



ACES Model User Guide: ACES Cloud

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1. Introduction

Energy system planning models allow users to analyse potential energy system transition pathways by making it possible to evaluate scenarios based on cost optimization. Such models can consider the impact of emissions and other key performance indicators and provide comprehensive, technology-specific descriptions of possible scenarios for an energy system transition. They can encompass inter-sectoral, inter-temporal and inter-regional relationships.

Net Zero Atlantic's Atlantic Canada Energy System (ACES) model seeks to be a valuable support tool for decision-makers in Atlantic Canada, characterizing all four Atlantic provinces and six greenhouse gas-emitting sectors: electricity, buildings, transportation, industry, agriculture, and waste. The high-resolution nature of ACES allows users to identify technological gaps in the system, cultivate development strategies and investment opportunities, and to anticipate sectoral growth to allow for a successful and beneficial transition to a low-carbon future.

This model, as well as the [Tools for Energy Model Optimization and Analysis \(Temoa\)](#) platform upon which it is built, is open-source. All aspects of the model are available for anyone to access and modify. This ensures model transparency and allows third parties to replicate model results and analyses. It also facilitates future model improvements and growth. The ACES model project has benefited from several other open-source energy system modelling endeavors, including [The Open Energy Outlook](#).

While ACES and Temoa are available as desktop models that can run entirely locally on your machine, our team worked with a software developer to create a cloud application that also allows users to easily run model scenarios on a server without using Python or computer coding. This document outlines [The ACES Model Framework](#), [The ACES Databases](#), and [Using the ACES Cloud Application](#). The [Technical Documentation](#) contains additional detailed technical information for ACES beyond the scope of this document. For instructions on running the desktop version of ACES, refer to the ACES Desktop version of the user guide. This version of the ACES Model and User Guide were publicly released in March 2022. Updates will be made over time – frequency to be determined.

2. The ACES Model Framework

The ACES model is made up of several software elements (Figure 2.1). The model architecture consists of 1) input files which contain the data for the energy system in question, 2) the modelling platform, Temoa, and 3) output files which present feasible model solutions.

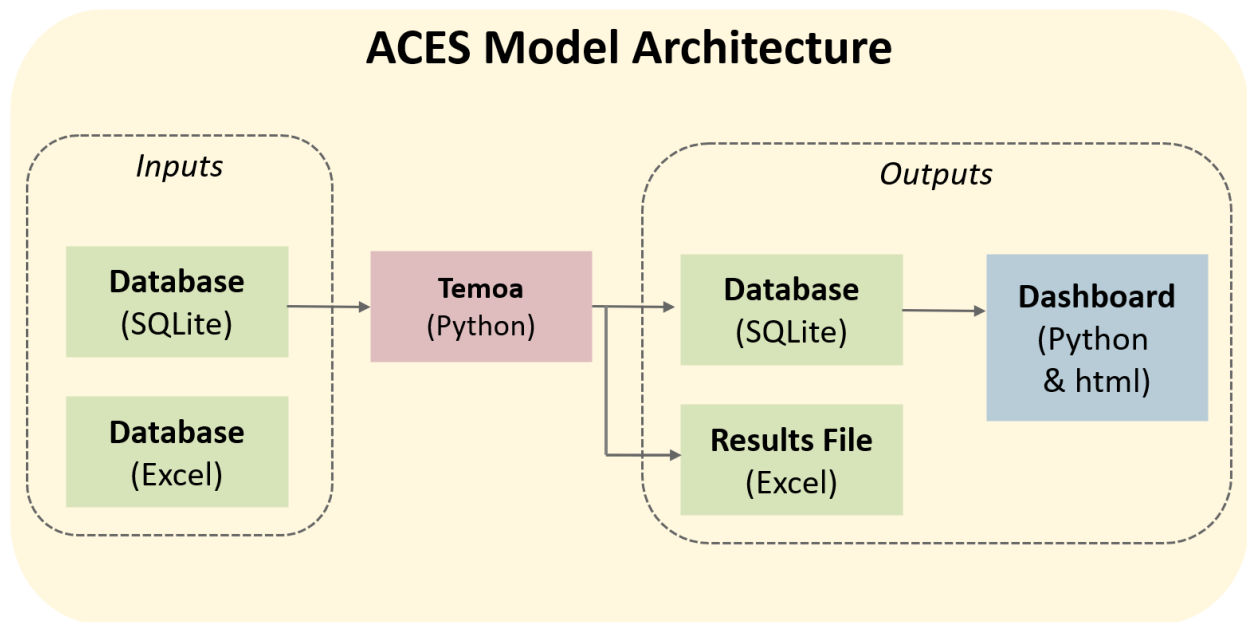


Figure 2.1: The ACES model architecture.

