ACES Model Technical Documentation

February 2022

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1. Introduction

This document provides detailed technical information on the Atlantic Canada Energy System (ACES) Model and functional decisions that were made. Here, you will find information on the Wind and Solar Site Selection and Capacity Factors, Representative Day Selection, and the SQLite Databases. Please note that to avoid repetition, several other sources are linked in this document to point documentation from original sources that were used to create the ACES model. For more general explanation on The ACES Model Framework, Model Databases, and Running ACES, please refer to the ACES Model User Guide.

2. Wind Site Selection and Capacity Factors

2.1 Existing Onshore Wind

In each region, the existing wind fleet is represented as a single generation technology, "E_WIND-ON_EX". The process by which their capacity factors are derived is outlined below:

1. Using publicly available data, a list documenting the names, capacities and locations of each wind farm is compiled. Table 1 provides this data for Prince Edward Island as an example.

Table 1: A list of existing wind farms in Prince Edward Island.

Name	Capacity [MW]	Location
North Cape	10.6	47.04284906467128, -64.00031673028577
Aeolus	3	47.04284906467128, -64.00031673028577
Engie Norway	9	47.00761030321843, -64.0335692850232
Eastern Kings	30	46.437228364683385, -62.0857299653888
WEICan	10	47.05254074080945, -63.996914753373176
Hermanville-Clearsprings	30	46.463925254735386, -62.30468415938275
West Cape	99	46.72041534605856, -64.37684112996843
Summerside	12	46.432620802242006, -63.813843308491165

2. The hourly generation from each of these wind farms is generated using the renewables.ninja[1] tool. For each wind farm, the following inputs are used:

   a. **Lat:** The wind farm's latitude.

   b. **Lon:** The wind farms' longitude

   c. **Dataset:** MERRA-2 (global)

   d. **Year:** 2019

   e. **Capacity:** The wind farm's capacity.

   f. **Hub height:** 80m

[1] This is a commonly used tool in energy systems modelling. A webpage with its documentation and a list of selected publications using the tool available here.

g. **Turbine model:** Vestas V90 3000

3. The hourly generation from each wind farm is then summed and divided by the total capacity to achieve the existing wind fleet's hourly capacity factors. The resulting average annual capacity factors are summarized in Table 2.

Table 2: Average annual capacity factors for the existing wind fleet in each region.

Nova Scotia	New Brunswick	Prince Edward Island	Newfoundland
35.16%	24.84%	39.18%	36.43%

2.2 New Onshore Wind

Due to the relatively strong wind resource in Atlantic Canada, the model includes up to four land-based wind technologies in each region. Including multiple technologies allows the model to better represent the spatial variability of the resource within each province.

The wind resource sites for each region are selected using data from the Pan-Canadian Wind Integration Study (PCWIS). The study evaluated 4,984 potential wind sites across the country and analyzed four wind penetration scenarios. The ACES model includes every wind site that was selected in at least one of the PCWIS scenarios. This includes 13 sites in Nova Scotia, 11 sites in New Brunswick, 6 sites in Prince Edward Island and 8 sites in Newfoundland. Sites within close proximity to one another are grouped as single technology in the ACES model. The specific locations and the groupings of the wind sites are pictured in Figure 1 for NS, NB and PEI and Figure 2 for Newfoundland. Note, the PCIWS did not include any viable sites in Labrador.

The hourly capacity factors for each grouping are calculated as the average of the hourly capacity factors for each individual site. The hourly capacity factors for each individual site are calculated using the renewables.ninja tool, which uses as input the precise locations (as provided in the PCWIS) in addition to the following wind turbine assumptions:

- Hub height: 120 m
- Turbine model: GE 5.5 158

These parameters are selected because they best match the representative onshore wind technology used in the 2021 NREL Annual Technology Baseline (moderate case), which is what the ACES model uses for the wind technology technoeconomic data. Specifically, the NREL ATB's representative wind technology has a hub height of 120 m, a rotor diameter of 175 m and a turbine rating of 5.5 MW. The GE 5.5 158 turbine has a rotor diameter of 158 m and a rating of 5.5 MW. As a final step, a 7.85% loss to the capacity factors output by the renewables.ninja tool is applied. This follows the approach in the PCWIS and is intended to account for maintenance and electrical losses that occur onsite prior to transmission and distribution.

