Viability of the Algonquin Power's Amherst Island Wind Energy Generating System

Association to Protect Amherst Island – Dec. 2011

Introduction

This report is concerned with the proposed Algonquin Power Company (APCo) 75MW wind energy project for Amherst Island for which the Ontario Power Authority (OPA) has made a contractual offer under the renewable energy FIT program. The purpose of the report is to explain why this development will be uneconomic and why our Association is fighting the development.

In the February 25th 2011 news release announcing the contract with the Ontario Power Authority APCo stated that the project would generate 247 GWh per year [1]. In order to generate this energy, the project would require an annual capacity factor (average power generated divided by the nameplate power) of 38%, a capacity factor never yet achieved in Ontario. In order to achieve a high capacity factor, APCo is planning to use high-efficiency Siemens 2.3 - 113 2.3 MW turbines.

An initial 25% capacity factor is more realistic, based upon publically available information from the nearby Wolfe Island wind energy generating system (WEGS), the specifications for the new Siemens turbine and the Siemens 2.3-93 turbine used on Wolfe Island, and making use of the Ontario wind atlas.

Further, the capacity factor for those Ontario projects that have operated for more than 3 years appears to be decreasing by about 2% per year. Therefore, over the life of the 20-year contract a capacity factor below 20% is expected.

Capacity Factor of Ontario Wind Energy Generating Systems (WEGS).

Table 1 shows the capacity factor for those WEGS that have been operating for at least 2 years. These capacity factors come from the hourly output data provided by the Independent Energy System Operator (IESO). The background for the table is given in Appendix A of this report.

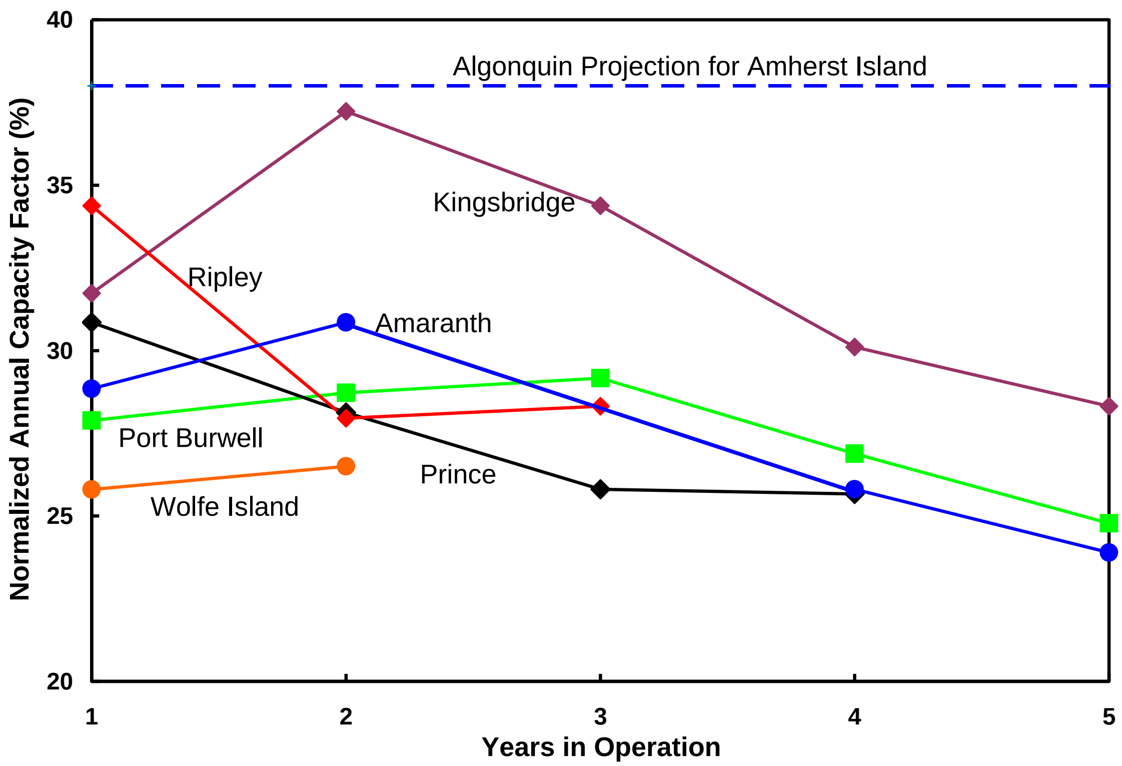
Notably, there has never been a capacity factor of 38%. The maximum is 35%, the minimum is 24% and the average is 29%.

Table 1: Annual Average Capacity Factor (Efficiency) Given as a Percentage.

Year July to June	Amaranth 1	Amaranth 1 and 2	Kingsbridge	Port Alma	Port Burwell	Prince	Ripley	Underwood	Wolfe Island
2006 – 2007	30		33		29				
2007 – 2008	29		35		27	29			
2008 – 2009			33		28	27	33		
2009 - 2010		24	28	34	25	24	26	26	24
2010 - 2011		28	32	35	28	29	33	32	30

There are variations from year to year. This is largely because the annual-average wind speed varies from year to year. In turn, the output of a wind turbine magnifies this variation; see Appendix B. The capacity factors can be normalized to remove this variation, as outlined in Appendix B. Figure 1 shows the normalized capacity factor for those Ontario WEGS that have been in operation for 3 years or more. Wolfe Island has been added because of its local significance.