2.1 Inputs

The inputs contain all the data necessary to completely characterize the energy system in question. This includes information and assumptions around the existing energy system, new technology options, and demand forecasts. The input file is what determines, for instance:

- The number of regions and their respective boundaries,
- The time-horizon and temporal resolution,
- Which sectors are included, and how those sectors interact,
- Which technologies, both new and existing, are included,
- How each of these technologies are characterized, i.e., their:
 - Financial assumptions (capital costs, fixed costs, discount rates, etc.)
 - Emission activity
 - Operational lifetime
 - Operational constraints
- The demands for energy services and how they change over time, and
- System-wide and user-defined constraints (i.e., technical, resource, emission, or policy constraints).

The input databases contain a substantial volume of data. Temoa uses the [SQLite](#) relational database management system to house the various input data. The ACES model includes several input databases in SQLite format that represent the Atlantic Canada energy system with varying degrees of sectoral and temporal detail. The contents of these databases are covered in detail in [The ACES Databases](#) section of this document.

In addition to the SQLite databases, model inputs (e.g., data and assumptions) for the ACES model are documented in great detail in several Microsoft Excel workbooks. The workbooks include information around data sources, explicit unit conversions, and any other assumptions and/or calculations used to convert the input data.

It is important to note that:

- 1) The Excel workbooks and the SQLite databases are not linked, and
- 2) Temoa uses the SQLite file as the model inputs. Therefore, revisions, edits, or additions to the model inputs must be made to the SQLite files in order to be recognized by Temoa. The model user is free to reflect these edits in the Excel workbooks as well.

In the ACES Cloud folder you can download from the model website, you will find the SQLite databases and the data_documentation/ directory where the Excel workbooks are located.

2.2. Temoa

At the core of the ACES model framework is the [Temoa](#) software package. Temoa was developed by Dr. Joseph DeCarolis – the current Administrator of the Energy Information Administration in the United States – at North Carolina State University. Temoa is an open-source framework for conducting energy system analysis and serves as the general foundation upon which a specific energy system can be abstracted and reproduced. Through a network of linked processes, Temoa defines the ways in which technologies, commodities, end-use demands, and other energy system components interact (Figure 2.2)