The resulting annual capacity factors for each wind technology within each region are summarized in Table 3.

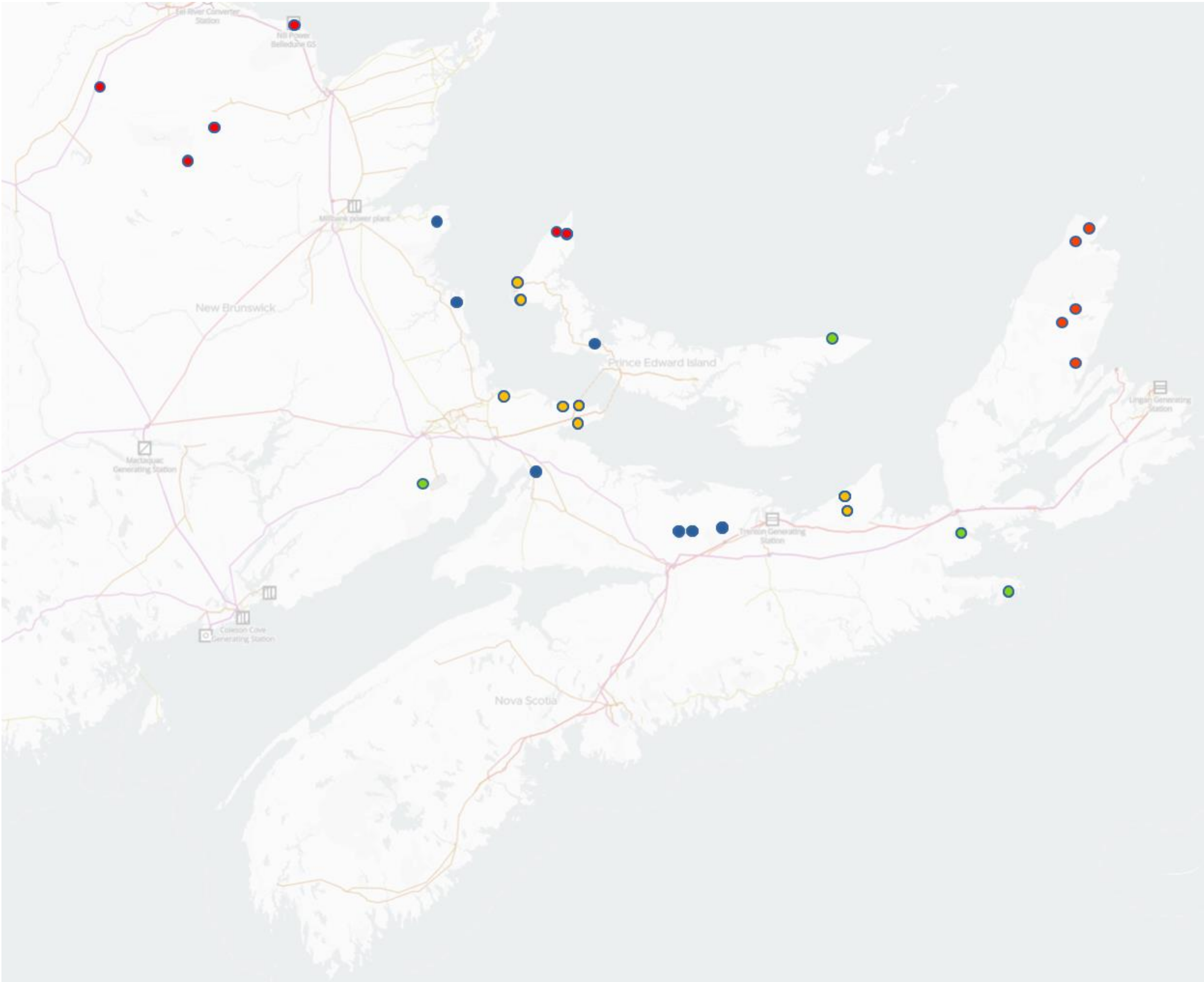

Figure 1: Map of the Maritimes indicating the locations and groupings of potential wind locations. The groupings are as follows: Red = E_WIND-ON-1, Green = E_WIND-ON-2, Blue = E_WIND-ON-3, Orange = E_WIND-ON-4

