Characterizing Nova Scotia's Onshore Wind Resource

This document provides an overview of the methodology used to characterize Nova Scotia's onshore wind resource in the Atlantic Canada Energy System (ACES) Model. More detailed information, in addition to the open-source model and data, are available through the online repository. In fact, this document serves as a summary of the *Wind-Resource-Characterization-NS.ipynb* file, which is an interactive file providing commentary and the executable code that generates all of the required data and visualizations.

Background

Nova Scotia is home to a relatively strong onshore wind resource (Figure 1) and faces a challenge to quickly grow and decarbonize its electricity generation sector. In 2019, wind was responsible for 11% of Nova Scotia's electricity generation whereas thermal generation from coal, coke and natural gas was responsible for 74%. The province must accelerate the deployment of clean generation technologies in order to meet anticipated load growth and its clean electricity standard of 80% by 2030.

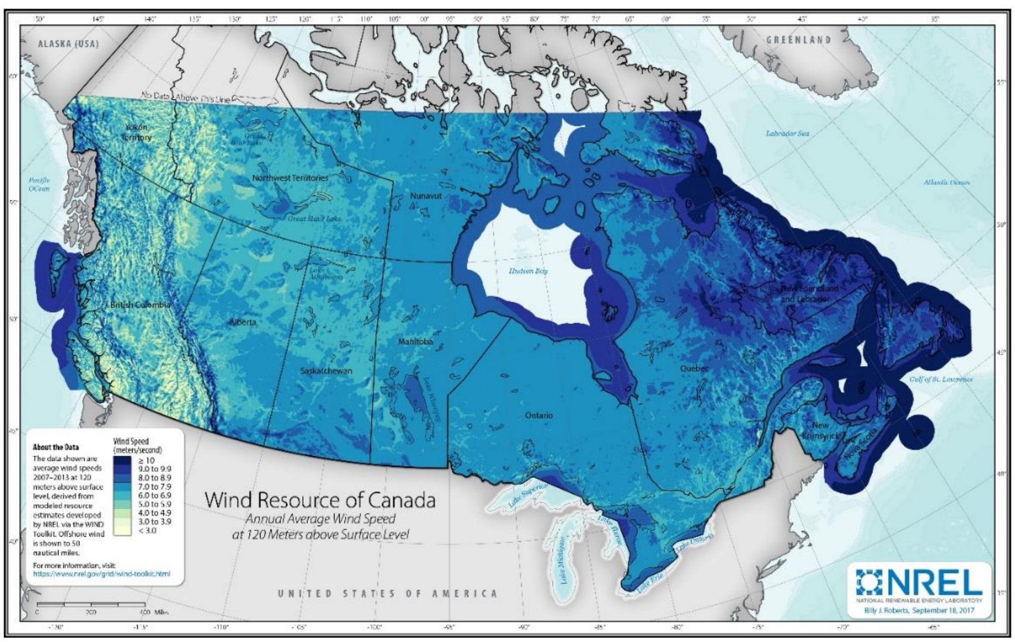

Figure 1: Average wind speeds at 120 meters above ground[1]. Nova Scotia is home to one of the strongest wind resources in North America.

[1] Draxl, C., B.M. Hodge, A. Clifton, and J. McCaa. 2015. Overview and Meteorological Validation of the Wind Integration National Dataset Toolkit (Technical Report, NREL/TP-5000-61740). Golden, CO: National Renewable Energy Laboratory.

Long-term electricity system optimization models, such as the ACES Model, can be used as a decision support tool to assist in such planning exercises. The objective of this project is to better characterize the onshore wind resource in Nova Scotia in the ACES Model, given its likely importance in Nova Scotia's decarbonization effort.

Prior to completing this work, the ACES Model modelled the onshore wind resource in Nova Scotia using a methodology that limited the ability of modellers to glean spatially explicit and temporally flexible insights. Moreover, the methodology did not take into account a number of technical factors, like incorporating array losses, which lead to an over-approximation of the resource strength. A detailed overview of the existing methodology is provided in the ACES Model Technical Documentation. This work provides a novel methodology to characterize the onshore wind resource in Nova Scotia using an open, reproducible, scalable, and rigorous approach.

Note: the onshore wind resource characterization outlined in this document is separate from the ACES Model itself. The approach can be thought of as a preprocessing tool that generates data that can be used as an input to the ACES Model.

Onshore Wind Resource Characterization

The process by which the onshore wind resource is characterized can be summarized as follows:

1. Discretize the province into a 30km grid over which historical weather variables are defined.
2. Calculate the normalized wind power for each grid cell for a historical weather year and for a given wind turbine, adjusting for turbulence, wake, and electrical losses.
3. Calculate the land area available for wind power development for each grid cell and translates this to a maximum wind resource capacity in MW.
4. Generate the following outputs:
    a. A csv file that contains summary information for each grid cell, including:
        - wind speed at 100m
        - NREL Wind Resource Class
        - annual capacity factors for a user-selected turbine
        - maximum wind resource capacity
    b. A csv file containing the hourly normalized wind power output for each grid cell for a user-selected turbine.

The methodology makes heavy use of atlite, an open-source Python package that processes weather data and converts it into energy system relevant quantities.

Loading the Nova Scotia Shapefile

A shapefile provides the geospatial data necessary for this analysis. Here, we use a shapefile provided by the Canadian Federal Government's website that provides the detailed land borders for all 13 Canadian provinces and territories. This will be used to define the spatial bounds over which we will download historical wind speed data. The figure below is generated from the shapefile.