Figure 1: Normalized Capacity Factor for Ontario WEGS as a Function of Years of Service



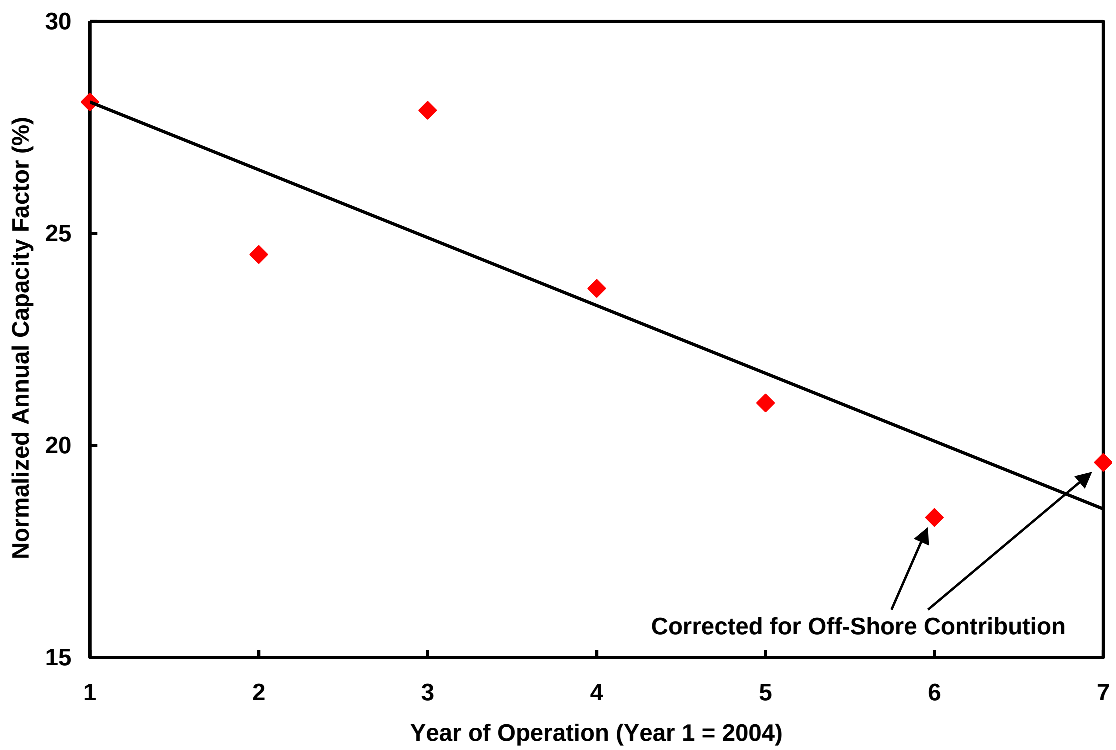
Typically, the Ontario WEGS start within the first year or two at a capacity factor of about 30% (Kingsbridge, on the shore of Georgian Bay, is an exception) and then decline. This decline is about 2% per year or a relative decline of 6% per year. This of course augurs very badly for a generating system designed for a 20 year life and with capital funding based upon a 20 year life. All of the analysis is based upon public WEGS power output data provided by IESO and involves only averaging, multiplying and dividing numbers in a spreadsheet.

Of course Ontario is not the only place with disappointing output from its WEGS.

- The Muir report from the UK shows a 24% capacity factor for the UK system over the period November 2008 to December 2010 [2].
- New York State WEGS, to the south of Amherst Island, shows capacity factors of 19% for 2009 and 23% for 2010 [2].
- An analysis of the European WEGS shows that over the years 2003 to 2007 the capacity factor of the EU15 56 GW system was 21% [3].

It turns out that the Ontario system is not the only one to show a systematic decrease in capacity factor with time. As shown in Figure 2, over a 7-year period the Danish WEGS showed an average 1.5% per year decline in normalized annual average capacity factor (see Appendix B). This corresponds to a relative decline of 6% per year.

Figure 2: Normalized Capacity Factor for Danish WEGS as a Function of Year of Service



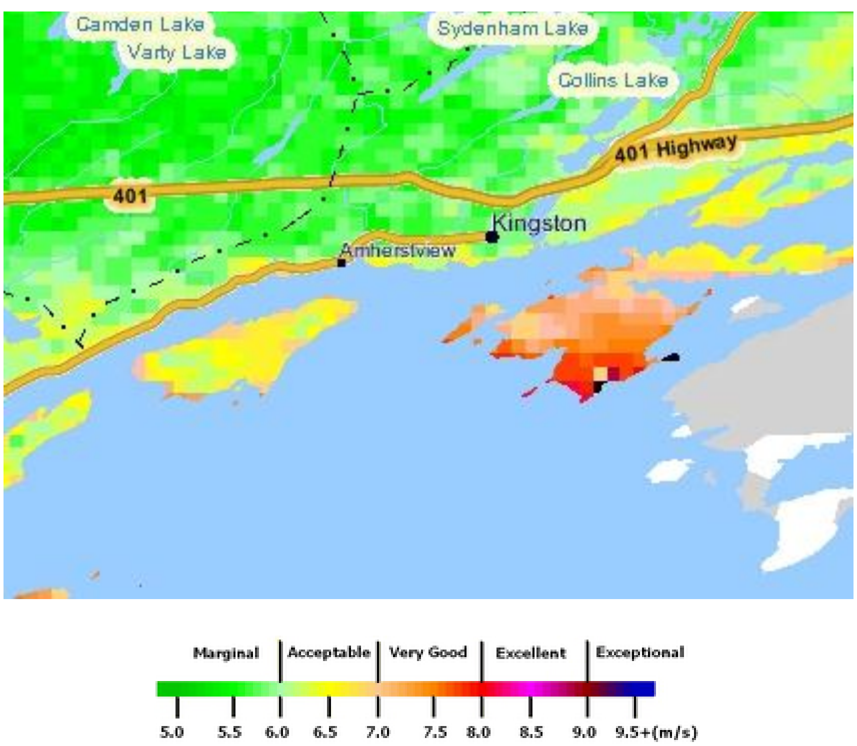
One obvious problem with many WEGS in Ontario is the high density of the turbines. In the words of Rolf Miller, Director of Wind Assessment at Chicago-based Acciona Windpower, turbines are being "shoe-horned in" in Ontario [4]. The latest research from John Hopkins University recommends a separation of turbines of 15 blade diameters to avoid wake loss [5] and hence loss of capacity factor. For a modern 2.3 MW turbine with a 90 metre blade diameter this recommendation corresponds to a density of about 0.5 turbine/km^2. The Wolfe Island project, as an example, corresponds to 1 turbine/ km^2, a high density which goes part way to explaining its poor performance. The effect of the high density is quite apparent: in modest wind speeds the down-wind turbines rotate more slowly than the up-wind turbines! However, this is only one possible cause of poor performance and does not explain the decrease in normalized capacity factor with time.