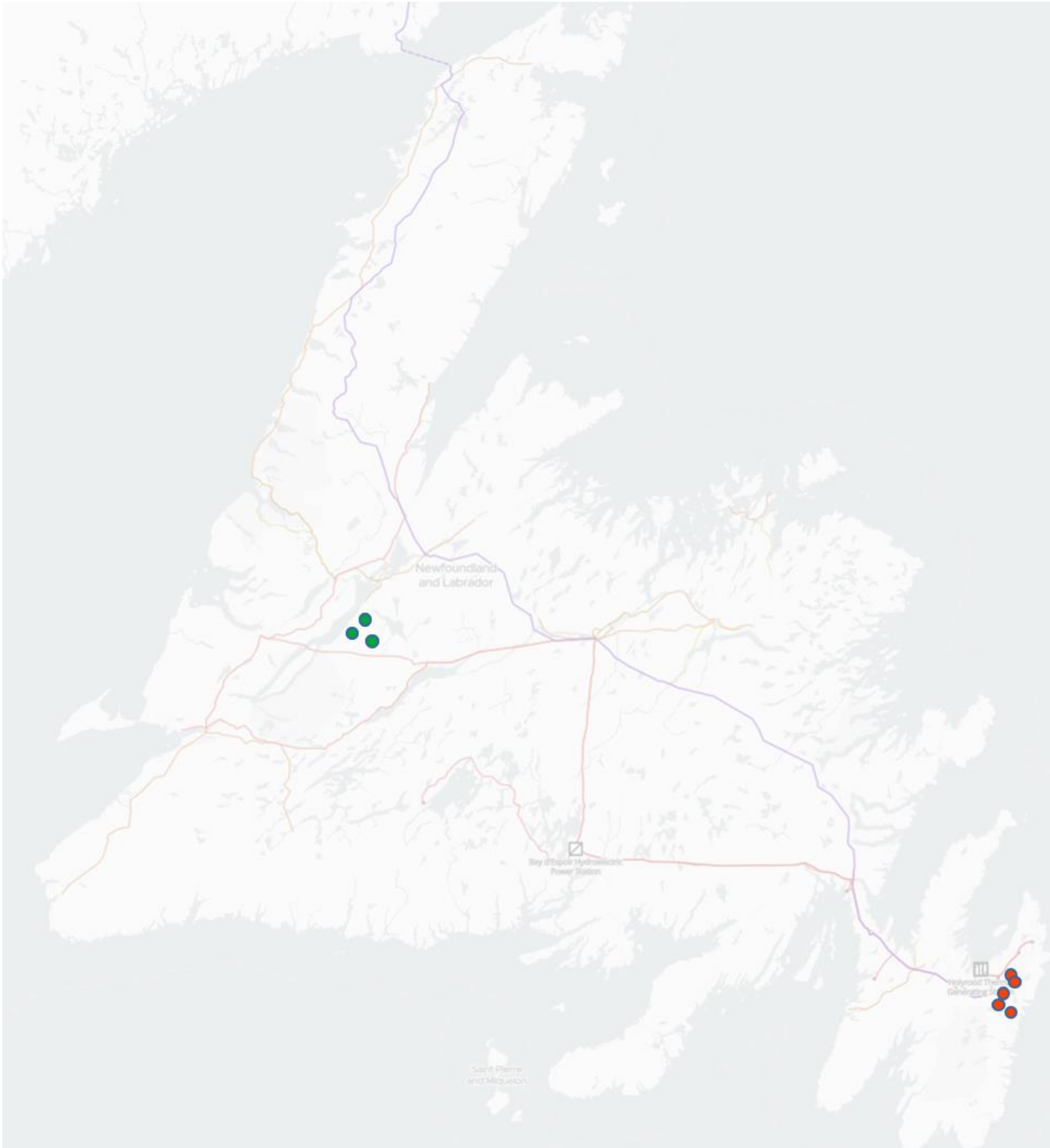

Figure 2: Map of the Newfoundland indicating the locations and groupings of potential wind locations. The groupings are as follows: Red = E_WIND-ON-1, Green = E_WIND-ON-2.