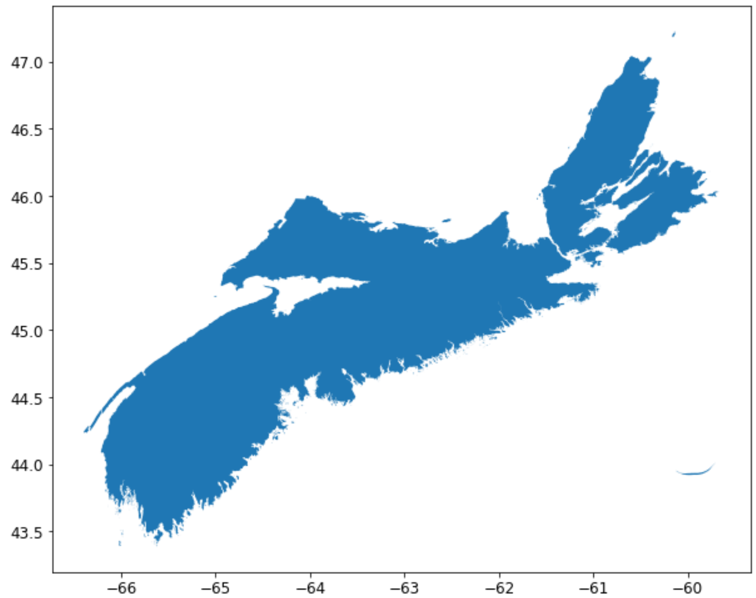

Figure 2: The spatial boundaries of Nova Scotia used in this analysis.

Historical Weather Data

For this step, we use the [ERA5 global reanalysis dataset](). This dataset provides hourly estimates for a large number of atmospheric, land, and oceanic climate variables at a 30km grid from 1959 to the present. We select 2019, as this is the weather year used for the ACES Model. Pictured below are average wind speeds at 100 meters above ground, average solar influx, and average hydro run-off for Nova Scotia.

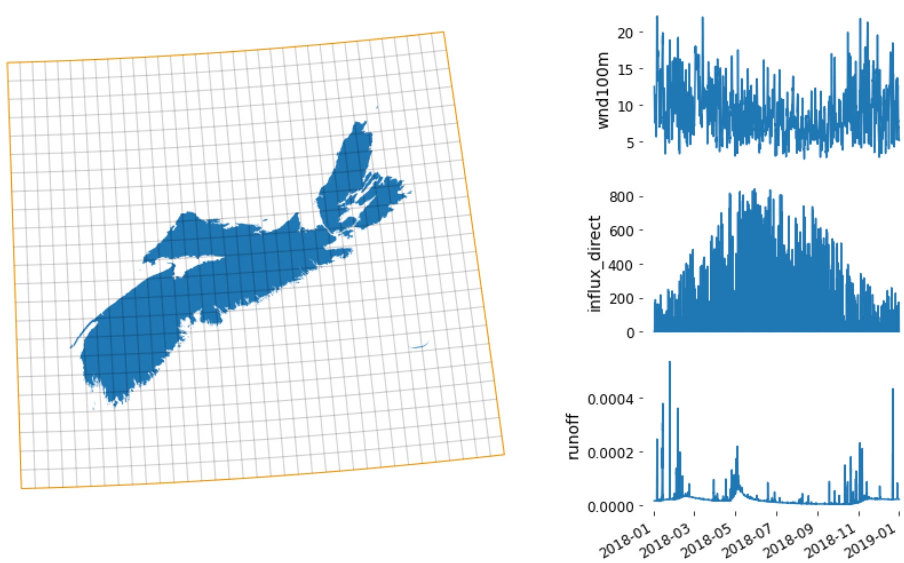

Figure 3: Sample outputs from the ERA5 reanalysis data set. Pictured here are average wind speeds at 100m, average direct solar influx, and average hydro runoff for Nova Scotia in 2018.

Of course, these data vary considerably throughout the province. The figure below displays the average wind speed at 100 meters for each grid cell in Nova Scotia.

