Power Generation Features.

Proposed 300 MW Wind Farm

Cumberland County, Nova Scotia.

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Abstract

This report explores the design and cost estimation of a "green field" wind power generation project in Cumberland County and adjacent marine areas in Nova Scotia. The project aims to generate 300 MW of power from wind turbines while emphasizing sustainability, safety, and cost-effectiveness. Location considerations, turbine design criteria, and cost considerations are discussed in detail.

The selection of ideal locations is based on wind resource data obtained from the Canadian Wind Energy Atlas, which provides comprehensive information about wind resources in the region. Nine candidate locations in Cumberland County are assessed for their wind speed and energy potential. Additionally, the performance of the selected Vestas V112 3.0 MW wind turbine model is evaluated in these locations.

The turbine design focuses on efficiency, sustainability, and minimal environmental impact. Design features include blade design with vortex generators, the use of glass-reinforced polyester for blade material, support tower selection, turbine height optimization, and a direct drive system for energy conversion. A total of 150 Vestas V112 3.0 MW turbines are proposed to meet the 300 MW capacity requirement.

Cost estimation is based on insights from the National Renewable Energy Laboratory's "2021 Cost of Wind Energy Review." The report provides component-level cost data, including turbine and balance of system costs. The total estimated capital expenditure (CapEx) for the project is $1,501 per kW. Operational expenditure (OpEx) is estimated at $40 per kW per year. The levelized cost of energy (LCOE) is calculated as $34 per MWh, considering a fixed charge rate of 5.88%, CapEx, OpEx, and net annual energy production. This LCOE aligns with the expected cost of energy produced by wind projects in Nova Scotia.

The project's estimated upfront cost is $450 million, with the wind farm expected to meet its power generation goals while contributing to reduced energy costs in Nova Scotia. This comprehensive analysis provides valuable insights for the development of a sustainable and economically viable wind power project in the region.

Power Generation

Task:

Power Generation: suggest you design facilities as a new "green field" project with cost estimates derived from publications of your choice - or your best estimates. Stay within Cumberland County and adjacent marine areas.

➢ ***Explain your choice of method(s), location(s), cost estimates and your technical rationale for safe operation***

Factors Favoring Wind Energy Over Solar PV System for 300 MW Power Generation in Cumberland County and Adjacent Marine Areas, Nova Scotia

The following factors support the preference for wind energy over a solar PV system for generating 300 MW of power in the salt caverns of Cumberland County and adjacent marine areas in Nova Scotia:

Geological and Geographical Conditions: The region's geological and geographical features are conducive to energy storage in salt caverns, enhancing the reliability and flexibility of wind energy. These salt caverns can store excess energy, allowing it to be used when needed, thereby increasing the effectiveness of wind energy generation. Solar PV systems would require Battery energy storage systems which would make the project more expensive.

Abundant and Consistent Wind Resource: The wind resource in the region, especially in marine areas, is abundant and consistent with an annual average of about 8 m/s. This consistency increases the capacity factor of wind turbines, ensuring a steady power supply. It also contributes to lower overall wind energy costs.

Variable and Seasonal Solar Resource: In contrast, the solar resource in the region is variable and seasonal, affecting the output and efficiency of a solar PV system. This variability can result in lower energy production during certain times of the year, making wind energy a more reliable option.

Reduced Environmental Impact: Wind energy may have a smaller environmental footprint generally compared to a solar PV system. Wind turbines require less land clearing and water use, reducing their impact on local ecosystems.

Location Considerations

An ideal location of the wind farm is to be selected based on the theoretical Power output that can be extracted from the wind's kinetic energy. So we have considered the different wind velocities and Energy at different locations at hub heights above 80m to facilitate careful site selection and ensure optimal energy production. The wind data is obtained using the "Canadian Wind Energy Atlas" [1] which is a significant project conducted by the Government of Canada and provides comprehensive information about the wind resource across the country. It involves detailed wind data and maps to support wind energy development and studies. Nine candidate locations in Cumberland County distributed along the Nothumberland Strait, Chignecto Bay and Minas basin were selected as shown in figure 1 [Link to Map] and their details presented in table 1.