Prediction of Capacity Factor for Amherst Island

Amherst Island is a poor site for a WEGS because of the poor wind resource, the small area available and the increased capital expenditure required to build on an island. Helimax, a consulting company, studied possible sites in Ontario for the Ontario Power Authority and Amherst Island did not even make the list of 60 sites considered [6].

Figure 3 is extracted from The Ontario Wind Atlas, again publically available. On the right in shades of red is Wolfe Island and on the left Amherst Island. The wind speeds are those appropriate for a turbine hub height at 80 metres.

Figure 3: Ontario Wind Atlas for Eastern Lake Ontario.



For the WEGS at the western end of Wolfe Island, the average wind speed is 7.5 metres/sec and for Amherst Island the average wind speed is 6.5 metres/sec. As discussed in Appendix B the power generated by a wind turbine varies with the cube of the wind speed. Compared with a turbine on Wolfe Island the power output of a similar turbine on Amherst Island would be reduced to $(6.5/7.5)^3$ or 65%. Therefore, the expected capacity factor would be 17% based upon the IESO data for Wolfe Island, less than one half APCo's stated capacity factor.

APCo plans to improve this by using the modern generation of high-efficiency turbines. In the most recent draft project description report prepared for APCo by Stantec Consulting Ltd., the Siemens 2.3 - 113 2.3 MW turbine is proposed, together with an 99.5 metre tower. With an average wind speed gradient parameter of 0.20 ± 0.05, appropriate for North America [7], the extra tower height will add (4.5 ± 1)% to the average wind speed, increasing it to 6.8 metres/sec This is in line with the prediction of the Ontario wind atlas.

As shown in Appendix C, the use of the Siemens 2.3 - 113 on an 80 metre tower on Wolfe Island would have increased the normalized capacity factor from 27% to 34%. On Amherst Island with a 99.5 metre tower and the lower wind speed this will be reduced to 25%. The use of the newer turbine and the high tower almost compensates for the poor wind resource on Amherst Island but at a cost, \$3.1M/MW versus \$2.07M/MW for Wolfe Island[1].

Therefore it is expected that the initial capacity factor will be 25%. It is also expected that this will decrease with time in accordance with the 6% per year relative decline.

APCo will tell you that they have positive wind resource data for Amherst Island. Canadian Hydro Developers collected similar data for Wolfe Island. The initial prediction for Wolfe Island was a capacity factor of 40%. Even after 6 months of operation a spokes-person for TransAlta, the new owner of the project, claimed that the annual capacity factor would be 34% [11], as opposed to the actual normalized capacity factor of 27%. In making the prediction for Amherst Island it is sensible to use the by-now measured capacity factor for Wolfe Island and the comparison of the Ontario Wind Atlas data for the two islands.

The problem of the poor wind resource is compounded by the lack of sufficient area on Amherst Island. The total area of the island is 16,500 acres. Of this, at least 3000 acres is environmentally protected or environmentally sensitive. Another 3000 acres or so is unavailable because of homes, schools and churches. There is considerable opposition to the Amherst Island development on our island, reducing the area further. The development is therefore left with

[1] The \$2.07M/MW was the initial estimate for the capital cost. This was increased to \$2.27M/MW after approval to build was received from the Ontario government [8] and to \$2.4M/MW part way into construction [9]. A similar cost over-run will increase the APCo development to \$3.6M/MW. The increase was attributed partly to bad weather [9] and partly to the difficulty of building on an island [10].

less than 10,000 acres or 40 km^2 for a 75 MW project. This compares with 95 km^2 required to meet the John Hopkins criterion for 33 x 2.3 MW turbines each with 113 metre diameter blades. Appendix D addresses the very real problem of wake loss for the Amherst Island project.

Financial Viability of the Amherst Island Project

A. Development Costs

APCo is estimating the capital cost to be $230 million. This reflects the high cost of the high-efficiency turbines, the cost of an underwater cable and the difficulty of building on an island with poor infrastructure.

B. Financial Carrying Costs

Investment banks will normally lend up to 80% of the capital cost at an interest rate of 6% to 8% (current rates) over a 10-year term.

C. Operations and Maintenance Costs

Estimating the cost of operations and maintenance (O & M) is difficult: there is virtually no experience of operating industrial wind turbines beyond 10 years. As a result, robust operational data remain relatively scarce. The International Energy Agency puts O & M costs in the range $10 to $30/MWh [12]. Taking an average of $20/MWh and an assumed 25% capacity factor adds $44,000/MW per annum. A recent major report, the Wind Energy Operations and Maintenance Report, puts the cost of operation and maintenance at US$27/MWh [13], at the top end of the IEA estimate. In addition, major maintenance has been found to be very expensive. Gearboxes expected to fail after 20 years are failing after 7 or 8 years [12]; rebuilds cost US$0.1M and crane costs are US$0.25M per in and out [14].

There is the additional cost of benefit to landowners ($5,000/MW per annum).

D. Anticipated Revenues

Based on the FIT tariff of $135/MWh various revenue projections can be made depending on the capacity factor. For example, at a 25% capacity factor the annual revenue is $300,000/MW. At the suggested APCo capacity factor of 38%, the annual revenue could be $450,000/MW.