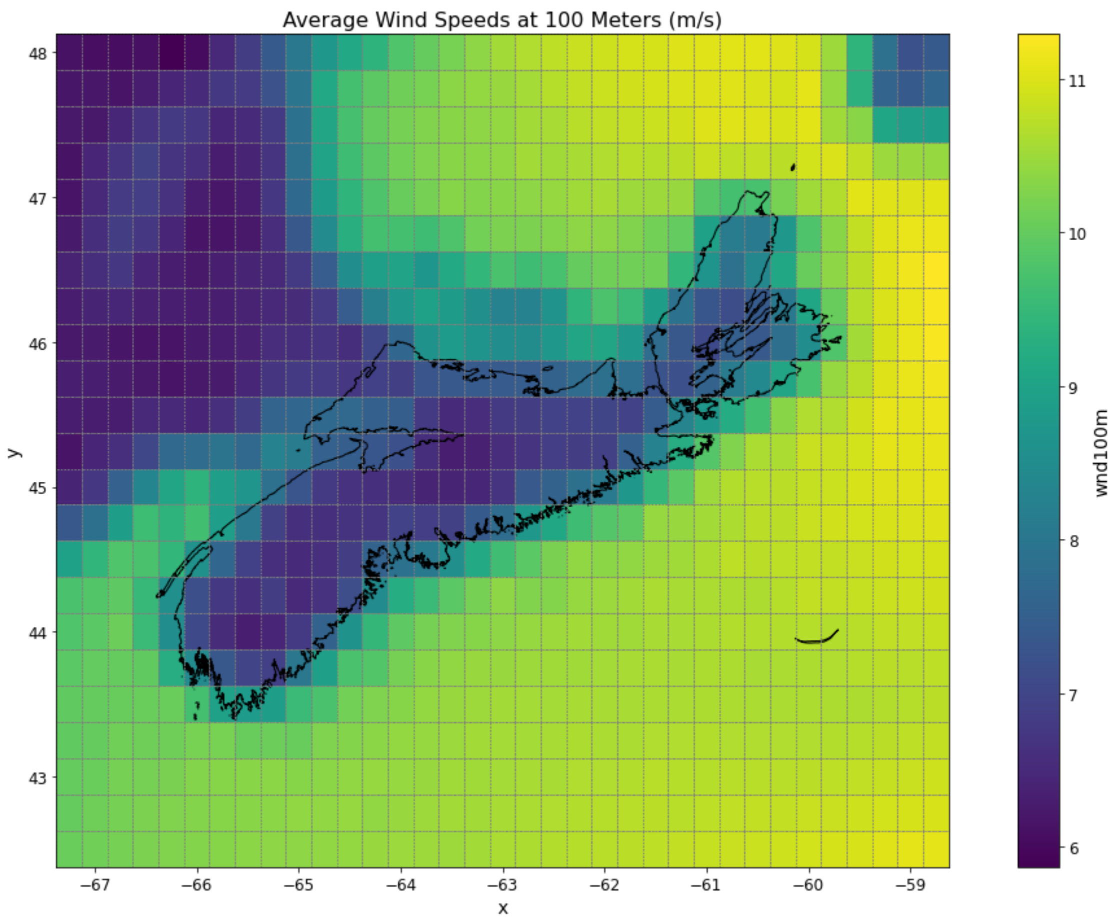

Figure 4: Average wind speed at 100 meters.

Wind Resource Quantification (Normalized Power)

Assign NREL Wind Resource Class to Each Grid Cell

The ACES model uses the 2022 NREL ATB to define the techno-economic parameters of wind turbines. We therefore use NREL technology assumptions in our calculations. To begin with, we assign each grid cell a "Land-Based Wind Resource Class" based on its average annual wind speed at 110 meters above the ground. The ERA5 data reports wind speeds at 100m, so we first extrapolate this to 110m using the logarithmic law described in [Andresen et al. (2015)](#).

Wind Speed Class	Min. Wind Speed (m/s)	Max. Wind Speed (m/s)	Wind Speed Range (m/s)	Percentile Range
1	9.01	12.89	3.88	<1%
2	8.77	9.01	0.24	1%–2%
3	8.57	8.77	0.2	2%–4%
4	8.35	8.57	0.22	4%–8%
5	8.07	8.35	0.28	8%–16%
6	7.62	8.07	0.45	16%–32%
7	7.1	7.62	0.52	32%–48%
8	6.53	7.1	0.57	48%–64%
9	5.9	6.53	0.63	64%–80%
10	1.72	5.9	4.18	80%–100%

Figure 5: The land-based wind resource classes defined in the 2022 NREL ATB.

Accounting for Losses

Atlite's built-in functions to convert wind speeds to generated power do not consider production losses. Here, we account for array losses, which include turbulence and wake losses, by drawing on insights and methodologies from the Pan-Canadian Wind Integration Study (PCWIS), authored by GE Energy Consulting. The PCWIS (pp. 94-95) states the following with respect to array losses:

> *"Based on industry experience, the combined turbulence and wake loss factor was estimated to be 10% for the average size wind plant used in this study (270 MW). To achieve this loss, a factor was applied to the wind speed at each cell. Applying a correction to the wind speed allows wind turbines to still reach rated power."*

Through iteration experiments, the PCWIS authors determine a 6.5% loss to wind speeds results in the desired 10% reduction to system wide power production. We therefore apply the same loss to wind speeds in this work.

Beyond array losses, icing and low temperature losses can be significant in Atlantic Canada. These losses are not currently considered in this analysis due to a lack of required data (e.g., relative humidity). As turbine technology progresses, however, icing and low temperature losses are becoming less of an issue.

Electrical losses are accounted for in the following section.

Calculating hourly normalized power values

Now we can convert the hourly wind speeds to normalized power values (i.e., *capacity factors)* for each grid cell. This, of course, depends on the specific wind turbine specifications.

Keeping our assumptions consistent with those used the ACES Model, we use the NREL ATB reference turbine for 2030 (Moderate Case), which is defined by the following characteristics:

- Hub height: 120m
- Rotor diameter: 175 m

- Specific power: 229 W/m2
- Turbine rating: 5.5 MW

The power curve, which is a function that converts wind speeds to generated power, is plotted below for reference. We see the curve is characterized by a cut-in speed of 3.0 m/s and a cut-out speed of 25 m/s.