Table 3: Summary of the annual capacity factors for each onshore wind technology across all regions.

Region	E_WIND-ON-1	E_WIND-ON-2	E_WIND-ON-3	E_WIND-ON-4
Nova Scotia	55.2%	47.5%	41.2%	43.7%
New Brunswick	42.4%	39.8%	44.7%	41.6%
Prince Edward Island	53.9%	53.8%	48.6%	47.0%
Newfoundland	48.0%	43.6%	--	--

2.3 New Offshore Wind

The locations and resource availabilities for the fixed-bottom offshore wind technologies are based off a Geological Survey of Canada analysis. The specific locations are:

- Nova Scotia: Sable Island Bank (precise location shown in Figure 8 in linked report)
- New Brunswick: Baie des Chaleurs (precise location shown in Figure 6 in linked report)
- Prince Edward Island: Northumberland Straight (precise location shown in Figure 7 in linked report)
- Newfoundland: St. George's Bay (precise location shown in Figure 9 in linked report)

Similar to above the approach with onshore wind, the renewables.ninja tool is used to determine the hourly capacity factors for the offshore wind technologies at these sites. The turbine assumptions used are:

- Hub height: 150 m
- Turbine model: Vestas V162 9500

These parameters are selected because they best match the representative fixed-bottom offshore wind technology used in the 2021 NREL Annual Technology Baseline (moderate case), which is what the ACES model uses for the wind technology technoeconomic data. Calculated annual capacity factors are shown in Table 4.

3. Solar Site Selection and Capacity Factors

3.1 New Utility-Scale Solar

The utility-scale solar resource location within each province is determined by selecting the location with the highest solar radiation potential, as determined by a Natural Resources Canada database. These are:

- Centreville, Nova Scotia
- Belledune, New Brunswick
- Cape Egmont, Prince Edward Island
- South Brook, Newfoundland

The NREL PVWatts Calculator is used to derive the hourly capacity factors using the following technical assumptions:

- Module type: Standard
- Array type: 1-axis tracking
- System Losses: 14%

- Tilt (deg): equal to the latitude.
- Azimuth (deg): 180
- DC to AC size ratio: 1.34
- Inverter efficiency: 96%

These parameters are selected to match those of the representative utility-scale solar technology in the 2021 NREL Annual Technology Baseline, which is what the ACES model uses for technoeconomic assumptions. Calculated annual capacity factors are shown in Table 4.

3.3 New Residential Solar

The residential solar resource location for each region is assumed to be its most populated city:

- Halifax, Nova Scotia
- Moncton, New Brunswick
- Charlottetown, Prince Edward Island
- St. John's, Newfoundland

The NREL PVWatts Calculator is used to derive the hourly capacity factors using the following technical assumptions:

- Module type: Standard
- Array type: Fixed (roof mount)
- System Losses: 14%
- Tilt (deg): 45
- Azimuth (deg): 180
- DC to AC size ratio: 1.2
- Inverter efficiency: 96%

Calculated annual capacity factors are shown in Table 4.

Table 4: Summary of annual capacity factors for offshore wind, utility scale solar and residential scale solar for each region.

Region	Offshore Wind	Utility Scale Solar	Residential Solar
Nova Scotia	62.5%	16.4%	13.9%
New Brunswick	44.3%	18.0%	13.8%
Prince Edward Island	56.7%	17.8%	13.6%
Newfoundland	51.6%	14.3%	12.7%

net-zero atlantic

4. Representative Day Selection

Representative days are selected with an optimization approach based on the work outlined in Poncelet et al. (2016)[2]. The idea is that a given year can be effectively represented by a subset of its days that are weighted in terms of their relative frequency.