There is a possibility of some extra revenue from the Federal Eco-Energy subsidy (about $10/MWh), and some carbon credits may also be possible. However, on July 28th 2011, the Hon. Joe Oliver, Minister of Natural Resources, announced that the Federal Government will not commit to additional funding of the Eco-Energy subsidy [15].

E. Return on Investment

A sensitivity analysis was conducted to determine the range of outcomes from different cost and revenue possibilities based on assumptions concerning the capacity factor. The standard financial model for judging the viability of a project is the combination of net present value (NPV) and internal rate of return (IRR). This has been done for the variables considered above. This analysis, summarized in Table 2 below, accounts for the net revenue over the full 20-year term of the project. The benchmark rate of return has been set at 7.5%. The depreciation has been assumed aggressive to avoid tax payments over the term of the debt financing. The corporate tax rate has been set at 27%. The optimistic case assumes debt financing of 6% and an O & M cost of $20/MWh. The realistic case assumes 8% and $27/MWh. The analysis confirms that with realistic parameters for a WEGS on Amherst Island there is unlikely to be any return for investors.

Table 2: Net Present Value and Internal Rate of Return

Three Annual Capacity Factor Scenarios Using Different Cost Assumptions			
	APAI Scenario: 25% CF	Algonquin Scenario: 38% CF	Long-Term Scenario: 20% CF
Optimistic Costs: 6% Loan; $20/MWh O&M; Investor Cost: $46M			
NPV (Project)	($105,000,000)	($26,000,000)	($138,000,000)
IRR (Project)	1.6%	6.1%	-0.3%
NPV (Equity)	**($47,000,000)**	**$32,000,000**	**($80,000,000)**
IRR (Equity)	**2.6%**	**11.2%**	**-0.5%**
Realistic Costs: 8% Loan; $27/MWh O&M; Investor Cost: $46M			
NPV (Project)	($132,000,000)	($56,000,000)	($166,000,000)
IRR (Project)	0.4%	4.5%	-1.7%
NPV (Equity)	**($74,000,000)**	**$1,000,000**	**($108,000,000)**
IRR (Equity)	**0.6%**	**7.6%**	**-2.5%**

NB: The NPV (Project) and IRR (Project) refer to the unlevered case, with no bank financing; these entries are for reference only. The NPV (Equity) and IRR (Equity) refer to return to the equity holders for the levered case with 80% bank financing. Numbers in brackets are negative.

G. Risk Factors

Without even beginning to consider all the environmental and socio-economic factors associated with this project, the key risk factors for potential investors are:

- the capacity factor likely to be achieved (not likely 38%, more likely 25%) and the observed decline in capacity factor over time;
- the initial cost of development;
- cost over-run due to the uncertain difficulties of building on an island;
- the cost of O&M over a 20-year period;
- the likelihood that the current rate regime will be maintained (unlikely given current fiscal situation);
- the cost of providing a bond to cover the cost of reclamation (cost not included in the above analysis);
- The possibility that mitigation measures will be necessary during the bird migratory season and through the winter in proximity to the owl woods [16];
- the likelihood that turbine noise will be out of compliance at non-participating receptors once the Ministry of the Environments exercises its compliance-testing protocol[2] [see also Appendix E];
- the ability of the APCo to convince the public and their elected representatives that the project is viable and a net benefit to the community.

Opposition to the Project.

Amherst Island is home to a large and organized opposition to a large wind energy project. The incorporated Association for the Protection of Amherst Island (APAI) has over 100 paid-up members and 175 people signed a petition to Loyalist Township to oppose a large project. This is from a population of 450 year-round and up to 800 with summer cottagers. There are many others who

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[2] To date, noise regulation relies only upon calculation of the sound pressure level at non-participating homes. The recent Kent-Breeze Environmental Review Tribunal found in favour of Suncor. However, the Tribunal also stressed that "Nevertheless, if the modeling does end up being inaccurate (recognizing the general point that pre-operation modeling has limitations as compared to accurate post-operation field measurements), then adjustments will have to be made to ensure ongoing compliance. The 40 dB limit is a real limit that Suncor must abide by regardless of its modeling exercises." The reasons for expecting non-compliance are: omission of the uncertainty inherent in the noise prediction calculations; omission of turbulent inflow noise from the prediction calculations; the allowance of generous parameters in the prediction calculations; the large number of complaints from those living in proximity to turbines; the number of buy-outs of abandoned homes by wind developers. On August 22, 2011, the Ministry of the Environment unveiled its protocol for compliance testing [17]. It is too early to know the result of applying the protocol.

do not want to declare their opposition for business or family reasons or not to upset neighbours. A twin group, SaveAI, has 25 or so active members. The opposition is not against wind energy as such; the reasons are the noise, flicker and safety problems associated with close proximity to wind turbines; the ensuing health problems; concern with ground-water problems; environmental concerns (Amherst Island is one of Canada's "Important Bird Areas" and lies on one of the major North American migratory bird pathways) and destruction of a beautiful island. Both groups will oppose a large-scale wind energy project by every possible means. Our goal is to stop the project.

Conclusion

It has been demonstrated that a wind energy generating system (WEGS) on Amherst Island is not financially viable. The reasons include:

- from the experience of other WEGS in Ontario it is estimated that, even with high-efficiency turbines, an Amherst Island WEGS would have an initial capacity factor of about 25%, well below the claim of 38% by APCo;
- a capacity factor decrease of up to 2% per annum as the system ages suggests that the long term capacity factor will be below 20%;
- the available land area is less than half that required to avoid wake loss;
- significant risk factors associated with the project including the high initial development cost, the prospect of cost over-run, the uncertainty of long-term operation and maintenance, the continuity of the generous feed-in-tariff program, the political uncertainty of a minority Ontario government, and the opposition based upon environmental and health concerns.

Acknowledgments

The assistance from colleagues with a professional background in finance is very much appreciated.