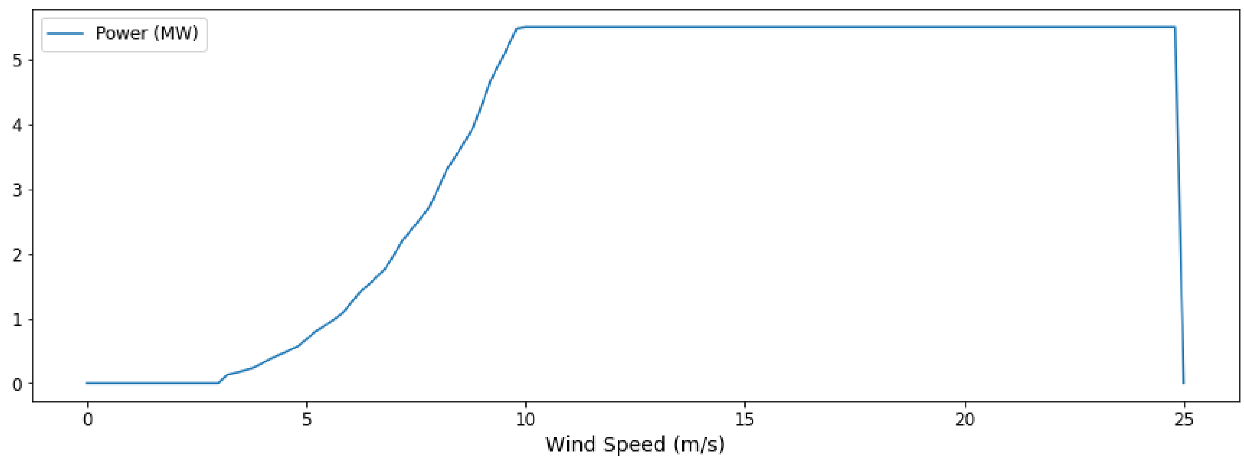

Figure 6: Power curve for the NREL ATB Reference Turbine for 2030 (Moderate Case).

By applying this power curve to the calculated wind speeds at the turbine hub height (120m), we can calculate the hourly normalized power values for each grid cell. Once computed, we apply a 2.85% electrical loss, in line with the assumptions in the PCWIS. The resulting annual capacity factor for each grid cell is plotted below:

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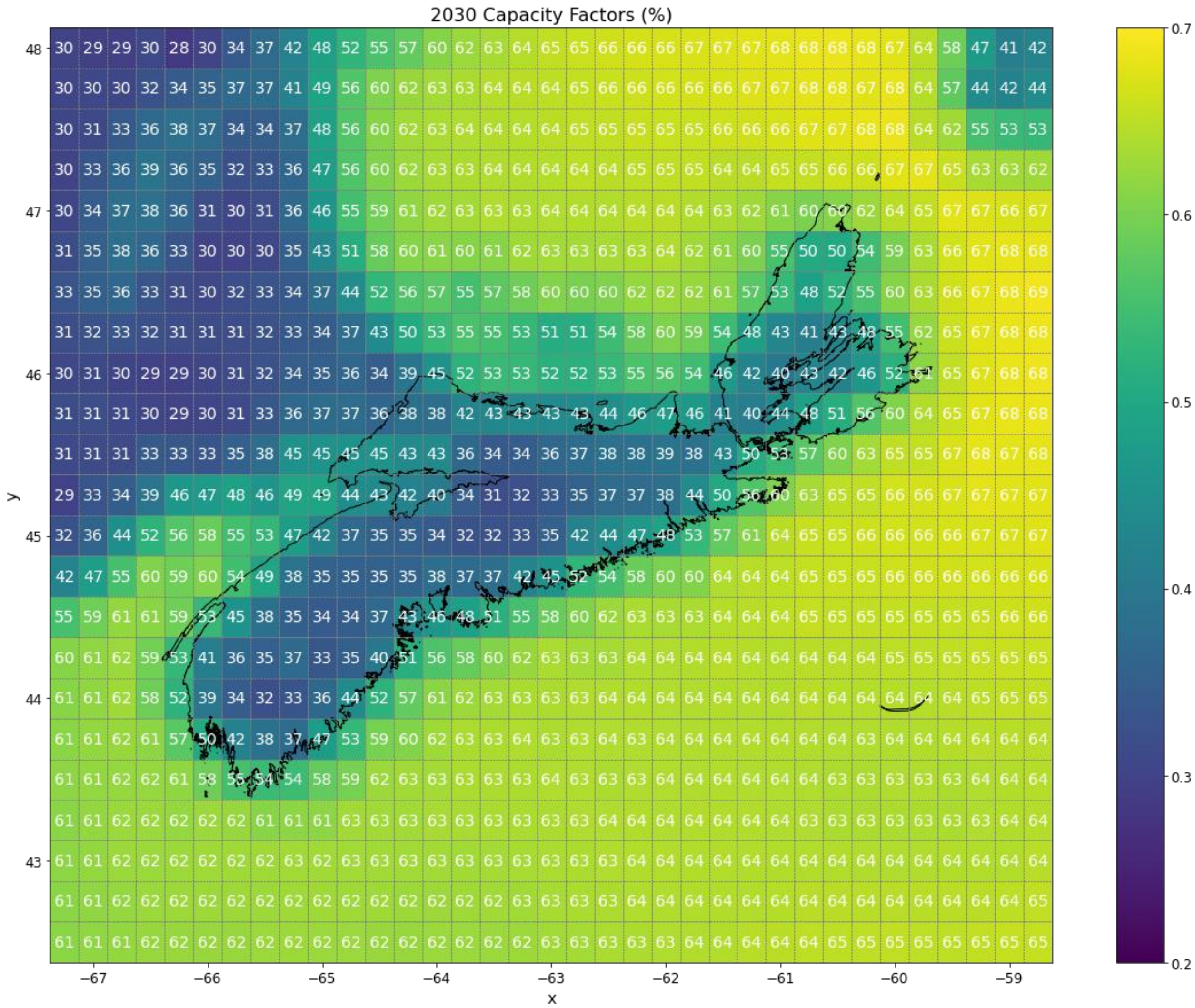

Figure 7: Annual capacity factors using the NREL ATB 2030 Reference Turbine.

The 2030 capacity factors above may seem high relative to the existing wind fleet in Nova Scotia, which has an [average annual capacity factor of 35%.] This is primarily a result of turbine technology -- the majority of existing wind turbines are over ten years old. Newer turbines, among other factors, benefit from taller and taller hub heights and therefore access to higher wind speeds.