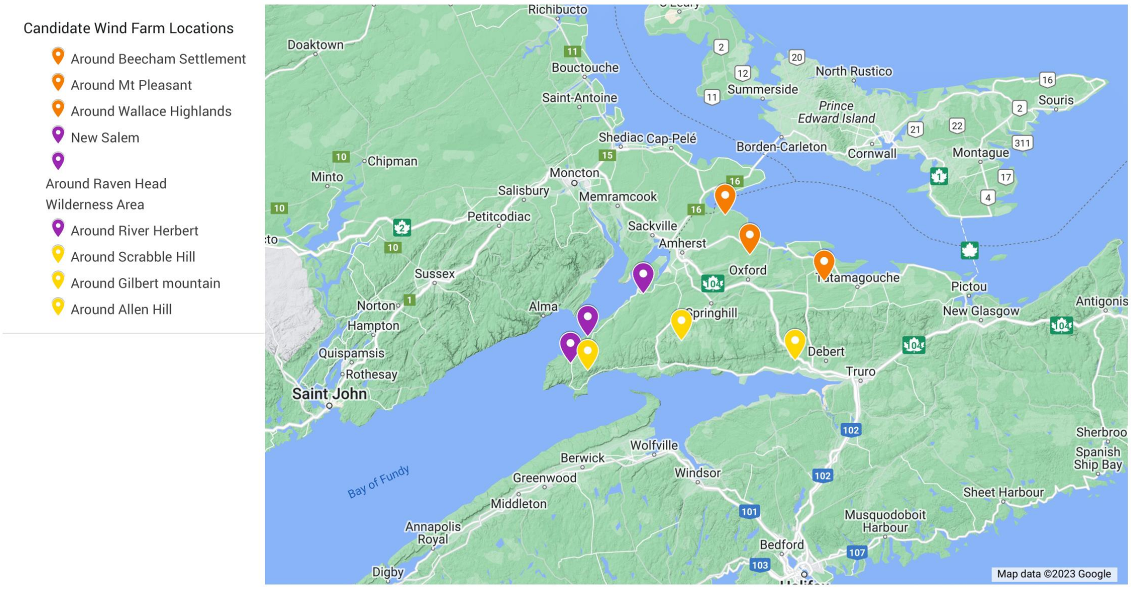

Figure 1 Candidate Wind Farm Locations in Cumberland County

The Cumberland County Wind Resource Data at 80 m hub height in table 1 indicates that the candidate locations close to the Northumberland Strait and Chignecto Bay offer more prospective Wind speeds and energies (power per square meter) compared to the Locations along the Minas Basin. However, Wind Resource data alone is not sufficient for making the decision on site selection. The performance of the wind turbines to be used is further investigated in these locations in the next section.

Table 1 Cumberland County Wind Resource Data at 80 m hub height

Cumberland County Wind Resource Data at 80 m hub height														
Region	Area (+10 Km radius)	Coordinates		Mean Wind Speed by Period (m/s)					Mean Wind Energy by Period (W/m2)					
		Latitude	Longitude	Winter	Spring	Summer	Fall	Annual	Winter	Spring	Summer	Fall	Annual
Along Northumberland Strait	Beecham Settlement	46.01254	-63.869929	9.49	8.33	7.07	8.33	8.16	727.8	524.4	295.62	494.5	491.38
	Mt Pleasant	45.82268	-63.85753	8	7.28	6.33	7.21	7.07	407.5	326.4	203.44	303.5	296.62
	Wallace Highlands	45.72643	-63.4678	7.99	7.16	6.13	7.1	6.96	441	341.9	204.56	319.3	311.25
Along Chignecto Bay	New Salem	45.42576	-64.79907	8.11	7.44	6.32	7.32	7.11	461.3	373.9	222.81	345.1	332.12
	Raven Head Wilderness	45.52326	-64.70766	8.95	8.25	6.93	8.1	7.85	686.3	563.9	308.88	507.8	489.25
	Around River Hebert	45.68033	-64.41733	7.99	7.25	6.27	7.21	7	441.8	354.4	220.94	335.1	317.88
Along Minas Basin	Scrabble Hill	45.43587	-63.62022	7	6.23	4.9	5.99	5.91	309.8	229.1	98.69	194.1	199.12
	Gilbert Mountain	45.50936	-64.21649	8.44	7.91	6.57	7.61	7.46	495.5	419.3	222.12	360	354.12
	Allen Hill	45.39858	-64.70744	8.16	7.35	6.18	7.26	7.06	440.5	339.9	198.44	316.6	307.38

Wind Turbine Design

Design Criteria:

a. Develop a wind turbine farm with a capacity to generate 300 MW of power.
b. Incorporate recyclable or sustainable materials in wind turbine construction to address the environmental concerns of the local community.
c. Utilize robust and weather-resistant materials in turbine construction to reduce maintenance requirements.
d. Strive to minimize the quantity of wind turbines while meeting the 300 MW power goal, considering the potential effects on local ecosystems and nature reserve.
e. Minimize the visual impact caused by the presence of wind turbines.