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[7] John Harrison, "Disconnect between Turbine Noise Guidelines and Health Authority Recommendations", Proceedings of the World Wind Energy Conference, June 2008.

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[10] Presentations to Probus (a Kingston association of professional and business people) and to the Kingston Branch of the Institute of Electrical and Electronics Engineers (IEEE) by John Foster, at the time a representative of TransAlta, the owner of the Wolfe Island WEGS.

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Revised December 16th, 2011

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Appendix A: Capacity Factor of Ontario Wind Energy Generating Facilities

The tables show the monthly capacity factors for the Ontario wind energy generating systems (WEGS) for the years July 2009 to June 2010 and July 2010 to June 2011. The capacity factor is the actual power output divided by the name-plate power; it is given as a percentage. The name-plate power for each WEGS is given in the second row. As an example, consider the July 2009 entry for Amaranth: The average hourly output for that month was 32 MW. Dividing by the nameplate power of 200 MW, we get 16%. The row labeled **Annual Average** is the 12-month average. The source of the numbers used to generate these tables, the hourly output of the Ontario WEGS, is publically available at: http://www.ieso.ca/imoweb/marketdata/windPower.asp.

The IESO hourly power output goes back to 2006. Similar tables to those shown here, for the earlier years, were used to derive Table 1 in this report.

Table 3: Capacity Factor (Efficiency) Given as a Percentage of the Nameplate Power Output: July 2009 – June 2010

Month	Amaranth	Kings-bridge	Port Alma I	Port Burwell	Prince	Ripley	Under-wood	Wolfe Island	Overall
Nameplate (MW)	**200**	**40**	**101**	**99**	**189**	**76**	**182**	**198**	
July	16	11	18	14	15	12	14	14	14
Aug.	18	21	21	17	19	21	21	16	19
Sep.	16	18	21	17	16	17	16	20	18
Oct.	25	35	39	34	29	30	33	32	31
Nov.	23	32	35	25	34	29	28	22	27
Dec.	31	43	41	36	29	37	39	35	35
Jan.	27	39	48	36	28	39	38	27	33
Feb.	24	25	31	23	21	25	24	23	24
Mar.	28	27	37	26	26	28	26	37	29
Apr.	34	38	47	30	31	36	34	29	33
May	24	24	37	27	25	24	22	20	25
June	19	18	27	18	19	18	18	17	19
Annual Average	**24**	**28**	**34**	**25**	**24**	**26**	**26**	**24**	**26**

Table 4: Capacity Factor (Efficiency) Given as a Percentage of the Nameplate Power Output: July 2010 – June 2011

Month	Amaranth	Dillon	Gosfield	Kings-bridge	Port Alma I	Port Alma II	Port Burwell	Prince	Ripley	Talbot	Under-wood	Wolfe Island	Overall
Nameplate (MW)	**200**	**78**	**50**	**40**	**101**	**99**	**99**	**189**	**76**	**99**	**182**	**198**	
July	16			13	16		12	15	14		16	17	16
Aug.	18			17	14		13	22	19		19	20	18
Sep.	29		22	34	31		26	37	33		35	32	32
Oct.	29			35	37		32	31	29		33	32	32
Nov.	32		39	42	40	37	33	44	40		39	33	37
Dec.	26		42	51	47	51	39	31	53		48	34	39
Jan.	27		38	36	38	43	33	25	39	33	36	27	33
Feb.	43	56	55	45	52	58	47	34	50	51	48	42	46
Mar.	27	40	34	31	38	41	26	28	32	35	29	29	31
Apr.	38	40	49	38	49	52	35	31	38	47	38	38	40
May	23	30	31	25	32	35	20	25	26	29	25	30	27
June	20	25	23	19	25	28	18	26	16	22	16	19	21
Annual Average	**28**			**32**	**35**		**28**	**29**	**33**		**32**	**30**	**31**

Appendix B: Correction of Capacity Factor for Annual Wind Speed Variation

It is common experience that some years are windier than others, just as some years are wetter or colder. To make sense of the annual average power output of the Ontario WEGS, the averages need to be corrected for the annual average wind speed.

Mathematically, the output of a turbine varies as the cube of the wind speed. This is easy to understand. The kinetic energy density of the atmosphere varies as the square of the wind speed. The volume of air passing through the blade circle varies linearly with the wind speed. Multiply these two factors and the power output varies as the cube of the wind speed. That is, if the wind speed doubles the power increases eight-fold.

There is a limit to the cube law at which the power output flattens off. However, for the range of wind speeds corresponding to most of the power output, the cube law is a reasonable representation.

A wind speed record for Toronto can be found at: http://toronto.weatherstats.ca/charts/wind speed-5years.html, with a similar URL for other Canadian cities. Only the records for Toronto go back a full 5 years and therefore Toronto was taken as a proxy for Ontario. The following table reproduces the average wind speeds for the years (July to June) shown. v is the annual average wind speed and v_0 is the five year average (16.87 km/h). As expected, the records show that 2010-2011 was indeed a windy year. The third row in the table is the cube of the ratio of the annual to five-year average wind speed. This is a measure of the extent to which the annual average WEGS power output would have been less than or greater than the five-year average.