Unfortunately, NREL does not provide turbine parameters or power curves for years other than 2030. This precludes us from being able to apply the above approach for each model year individually. Instead, NREL does provide annual capacity factors for each wind resource class for the years 2020-2050 (pictured below). These values are used in the ACES Model to ensure the capacity factors are appropriate for the model period in question. To be precise, we do not prescribe these specific capacity factors to the Nova Scotia wind resource. Rather, we apply a learning rate factor for the wind class and year in question relative to 2030.

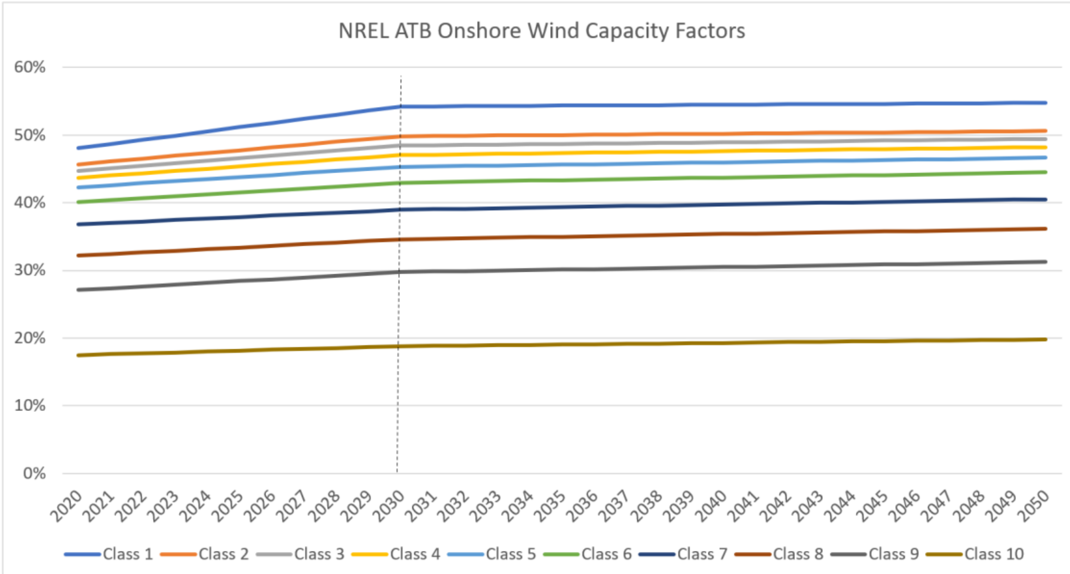

Figure 8: 2022 NREL ATB annual capacity factors for onshore wind.

Below, we use the data to visualize the capacity factors for 2022.

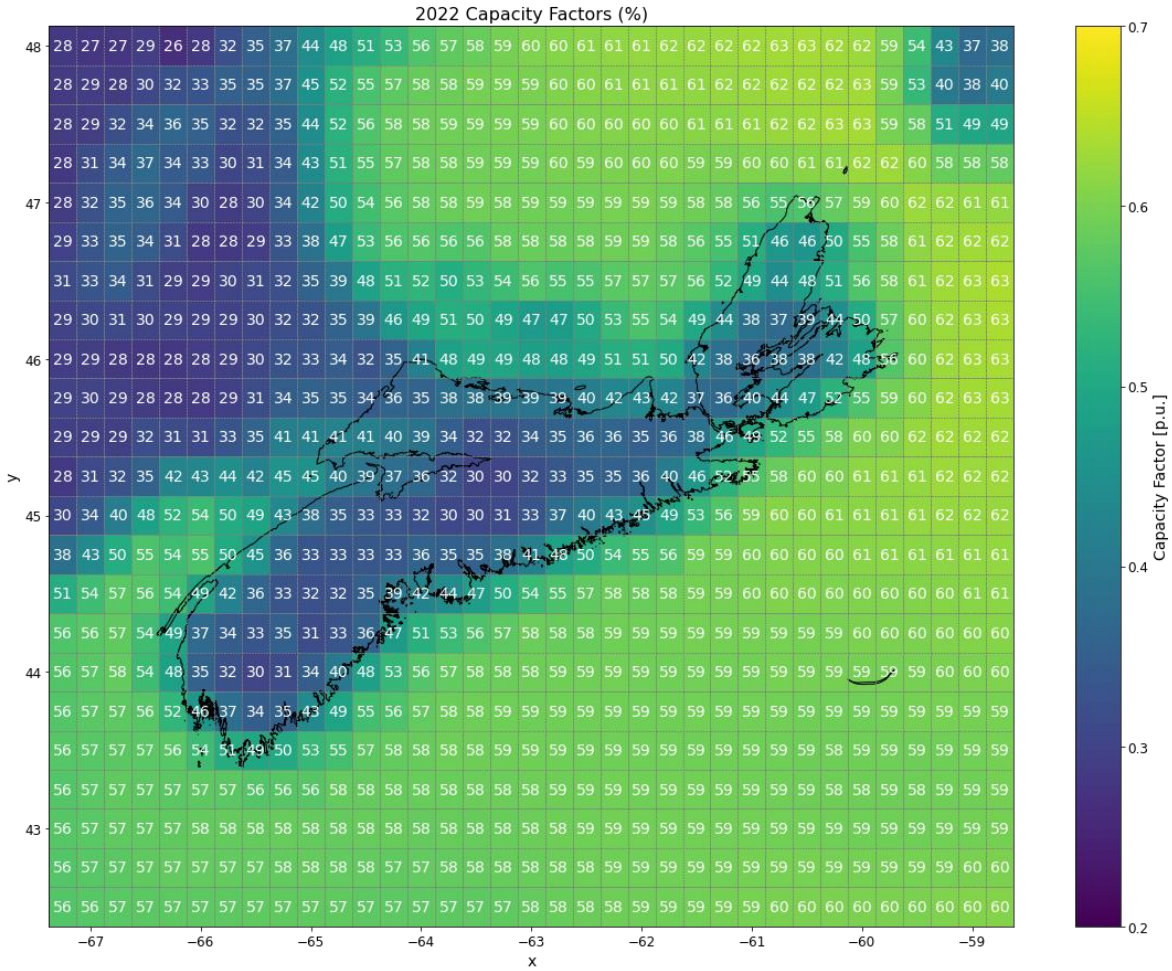

Figure 9: Calculated annual capacity factors for 2022.