To determine which days are selected and their respective weights, the following approach is taken:

1. First, a metric by which we determine the 'representativeness' of a set of days must be defined. The most common approach found in literature is to use the comparison between the annual 'duration curves' of a set of loads and/or technologies with those of the weighted representative days. For instance, we may be interested in how well the representative days can approximate the load duration curve and the production duration curves of the wind and solar resources.

   We select the approximation error of the following curves to serve as the metric:

   1. Normalized load duration curve
   2. Normalized existing wind production duration curve
   3. Normalized new wind availability (i.e., capacity factor)

2. Each day of the year is then encoded into a vector; that is, the hourly load, existing wind production and new wind availability is encoded into a vector with length 3x24=72.

3. The problem of selecting the optimal set of representative days with their respective weights is then encoded into a combinatorial optimization problem. The problem is told to select K days (where K is a user input) with corresponding weights such that a) the weights sum to 365 and b) the root-mean-square error between the approximated duration curves and the annual duration curves is minimized.

The approach also enables the user to select a set of days that are forced to be included. For instance, the model user may wish to force the representative day selection algorithm to select as one of the representative days the day with the peak annual load. Alternatively, the user may wish to select three consecutive days with relatively high loads and low wind resource availability.

As an example, here is the annual (in black) and approximated (in red) duration curves for K=8.

[2] Poncelet, Kris, et al. "Selecting representative days for capturing the implications of integrating intermittent renewables in generation expansion planning problems." IEEE Transactions on Power Systems 32.3 (2016): 1936-1948.

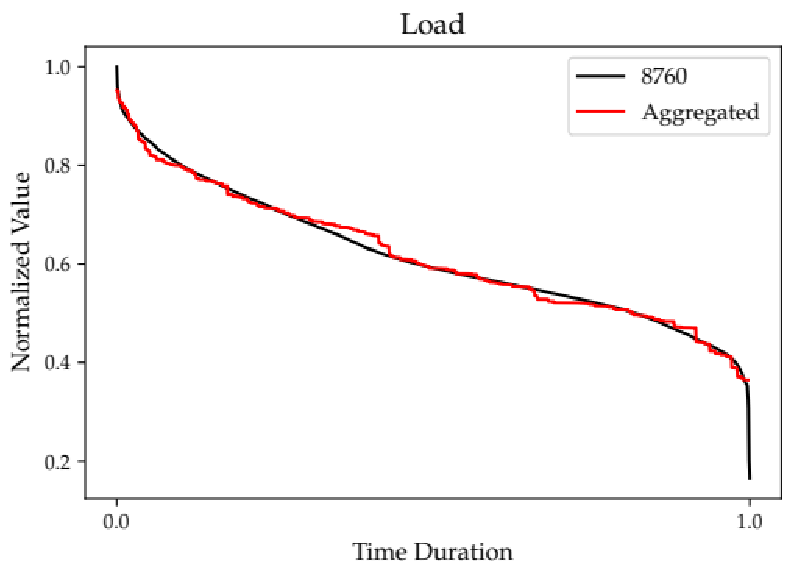

Figure 3: Measured and aggregated load duration curves.

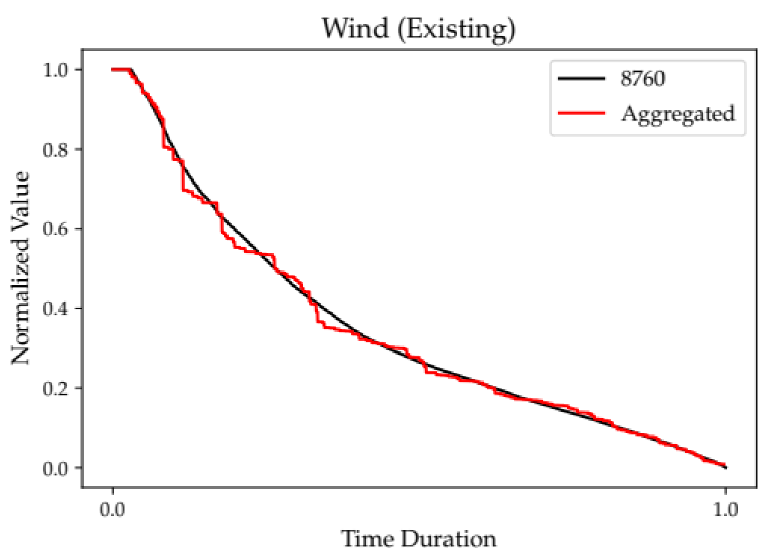

Figure 4: Measured and aggregated existing wind production duration curves.