Year	2006-2007	2007-2008	2008-2009	2009-2010	2010-2011
v (km/h)	17.08	16.56	16.64	16.50	17.59
$(v/v_0)^3$	1.04	0.94	0.96	0.93	1.13

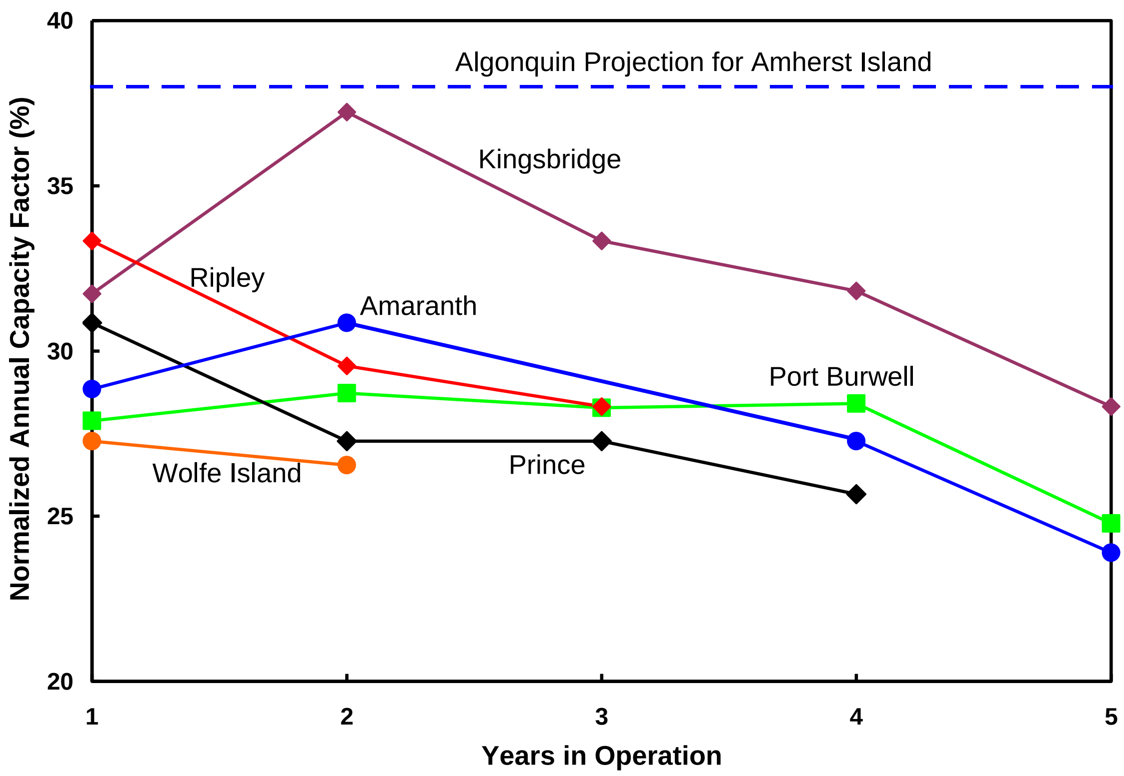
In order to get a picture of the long-term performance of the Ontario WEGS, the WEGS that have been operating for 3 to 5 years have had their annual capacity factors corrected for this variation in wind speed from year to year. This was done by dividing the annual average capacities in Table 1 of the report by the numbers in the third row of the table above. It is the resulting corrected, or normalized, capacity factors that are plotted in Figure 1 of the report. Once again, I emphasize that all of the numbers used to obtain Figure 1 are in the public domain.

A possible criticism is that Toronto may be an arbitrary choice for the proxy for Ontario. It was done because only Toronto has records going back 5 years. To investigate to what extent this introduces uncertainty, a comparison was made with the cities for which the records go back 3 years. The five cities, widely spaced, were Hamilton, Kingston, North Bay, Ottawa and Thunder Bay. The table below compares the ratio $(v/v_0)^3$ for Toronto and the average of the five cities.

Year	2008-2009	2009-2010	2010-2011
$(v/v_0)^3$ Toronto	0.96	0.93	1.13
$(v/v_0)^3$ Five Cities	0.99	0.88	1.13

The general trend is similar, with 2010-2011 being significantly windier than the previous year. The combined results for the 5 cities and Toronto, for the past three years, can be used to revise the normalized capacity factor graph, Figure 1 of the report. This revision is shown as Figure 4 below. The performance of the Ontario WEGS remains the same; after a year or two, the normalized capacity factor trends down by about 2% per year.

Figure 4: Normalized Capacity Factor for Ontario WEGS as a Function of Years of Service: Revised to Include Recent Wind Speed Records from 5 Cities.