Design Features:

Blade Design – Prioritize blades with vortex generators to enhance turbine power output. Vortex generators energize blade airflow, boosting overall performance [2]. Investing in these generators aligns with the power output goal, yielding better results.

Blade Material – Opt for glass reinforced polyester for turbine blades, which outperforms tubular steel. The material's durability withstands Cumberland county weather and remains highly recyclable, offering up to 80% original strength through thermal decomposition [3]. This material also handles high wind velocities better, reducing permanent deformation risk.

Support Tower – Truss-designed towers handle wind turbulence more effectively than standard poles. However, cost-efficient state-of-the-art concrete towers are simpler to construct and maintain. While truss towers have slight efficiency advantages, concrete towers prove more economical.

Turbine Height – Balancing power, visual impact, and cost is crucial. A 140m turbine generates significant power, but 100m offers better economic feasibility. A 140m turbine may reduce turbine count but poses higher visual pollution, bird risks, and maintenance complexities. Choosing a 100m turbine farm balances these factors well.

Nacelle Transmission – Nacelle design is pivotal for energy conversion. Opt for a direct drive system over a single-stage gear system. While direct drive has higher manufacturing costs, its lower maintenance needs and efficiency advantages make it a more suitable choice [4].

Turbine Power Output and Rating – The wind farm shall be designed for 300 MW. However, to economize on the land area for implementing such huge wind farms, higher power wind turbines are recommended to limit the area needed. For instance, 2.0-MW turbines (or higher) are preferred. Opt for a 3 MW turbine power rating to achieve a balance between efficiency and scalability. A 3 MW turbine provides a significant power output while allowing for cost-effectiveness by minimizing the number of Turbines in the overall wind farm design.

Design Decision:

The proposed Wind Turbine model to be used is the Vestas V112 3.0. It has a rated power output of 3,000.0 kW, a key factor in generating substantial energy at a slightly less rated wind speed of 12 m/s. Its cut-in wind speed is 3.0 m/s and has a cut-out wind speed of 25.0 m/s. Figure 2 depicts the power curve of this wind turbine [5]. Assuming an average capacity factor of 65%, each turbine in the wind farm would have a power output of close to 2 MW, meaning a total of 150 turbines would be able to meet the 300 MW capacity. The performance of this turbine model in the candidate locations is summarized in table 2.

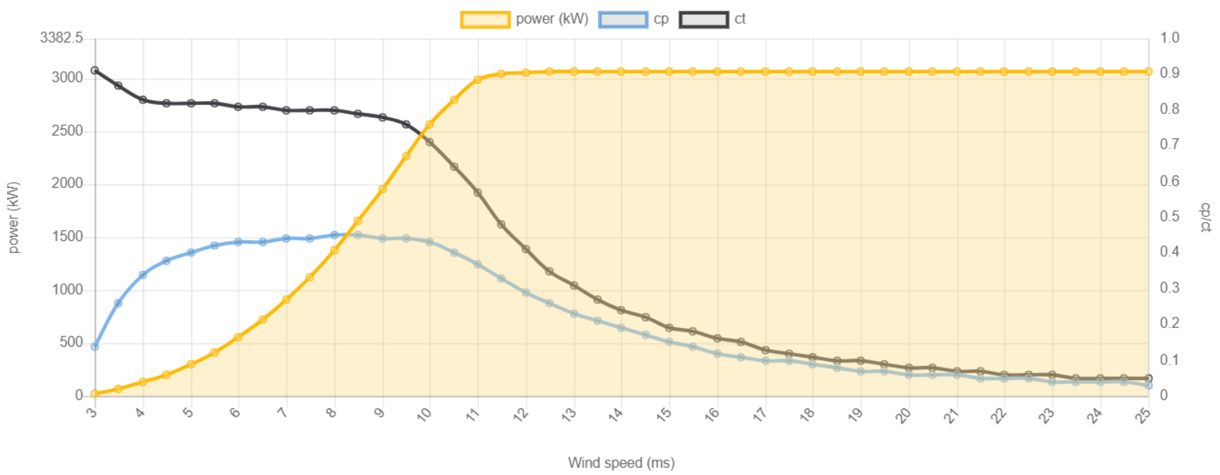

Figure 2 Vestas V112 3.0 MW power Curve [5]