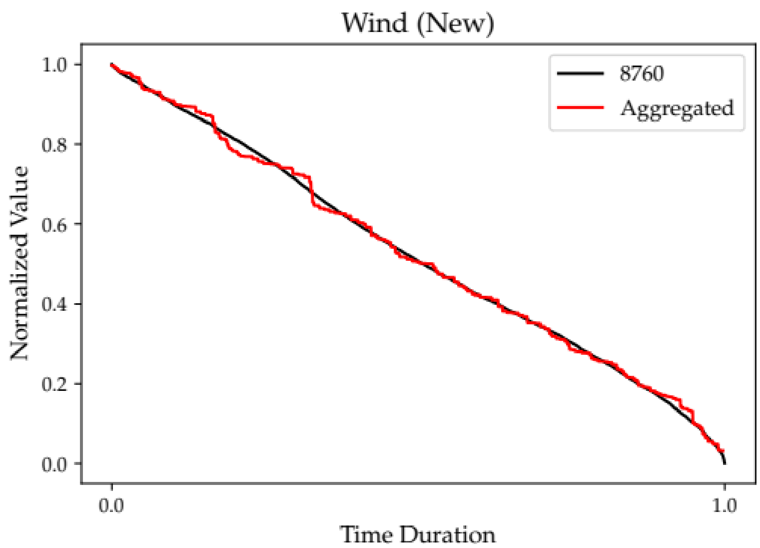

Figure 5: Measured and aggregated new wind production duration curves.

5. Overview of SQLite Tables

This section provides an overview of the input SQLite database tables. Detailed information for most of these tables is found via Temoa's official documentation. Tables marked with an asterisk (*****) are unique to the ACES model and are described in greater detail.

In general, tables that start with a capital letter (eg. CostInvest, EmissionLimit) are technology-specific parameters. Tables that start with a lowercase letter represent the sets across which the parameters are indexed (e.g., technologies, regions, years). Tables that start with "Output_" (eg. Output_Costs) are where Temoa prints model outputs, which are model variables that Temoa solves for. It is important to note that model users do not complete the output tables; once the model solves, these tables are automatically updated.

CapacityCredit

See Temoa's official documentation.

CapacityFactorProcess

See Temoa's official documentation.

CapacityFactorTech

See Temoa's official documentation.

CapacityToActivity

See Temoa's official documentation.

CostEmissions*

This parameter permits emissions pricing and is indexed over the following sets: regions, periods, and emission commodities. The units of this parameter should be in [cost units]/[emission units]. In the ACES model, our base dataset uses the units of M$/kt. This table is where a carbon tax would be implemented.

CostFixed

See Temoa's official documentation.

CostInvest

See Temoa's official documentation.

CostVariable

See Temoa's official documentation.

Demand

See Temoa's official documentation.

DemandSpecificDistribution

See Temoa's official documentation.

DiscountRate

See Temoa's official documentation.

Efficiency

See Temoa's official documentation.

EmissionActivity

See Temoa's official documentation.

EmissionLimit

See Temoa's official documentation.

EmploymentPerCapacity*

This parameter indicates the number of jobs per unit of capacity of a technology in all of the periods throughout its technical lifetime. Period and vintage information are included because technologies require varying amount and type of labour over their lifetime: from construction to annual maintenance to retirement.

ExistingCapacity

See Temoa's official documentation.

GlobalDiscountRate

See Temoa's official documentation.

GrowthRateMax

See Temoa's official documentation.

GrowthRateSeed

See Temoa's official documentation.

LifetimeLoanTech

See Temoa's official documentation.

LifetimeTech

See Temoa's official documentation.

LinkedTechs

See Temoa's official documentation.

MaxActivity

See Temoa's official documentation and information on constraints (equation 27).