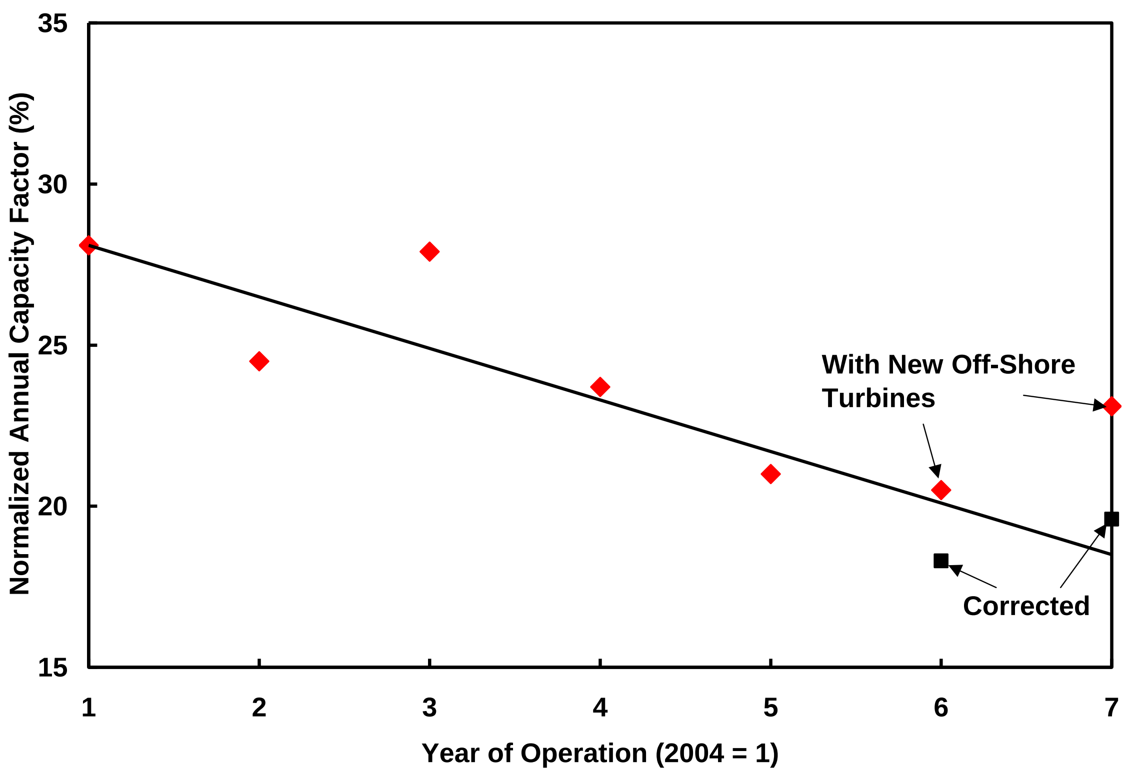


My colleague, Wayne Gulden, repeated the above analysis for the Danish WEGS using wind speed data for Copenhagen. The results, capacity factor (%) as a function of year of operation, are shown in Figure 5 below as red diamonds.

Over the years 2004 to 2008, the nameplate power of the Danish WEGS remained little changed at 3.1 GW. In 2008, off-shore wind turbines were starting up, increasing the nameplate power by about 20% by 2010. The normalized annual average capacity factor decreased from 28% to 21% from 2004 to 2008. With the addition of the off-shore turbines there is the suggestion of an increase in capacity factor. On the assumption that the off-shore turbines are contributing a conservative 40% capacity factor, the on-shore turbine contribution can be separated out. This is shown by the black squares for years 6 and 7 in Figure 5. A linear regression analysis showed a decrease of 1.6% per annum. Over the 7-year period there was little change in the total on-shore nameplate power (3.1 GW) suggesting that the analysis was looking at the true aging of the WEGS.

In both cases, Ontario and Denmark, the annual declines of 2% and 1.5% respectively correspond to a relative decline of between 6 and 7% per annum. It seems that maturity is no antidote for the aging process.

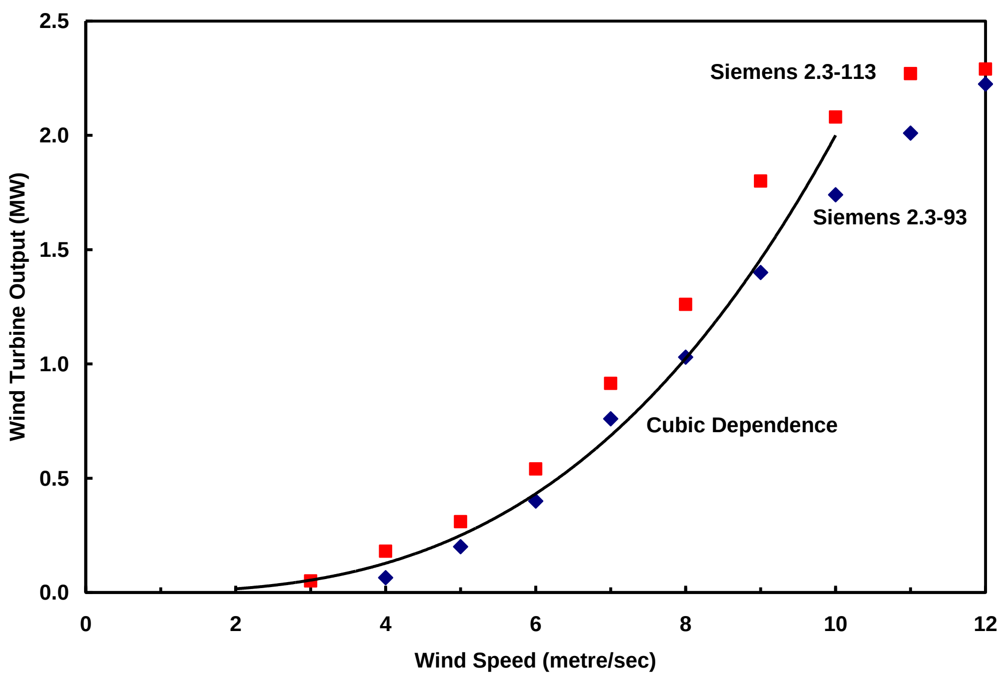
Figure 5: Normalized Capacity Factor for the Danish On-Shore WEGS as a Function of Year: Corrected for the Effect of New Off-Shore Turbines



Appendix C: Estimate of Capacity Factor with Siemens 2.3-113 Turbines

The purpose of this appendix is to use the Wolfe Island performance figures to estimate the capacity factor of the Amherst Island WEGS. Figure 6 shows the power output of the Siemens 2.3 - 93 turbine in operation on Wolfe Island and the Siemens 2.3 - 113 turbine proposed for Amherst Island. The numbers are taken from the publically available specification sheets. The solid line represents a cubic dependence of power output upon wind speed.

Figure 6: Power Output of the Siemens 2.3 MW Wind Turbines



The new high efficiency turbine has a lower cut-in speed, 3 m/s compared to 4 m/s, as well as a higher power output at all wind speeds. It was designed specifically for sites with marginal wind resource.

There is a clear output advantage at low wind speed and, otherwise, an advantage of about 20% at higher wind speeds. Because the advantage varies with wind speed, it would help to know the distribution of wind speeds. That is not known. However, thanks to the IESO data base, the distribution of power output of the Wolfe Island WEGS is known. Table 5 is a worksheet based upon this distribution.

Columns 1 and 2 are ranges of power output from the 198 MW Wolfe Island WEGS and the number of hours performing in those ranges over the period July 2009 to June 2011.

Column 3 converts the output range to a capacity factor. For example 0 to 10 MW converts to 5/198 = 2.5%, 10 to 20 MW converts to 15/198 = 7.6% and so on.