Table 2 Cumberland County: Performance of 3 MW wind Turbine with 12 m/s Rated Speed at 80 m hub height

Cumberland County: Performance of 3 MW wind Turbine with 12 m/s Rated Speed at 80 m hub height									
Region	**Area (+10 Km radius)**	**Coordinates**		**Mean Power Output by Seasons in KW**					**Annual Average Use Factor**
		Latitude	**Longitude**	**Winter**	**Spring**	**Summer**	**Fall**	**Annual**	
Along Northumberland Strait	Beecham Settlement	46.0125	-63.8699	1892.4	1632.27	1343.01	1651.4	1593.52	53.12%
	Mt Pleasant	45.8227	-63.8575	1598.2	1398.01	1133.31	1387.8	1342.97	44.77%
	Wallace Highlands	45.7264	-63.4678	1572.4	1349.66	1074.31	1343	1300.42	43.35%
Along Chignecto Bay	New Salem	45.4258	-64.7991	1600.3	1423.76	1130.13	1402	1339.71	44.66%
	Raven Head Wilderness	45.5233	-64.7077	1735.6	1577.51	1292.87	1562.8	1492.61	49.75%
	Around River Hebert	45.6803	-64.4173	1568.8	1371.85	1112.95	1368.6	1308.83	43.63%
Along Minas Basin	Scrabble Hill	45.4359	-63.6202	1315.2	1100.4	700.61	1034.1	1011.64	33.72%
	Gilbert Mountain	45.5094	-64.2165	1691.6	1558.43	1203.38	1492.1	1445.16	48.17%
	Allen Hill	45.3986	-64.7074	1631.1	1413.16	1087.66	1396.9	1334.6	44.49%
Data Source: http://www.windatlas.ca/nav-en.php?no=12&field=E1&height=80&season=ANU									

A key feature is the "use factor," also known as the "capacity utilization factor," It represents the ratio of the actual energy output of a wind turbine or wind farm to its maximum potential energy output if it were operating at its rated capacity continuously. Expressed as a percentage, it provides a measure of how effectively the chosen turbine would be producing energy over a period of a year. The shows that regions close to Northumberland Strait are the best locations for the wind turbines, since we generally aim for a location with the highest mean annual use factor.

Cost Considerations

To estimate the costs associated with this wind energy generation project, we relied on insights provided by the National Renewable Energy Laboratory (NREL) in their comprehensive report the "2021 Cost of Wind Energy Review." [6] This report serves as a foundational resource for assessing the levelized cost of energy (LCOE) for both land-based and offshore wind power plants. The data and results are derived from 2021 commissioned plants, representative industry data, and state-of-the-art modelling capabilities. The report provides insight into current component-level costs and gives a basis for understanding the variability in wind energy LCOE in US dollars. The cost estimation methodology drew upon three key components highlighted in this report:

1. **Turbine Component Costs**: The estimated costs associated with the wind turbines themselves are referenced the internal Cost and Scaling reference model utilized by NREL. It serves as a significant benchmark for understanding the cost dynamics of wind turbine components.
2. **Balance of System (BOS) Component Costs**: These costs account for various auxiliary systems and infrastructure necessary for establishing wind energy generation. They are derived from the Land-based Balance of System Systems Engineering (LandBOSSE) model, as developed by Eberle et al. in 2019.
3. **Construction Financing**: The cost estimation assumed a construction duration of 3 years and distributed the associated capital and interest expenses over this period. This approach aligns with the practical considerations of wind energy project development.