Wind Resource Quantification (Resource Potential)

Now that we have derive hourly capacity factors for particular grid cells, we can shift our attention to the question of wind resource availability -- i.e., how much wind capacity can be installed in each grid cell.

Atlite does not contain any information relating to land-use or land-cover. For that, we'll need a [land cover map] of Canada. This land-cover map consists of a number of layers, each corresponding to a particular land-cover class. We make the assumption that the following layers are not suitable for wind power development: "Urban and built-up", "Water", "Wetland", "Cropland", and "Protected and conserved areas[2]".

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[2] Note: the federal land-cover maps do not include a layer for protected and conserved areas. We instead use another federal map for this layer.

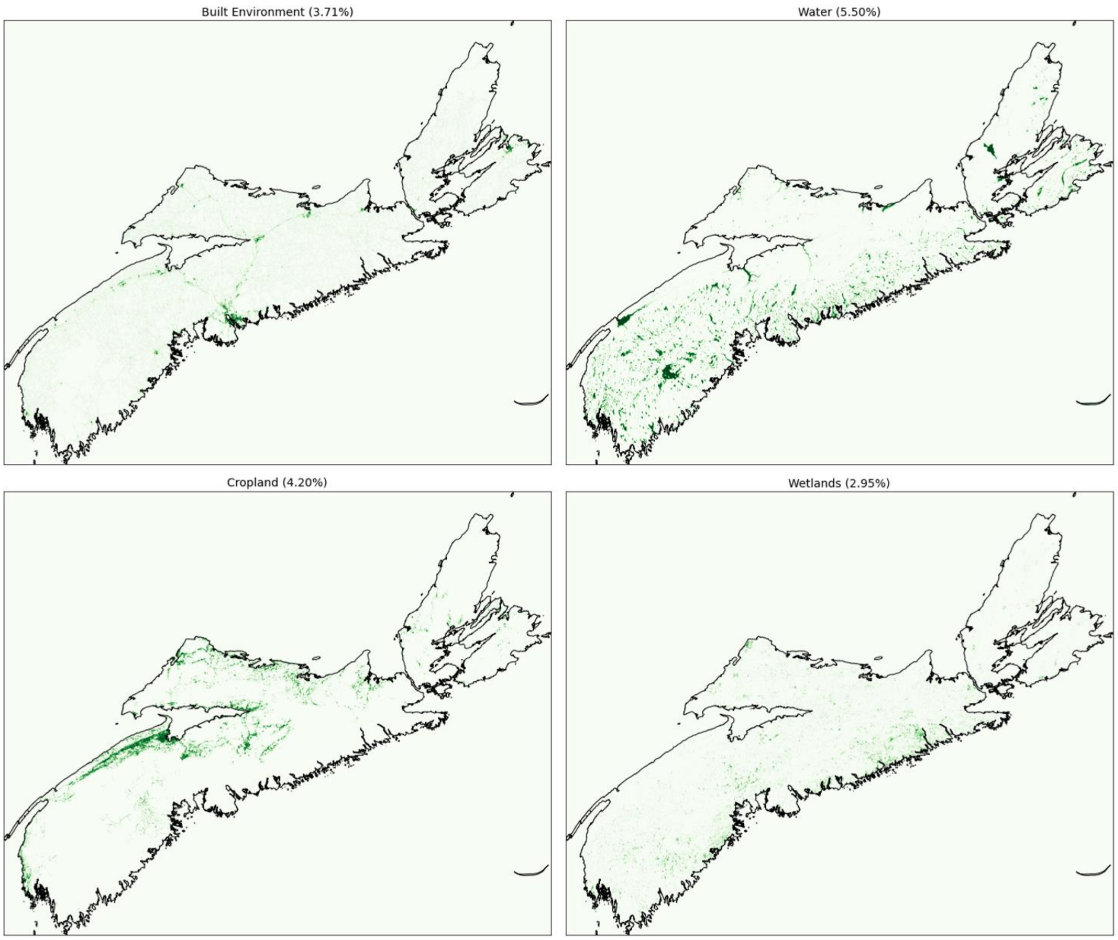

Figure 10: Illustration of several land-cover layers in Nova Scotia: "Built Environment" (top left); "Water" (top right); "Wetlands" (bottom right); "Cropland" (bottom left).