Column 4 converts the number of hours to a fraction of the number of hours in 2 years. It is a weighting factor. Column 5 is the product of the numbers in columns 3 and 4 which gives the contribution to the overall capacity factor. The sum at the foot of the column is the 2-year average capacity factor, 27%.

Column 6 is the advantage of the new turbine, the ratio of outputs. Column 7 is the multiple of columns 5 and 6. It is the expected contribution to the overall capacity factor for the new turbines assuming the same wind speed distribution. The sum at the foot of the column is the estimated capacity factor, 34%.

Table 5: Worksheet to Estimate the Capacity Factor for the Siemens 2.3 – 113 Turbine, assuming the Wind Speed Distribution for Wolfe Island.

Range (MW)	Number of Hours	CF (%) 2.3 - 93	Fraction of Time	Contribution 2.3 - 93	Advantage	Contribution 2.3 - 113
0-10	5108	2.5	0.292	0.7	2.8	2.1
10-20	2062	7.6	0.118	0.9	1.6	1.4
20-30	1598	12.6	0.091	1.2	1.43	1.6
30-40	1255	17.7	0.072	1.3	1.35	1.7
40-50	980	22.7	0.056	1.3	1.25	1.6
50-60	825	27.8	0.047	1.3	1.21	1.6
60-70	664	32.8	0.038	1.2	1.20	1.5
70-80	575	37.9	0.033	1.2	1.20	1.5
80-90	503	42.9	0.029	1.2	1.21	1.5
90-100	433	48.0	0.025	1.2	1.23	1.5
100-110	349	53.0	0.020	1.1	1.26	1.3
110-120	350	58.1	0.020	1.2	1.28	1.5
120-130	291	63.1	0.017	1.0	1.29	1.4
130-140	272	68.2	0.016	1.1	1.25	1.3
140-150	308	73.2	0.018	1.3	1.21	1.6
150-160	290	78.3	0.017	1.3	1.19	1,5
160-170	301	83.3	0.017	1.4	1.14	1.6
170-180	379	88.4	0.022	1.9	1.12	2.1
180-190	787	93.4	0.045	4.2	1.07	4.5
190-198	190	98.5	0.011	1.2	1.01	1.1
Total			1.00	27%		34%

Finally, as noted on page 5 of above, the expected average wind speed on Amherst Island at a height of 100 metres is estimated to 6.8 metre/s, compared to 7.5 metre/sec on Wolfe Island at a height of 80 metres. Therefore the 34% is reduced by the factor $(6.8/7.5)^3$. That is, the estimated initial capacity factor is 25%.

Appendix D: Wake Loss on Amherst Island

Operating turbines create a wake behind them. Figure 7 illustrates this:

Figure 7: Wake Turbulence Behind Turbines Illustrated by Sea Fog.

This wake adds turbulence and subtracts wind speed (wake loss). There have been wind tunnel experiments and field experiments to measure the wake loss. The wind speed loss is largest along the axial direction and decreases in the radial direction. As is obvious from Figure 8, the wake loss extends in the radial direction beyond the blade radius.

Field measurements from on-shore and off-shore turbine experiments have been represented by the formula:

$$\frac{\Delta u}{u} = \frac{x}{D}$$

where Δu is the decrease in wind speed on the axis, u is the uninterrupted wind speed, x is the distance behind the turbine and D is the blade diameter [18, 19]. For instance, at 5 blade diameters behind the turbine, the on-axis decrease in wind speed is 20%. From wind tunnel and field measurements, going out in the radial direction there is a Gaussian decrease in wake loss [19, 20]. Averageing over the area swept by the blade the wake loss can be represented by:

$$\frac{\Delta u}{u} = 0.66\frac{x}{D}$$

Continuing with the above example, the average wake loss is 13%. As noted in Appendix B, the wind turbine power output varies as the cube of the wind speed, that is 0.87^3 = 66% in this case. Therefore, a turbine 5 blade diameters downwind of a neighbour will lose one third of its capacity factor.
Looking at the proposed layout of the Amherst Island project I note that many of the turbines are within, or close to, 5 blade diameters (565 metres) of an upwind turbine for the prevailing wind direction. Figure 8 below shows the proposed turbine sites. Overlaying the map is a wind rose showing the prevailing wind direction and white circles representing the John Hopkins recommended exclusion zones for turbines T01, T19 and T25. To show all of the exclusion zones would clutter the figure.

Figure 8: Project Map with Added Exclusion Zones

(Figure 9 courtesy of Wayne Gulden)

Comparing this map with the layout for Wolfe Island, I note that of the 37 tubine sites shown above, only 8 (22%) can be considered upwind and therefore operable without wake loss; For Wolfe Island, 30 of the 86 sites (35%) can be considered upwind. As expected for such a dense array, in the event that this project goes ahead, the wake loss is going to be significant.

Appendix E: Noise Compliance

Figure 9 is the predicted noise contour map for the Amherst Island WEGS. The coloured fill shows the regions where the noise level will be above 40 dBA, the Ministry of the Environment limit for turbine noise. The contour spacings are 1 dBA. Note how many residences are close to the 40 dBA contour.

It is emphasized that the prediction code has an uncertainty of ±3 dBA. Manufacturers quote an uncertainty of ±1 or ±2 dBA in the sound power level of their turbines. These combine to give an uncertainty of ±4 dBA. That is, the 40 dBA contour is really a range 36 to 44 dBA. The noise sound pressure level at many of those residences is going to be out of compliance. This is a real and important risk factor for the WEGS if it goes ahead.

The compliance risk will be compounded by the fact that turbulent inflow noise has been ignored by Hatch, the noise consultants. Their argument is that the Ministry of the Environment does not require that it be considered. This will be no consolation to APCo when compliance audits are done.

Figure 9: Noise Contour Map for APCo WEGS on Amherst Island