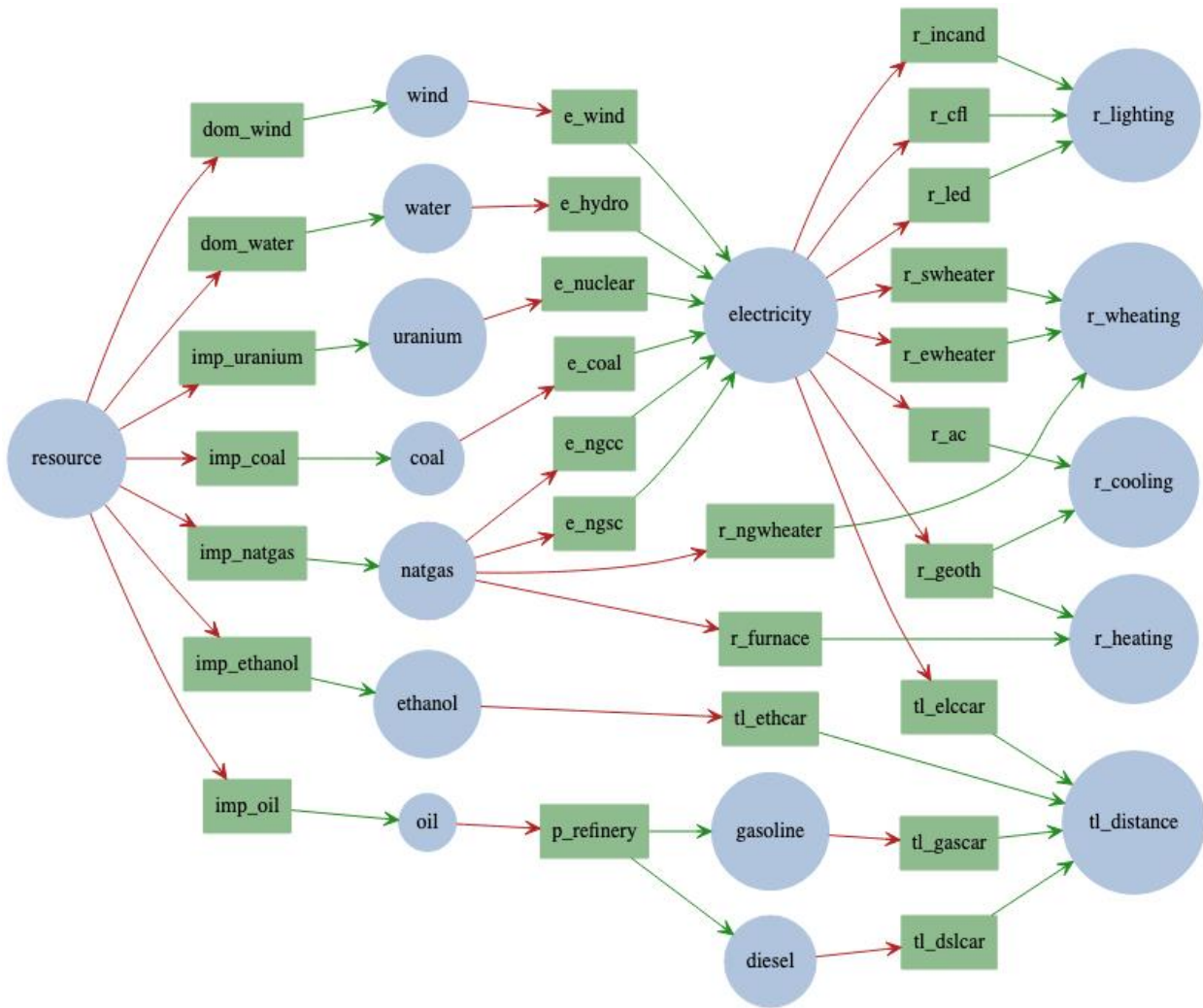


Figure 2.2: An energy system network diagram produced by Temoa for an example energy system. Technologies (green boxes) convert input commodities (blue circles) to output commodities that ultimately satisfy end-use demands. Image source: https://github.com/TemoaProject/teo/blob/master/OEO_Roadmap.md. Used with permission.

A process consists of a technology that converts one or several input commodities into one or several output commodities. Technologies are characterized by multiple parameters and constraints. For instance, in Figure 2.2, the coal power plant technology, “e_coal”, converts coal into electricity and is characterized in part by its capital cost, fixed cost, variable cost, discount rate, financial lifetime, operational lifetime, vintage, emissions per unit activity, efficiency, ramping limits and maximum allowable capacity (Table 2.1).

Table 2.1: Definitions of terms used to characterize technologies in Temoa and ACES (adapted from [Temoa Documentation](#)).

Technology-Specific Characterization	Name in Temoa	Definition
Capital Cost	CostInvest	The upfront investment cost.
Fixed Cost	CostFixed	Fixed operations and maintenance costs. These costs are proportional to the installed capacity of the technology.
Variable Cost	CostVariable	Variable operations and maintenance costs. These costs are proportional to the activity/output of the technology.
Discount Rate	DiscountRate	The technology-specific interest rate on investment. This is analogous to the weighted average cost of capital (WACC).
Financial Lifetime	LifetimeLoanTech	The number of years over which the capital cost is amortized.
Operational Lifetime	LifetimeTech	The total useful lifetime of the technology.
Emission Activity	EmissionActivity	The emissions produced by the technology per unit of activity. This parameter can be defined for multiple emission commodities, e.g., CO ₂ , CH ₄ , etc.
Efficiency	Efficiency	The fraction of the technology's useful output per unit of input.
Capacity Factor	CapacityFactorTech	The fraction of the technology's output over its capacity indexed over each time step. This parameter is used in place of efficiency for technologies whose output is variable and resource dependent, e.g. solar power.
Input Split	TechInputSplit	The relative proportions of the technology's fuel inputs, if applicable. For instance, this parameter could be used to stipulate the relative proportion of hydrogen and natural gas inputs to an industrial application. Not applicable for technologies with one input commodity.
Output Split	TechOutputSplit	The relative proportions of the technology's outputs, if applicable. For instance, this parameter could be used to prescribe the output shares of an oil refinery with multiple outputs, e.g., diesel and kerosene. Not applicable for technologies with one output commodity.
Existing Capacity	ExistingCapacity	The given technology's capacity prior to the first model year. This parameter is used to characterize the existing energy system.
Growth Rate	GrowthRateMax	The rate at which the technology's capacity can increase year-over-year. This can be used in conjunction with a "Growth Rate Seed" parameter that stipulates the initial capacity from which the increases begin in the