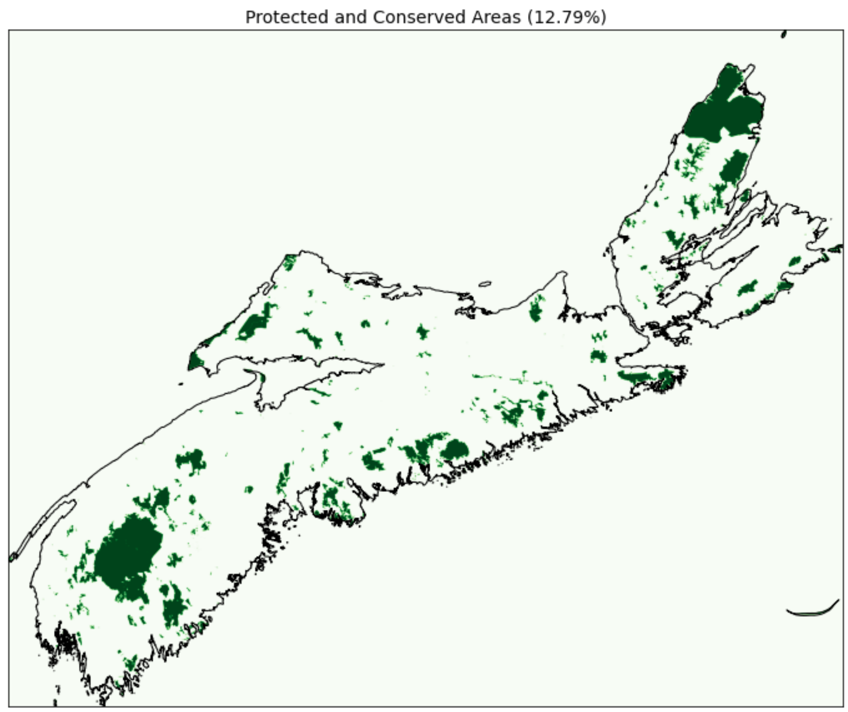

Figure 11: Illustration of protected and conserved areas.

By removing the above layers from consideration, we are left with the following map detailing areas that are considered eligible for wind power development:

Area Eligible for Wind Power Development (71.88%)

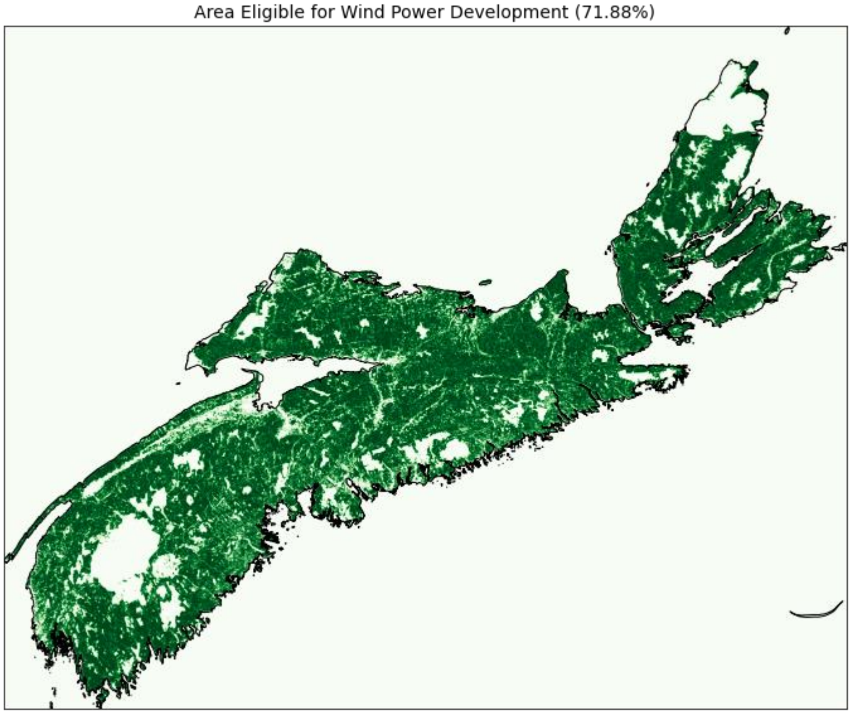

Figure 12: Area assumed eligible for wind power development.

Although its nice to have the land availability maps at such a high spatial resolution, we now aggregate it to the grid cell resolution to ensure consistency across data points.

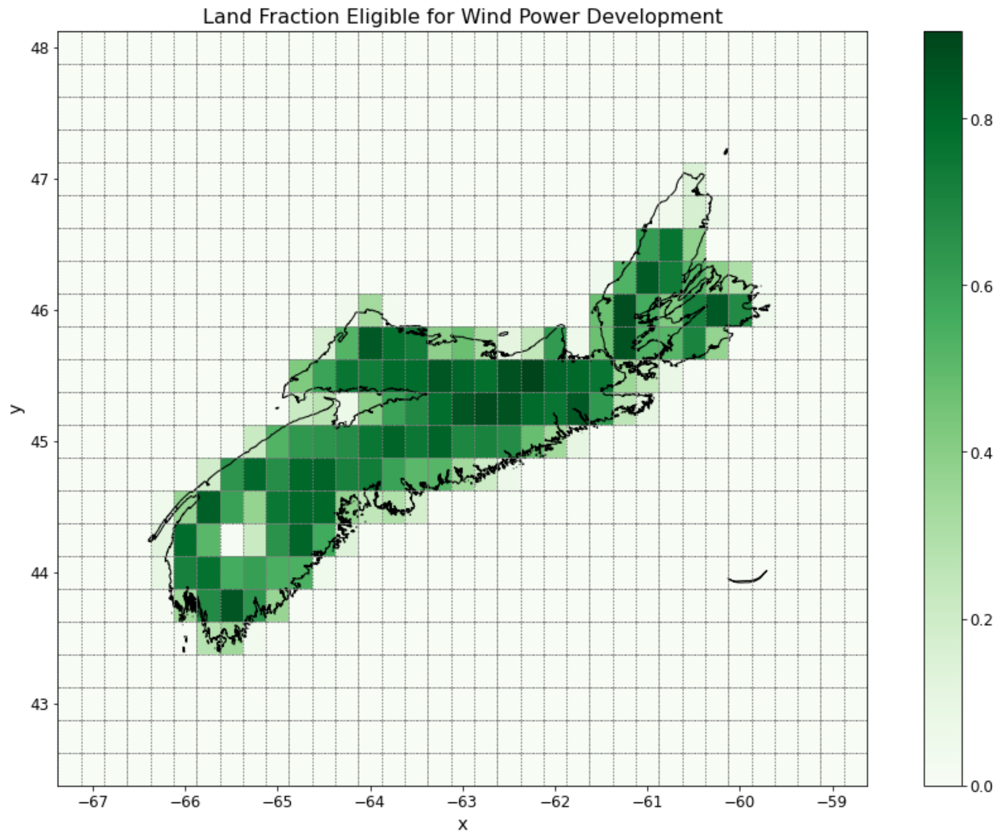

Figure 13: Land fraction assumed eligible for wind power development at the ERA5 grid cell level.