MaxCapacity

See Temoa's official documentation and information on constraints (equation 30).

MaxSeasonalActivity*

This parameter is similar to the

MaxActivity parameter, however it stipulates the maximum activity that can occur during a single "season". Note, the ACES model uses the notion of representative days, so a "season" here refers to a day.

This constraint, for instance, is used to limit the amount of natural gas that the Maritimes and Northeast pipeline can import to New Brunswick and Nova Scotia in any given day to 0.481 PJ (or 440 million cubic feet per day).

MinActivity

See Temoa's official documentation and information on constraints (equation 28).

MinCapacity

See Temoa's official documentation and information on constraints (equation 31).

MinGenGroupTarget

See Temoa's official documentation and information on constraints (equation 29).

MinGenGroupWeight

See Temoa's official documentation and information on constraints (equation 29).

MinSeasonalActivity*

This parameter is similar to the MinActivity parameter, however it stipulates the minimum activity that can occur during a single "season". Note, the ACES model uses the notion of representative days, so a "season" here refers to a day.

This constraint, for instance, is used to impose minimum flow rates (via daily energy budgets) for certain hydroelectric facilities.

MyopicBaseyear
ACES model users can ignore this table.

Output_CapacityByPeriodAndTech
A calculated model output that lists the total capacity of each technology type in each model period.

Output_Costs
A model output listing all the costs incurred, both discounted and undiscounted. This includes investment costs, fixed costs, variable costs, and emissions costs.

Output_Curtailment
A model output equivalent to Temoa's V_Curtailment variable.

Output_Emissions
A model output tabulating the sources and quantity of all emissions.

Output_Employment*
A model output tabulating the number of jobs resulting from each technology type.

Output_ImplicitEmissionsPrice*
A model output that states the implicit emission price, or shadow price, of an associated EmissionLimit.

Output_Objective
The objective value of the model run, i.e., the total discounted system cost. This value is equal to all "discounted costs" printed in the Output_Costs table and accounts for investment costs, fixed costs, variable costs and emissions costs. Its precise formulation is available in Temoa's official documentation[3].

Output_VFlow_In
A model output tabulating the commodity flows into each technology in each model timestep.

Output_VFlow_Out
A model output tabulating the commodity flows into each technology in each model timestep.

Output_V_Capacity
A model output tabulating the total capacity of each technology in each period by vintage. A summarized version of this table is presented in Output_CapacityByPeriodAndTech.

PlanningReserveMargin
See Temoa's official documentation and information on constraints (equation 20).

RampDown
The fraction of a technology's capacity that it can decrease its power output by in one hour.

[3] The ACES model has slightly edited this formulation to include emission costs (which follow the same approach as variable costs).

RampUp
The fraction of a technology's capacity that it can increase its power output by in one hour.

SegFrac
See Temoa's official documentation.

StorageDuration
See Temoa's official documentation.

TechInputSplit
See Temoa's official documentation.

TechOutputSplit
See Temoa's official documentation.

commodities
An exhaustive list of all commodities used in the model.

commodity_labels
Labels by which commodities are categorized. It is advisable not to edit this table.

groups
A list of groups to which technologies in tech_groups can belong.

regions
A list of all regions in the model.

sector_labels
A list of all sectors in the model.

subsector_labels*
A list of all subsectors in the model.

tech_annual
A list of all technologies that produce constant annual output.

tech_curtailment
A list of all technologies whose output can be curtailed at no cost.

tech_exchange
A list of all technologies that facilitate commodity flows between regions (e.g. electricity transmission).

tech_groups
A list of all technologies that belong to a group.

tech_mga
ACES model users can ignore this table.

tech_ramping
A list of all technologies that are characterized by ramp rates.

tech_reserve
A list of all technologies that are characterized by a CapacityCredit.

technologies
An exhaustive list of all technologies.

technology_labels
Labels by which technologies are categorized. It is advisable not to edit this table.

time_of_day
The set of time steps that together constitute a day.

time_period_labels
Labels by which time_periods are categorized. It is advisable not to edit this table.

time_periods
A list of all periods (i.e., years) in the model.

time_season
A list of all representative days in the model.