. 10	2011	Middelgrunden, Denmark	Fire	Restoration
Nacelle in wind turbine T86	2011	Tim, Denmark	Dust	Restoration
Wind turbine	2011	Texas, USA	Fire	Restoration
2 hubs	2010	Low St., Denmark	Fire	Restoration
Control panel, etc. in WTG ID 3920159	2010	Tim, Denmark	Fire	Analyses, advising and restoration
Equipment for wind turbines	2010	Esbjerg and Ringkøbing, Denmark	Fire and powder	Advising and restoration
Wind turbine T207 at Biglow III Wind Farm	2010	Oregon, USA	Fire	Analyses, advising and restoration
Control panel for wind turbine	2010	Vinderup, Denmark	Short circuit	Restoration
3 wind turbines	2010	Nees, Denmark	Waterblast	Advising and restoration
Generators in two wind turbines	2009	Tim, Denmark	Contamination of oil	Advising and restoration
Control panel for wind turbine 9124	2009	Nykøbing M., Denmark	Fire	Restoration
Wind Turbine no. 10, La Nogueira Wind Park	2009	La Nogueira, Spain	Fire	Analyses and advising
Wind turbine	2009	Oregon, USA	Fire	Analyses, advising and restoration
E82 wind turbine	2009	Santos Praia Formosa site, Brazil	Fire	Analyses and advising
Three wind turbines	2009	Marienkoog, Germany	Contamination of liquid calcium chloride	Restoration
Wind turbines	2009	S. Agata Di Puglia, Italy	Fire	Restoration
WTG ID 43423	2009	Randers, Denmark	Fire	Analyses and restoration
Wind turbine 3	2009	Tim, Denmark	Fire	Restoration
11 wind turbines	2008	Texas, USA	Salt water	Restoration
Wind turbines	2008	Texas, USA	Fire	Restoration

Figure 32 - AREPA Wind Turbine Task List [85]

Appendix V – Implementation Considerations Extra Figures and Tables

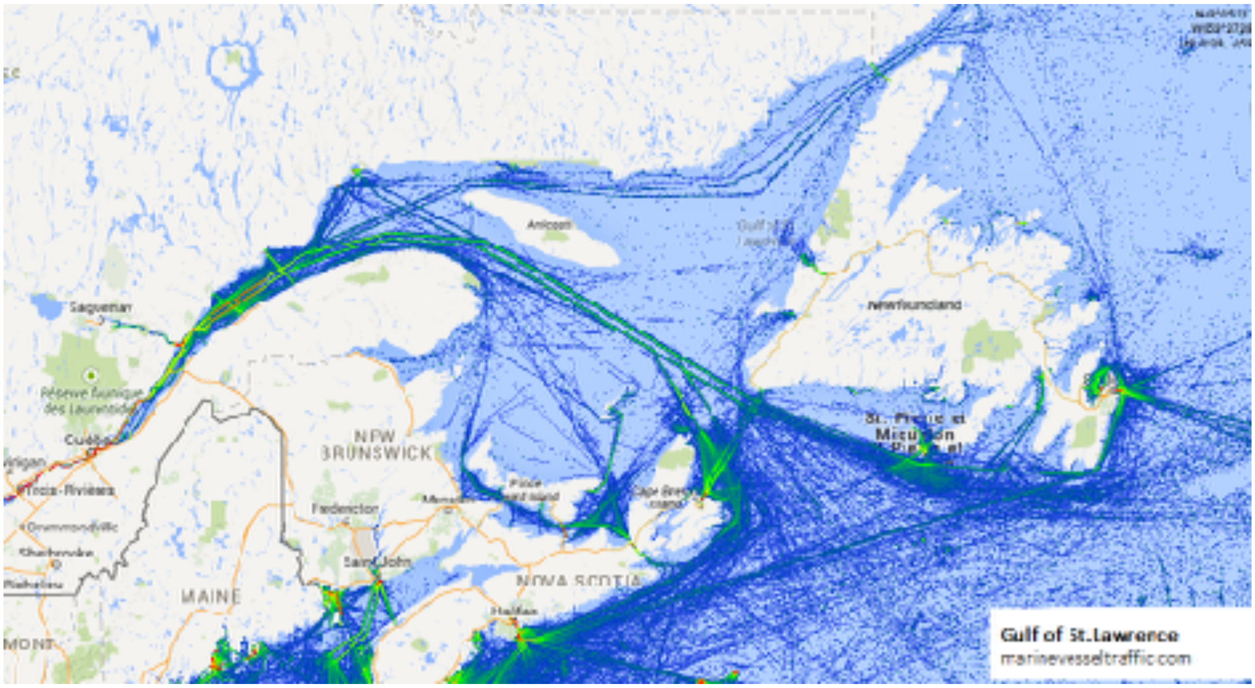


Figure 33 - Gulf of St. Lawrence Marine Vessel Traffic [66]