From there, the maximum wind resource potential in each grid cell is calculated by applying a wind power "land-area impact" factor. For the LAI factor, we use the median value of 368.3 km2/GW (equivalent to 2.715 MW/km2) provided in [Palmer-Wilson et al. (2019).](#)

Output Files

Two output files are generated from the presented methodology.

First, a csv file containing summary information for each grid cell is created, a sample of which is shown below.

y	x	lon	lat	Average Wind Speed at 110m (m/s)	NREL ATB Wind Class	Capacity Factor (2030)	Capacity Factor (2022)	Availability	Max Capacity (MW)	Technology Name
43.50	**-65.50**	-65.50	43.50	8.980038	2	0.540680	0.498731	0.340560	519.298556	E_WIND-ON-43.5-65.5
43.75	**-66.00**	-66.00	43.75	8.578149	3	0.505667	0.466598	0.337779	512.950013	E_WIND-ON-43.75-66.0
	-65.00	-65.00	43.75	8.158484	5	0.475430	0.438265	0.363170	551.508901	E_WIND-ON-43.75-65.0
44.50	**-66.00**	-66.00	44.50	8.734916	3	0.536219	0.494790	0.362209	543.206365	E_WIND-ON-44.5-66.0
44.75	**-65.50**	-65.50	44.75	8.197647	5	0.494743	0.456067	0.643853	961.495042	E_WIND-ON-44.75-65.5
45.00	**-62.00**	-62.00	45.00	8.254102	5	0.489483	0.451219	0.339140	504.287373	E_WIND-ON-45.0-62.0
45.25	**-61.50**	-61.50	45.25	8.402836	4	0.503354	0.464364	0.625803	926.528632	E_WIND-ON-45.25-61.5
45.50	**-61.25**	-61.25	45.50	8.431116	4	0.506791	0.467535	0.352261	519.267659	E_WIND-ON-45.5-61.25
45.75	**-60.75**	-60.75	45.75	8.237394	5	0.484319	0.446458	0.519146	761.912819	E_WIND-ON-45.75-60.75
	-60.50	-60.50	45.75	8.573614	3	0.514551	0.474795	0.706158	1036.375830	E_WIND-ON-45.75-60.5
	-60.25	-60.25	45.75	9.215148	1	0.564067	0.520932	0.371967	545.908881	E_WIND-ON-45.75-60.25

Figure 14: A sample of the summary csv output file.

Second, a csv file containing hourly normalized power values for each grid cell is created, a sample of which is shown below. Note that these values are using the NREL ATB 2030 reference turbine, and should therefore be scaled appropriately for years before and after 2030.

time	E_WIND-ON-43.5-66.0	E_WIND-ON-43.5-65.75	E_WIND-ON-43.5-65.5	E_WIND-ON-43.5-65.25	E_WIND-ON-43.75-66.25	E_WIND-ON-43.75-66.0	E_WIND-ON-43.75-65.75
2017-12-31 21:00:00	0.971500	0.971500	0.971500	0.971500	0.971500	0.971500	0.807151
2017-12-31 22:00:00	0.971500	0.971500	0.971500	0.971500	0.971500	0.971500	0.715708
2017-12-31 23:00:00	0.971500	0.971500	0.971500	0.893030	0.971500	0.971500	0.647920
2018-01-01 00:00:00	0.971500	0.971500	0.970615	0.839933	0.971500	0.971339	0.646630
2018-01-01 01:00:00	0.971500	0.971500	0.968290	0.857651	0.971500	0.927530	0.595925
...	...	...	...	...	...	...	...
2018-12-31 16:00:00	0.026875	0.020007	0.024129	0.028594	0.072250	0.030801	0.025105
2018-12-31 17:00:00	0.047803	0.030148	0.028804	0.035038	0.125182	0.060992	0.033255
2018-12-31 18:00:00	0.095707	0.050184	0.023887	0.000000	0.224559	0.099231	0.053502
2018-12-31 19:00:00	0.185101	0.125757	0.070807	0.038406	0.342564	0.196937	0.133662
2018-12-31 20:00:00	0.381371	0.268017	0.174034	0.129017	0.565313	0.340675	0.227026

8760 rows × 158 columns

Figure 15: A sample of the hourly normalized power output file.

Usage in the ACES Model

Each grid cell in the above formulation serves as a potential wind resource in the ACES Model. Model users can select which set of grid cells ought to be included in the model on a case-by-case basis, keeping in mind that increasing the number of wind resources increases the model size and therefore the time and memory requirements.

At present, we filter the wind resource regions by their *NREL Wind Resource Class* (i.e., resource strength) and their *Availability* (i.e., fraction of the grid cell that is eligible for wind development). The present filters are:

- Availability ≥ 0.3
- NREL Wind Resource Class ≤ 5

The application of these filters results in the 17 wind resource options summarized in Figure 14. Each of these resource options are represented by a distinct technology in the ACES Model and are defined by a number of other techno-economic parameters outlined the ACES Model documentation.