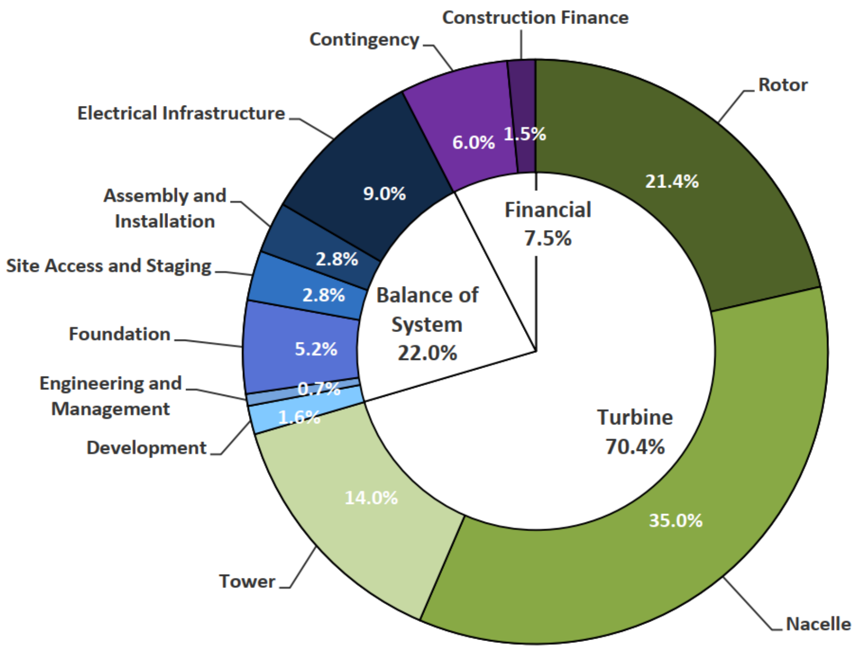

Figure 3 Land-Based Wind Project Component Cost Breakdown [6]

Estimated Total installed project Capital Expenditures (CapEx)

The culmination of all cost components results in a Total estimated Capital Expenditure (CapEx) of $1,501 per kilowatt (kW). Table 3 provides comprehensive figures encompassing the costs associated with wind turbines, their components, balance of system elements, and financial considerations in U.S. Dollars.

Table 3 CapEx Breakdown for the Reference 3MW Wind Turbine

CapEx Breakdown for the Reference 3MW Wind Turbine			
Parameter	**Elements**	**Value ($/kW)**	**CapEx**
Wind Turbine	Rotor	313	1,030 ($/kW)
	Nacelle	512	
	Tower	204	
Balance of System (BOS)	Engineering	23	322 ($/kW)
	Project management	10	
	Foundation	75	
	Site access, staging, and facilities	40	
	Assembly and installation	41	
	Electrical infrastructure	132	
Financial	Construction finance	23	113 ($/kW)
	Contingency	90	
Total CapEx		1,501	1,501 ($/kW)

Source: NREL 2021 Cost of Wind Energy Review Report.

Estimated project Operational Expenditures (OpEx)

The operational expenditure (OpEx) estimation for land-based wind plants is based on information derived from comprehensive study of projects with complete OpEx records spanning the years 2000 to 2020. Results From this Survey of Wind Industry Experts estimates the OpEx at $40/kW-yr.

Estimation of Levelised cost of electricity (LCOE)

The LCOE is given in dollars per megawatt-hour [$/MWh] and is a metric used to assess the cost of electricity generation. The specific LCOE method applied in this analysis is described as:

$$LCOE = \frac{(CapEx * FCR) + OpEx}{\left(\frac{AEP_{net}}{1000}\right)}$$

Where: LCOE = levelized cost of energy (dollars per megawatt-hour [$/MWh]), FCR = fixed charge rate (%), CapEx = capital expenditures (dollars per kilowatt [$/kW]), AEPnet = net average annual energy production (megawatt-hours per megawatt per year [MWh/MW/yr]) and OpEx = operational expenditures ($/kW/yr).

The estimated Levelized cost of energy is $34/MWh for a Wind turbine rating of 3 MW, CapEx of $1,501/kW, Fixed charge rate of 5.88%, Operational expenditures of $40/kW/yr and Net annual energy production 3,775 MWh/MW/yr. This cost maybe proportionally higher in the real case due to other cost factors involved. [6]

This shows that the project can meet the expected cost of energy produced by wind projects of $53.17 per megawatt hour in Nova Scotia [7].

Summary of Project Details and Estimated Total Upfront Costs

The estimated upfront cost of the project is $450 million as shown in Table 4. In conclusion the wind farm project will be able to successfully generate the required power output while still meeting the expectation of reduced energy cost in Nova Scotia.

Table 4 300 MW Wind Energy generation Project Details

300 MW Wind Energy generation Project Details		
Parameter	**Units**	**Value**
Wind Farm Capacity	MW	300
Turbine Power Rating	MW	3
Number of Turbines		150
Rotor Diameter	m	112
Hub Height	m	100
Cut-in Wind Speed	m/s	3
Cut-Out wind speed	m/s	25
Estimated Capacity Factor	%	53.1
CapEx	$/kW	1501
OpEx	$/kW/yr	40
Estimated LCOE	$/MWh	34
Total Upfront Cost	$	450.3 million

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