		event that the technology in question has zero existing capacity.
Minimum and Maximum Capacity	MinCapacity; MaxCapacity	The upper and lower limit of allowable installed capacity for a given technology in a given year.
Minimum and Maximum Annual Activity	MinActivity; MaxActivity	The upper and lower limit of allowable output/activity for a given technology in a given year.
Minimum and Maximum Daily Activity	MinSeasonalActivity; MaxSeasonalActivity	The upper and lower limit of allowable output/activity for a given technology in a given day. This is used, for instance, to limit the daily throughput of hydro facilities or natural gas pipelines.
Ramping Limits	RampDown; RampUp	The rate at which the technology's activity can increase from one timestep to the next.
Capacity to Activity	CapacityToActivity	The parameter converting capacity units to activity units. Intuitively, this can be thought of as the maximum amount of activity one unit of capacity can produce over one year.
Capacity Credit	CapacityCredit	The share of the technology's nameplate capacity that is considered to be firm. This is used to satisfy the system-level reserve margin constraint.

Temoa determines the optimal investments in new technologies and operational decisions for both new and existing technologies over a user-defined time horizon. These decisions are driven by the objective of minimizing the total discounted system cost while satisfying a set of constraints. These constraints include default system-level constraints, such as conservation of energy, in addition to user-defined constraints, such as emission limits.

Table 2.2 Descriptions of constraints that can be applied in ACES (adapted from [Temoa Documentation](#)).

Constraint	Definition
Demand Constraint	This constraint ensures each end-use demand, e.g., residential space heating, is satisfied in each time step.
Conservation of Energy	This represents a number of constraints throughout the system that ensure energy is not created nor destroyed – only converted from one form to another.
Demand Activity Constraint	<p>For end-use demands that can be met by several technologies, this constraint ensures the relative contribution by each technology is fixed for all time steps in a given year.</p> <p>Consider the case of residential space heating where the demand can be met by two technologies: propane furnaces and baseboard heaters. This constraint ensures that for each time step, each technology is responsible for meeting the same share of the heating demand. In the absence of this constraint, the model would dispatch heat pumps when electricity is cheap (e.g. periods of low electricity</p>

	demand and high wind speeds) and furnaces when electricity is expensive (e.g., periods of high demand and low wind speeds).
Storage Constraints	There are a number of constraints that together ensure energy storage technologies are properly constrained. The technicalities are beyond the scope of this document. Interested readers may refer to the Temoa documentation .
Reserve Margin Constraint	This constraint applies to the electricity sector and requires there be sufficient firm capacity in place to ensure system reliability.
Emission Limits	The upper limit for a given emission commodity indexed by region and year.
Minimum and Maximum Group Activity Constraints	Similar to the Minimum and Maximum Activity parameter, however this is defined for groups of technologies.

Temoa is flexible in terms of the energy systems it can represent. It can be used to characterize one or all the individual energy sectors, allows for user-defined spatial and temporal resolution, and has no limit in the number of technologies it can include. Additionally, Temoa provides a user-friendly system to implement and analyse an array of user-defined scenarios. To create scenarios, users can implement changes to one or several techno-economic (e.g. technology cost and efficiencies), macro-economic (e.g. anticipated end-use demands), or policy-driven parameters (e.g. cost of emissions or emissions limit) in the model.

More detailed information on Temoa is always available through Temoa's [official documentation](#).

The model code (i.e., Temoa) is conceptually distinct from the model input data. The model code, which is located within the `temoa_model/` directory, defines the energy system model in an abstract algebraic sense. It is the input databases that contain all the information that characterize the physical energy system in question.

2.3 Outputs and Visualizations

Once a particular input database is solved by Temoa, the model results are printed to an SQLite database and to a dedicated Excel workbook. These can be downloaded from the ACES Cloud application onto your device.

Model users can also create bespoke data visualizations of the model outputs. The ACES Cloud allows you to generate network diagrams of the energy system per region and time-period, as well as capacity, output flow, and emissions plots of your scenario.

3. The ACES Databases

Several databases are included in the ACES model that are distinguishable based on sectoral scope, meaning the amount energy sectors that are included in that database. These pre-existing databases are:

1. ACES-7D-6S.sqlite
2. ACES-7D-3S.sqlite
3. ACES-7D-1S.sqlite
4. ACES-Testing.sqlite

The 7D indicates seven representative days are used. A discussion of representative days and temporal resolution can be found in Section 3.2. The number preceding the “S” in the file names is the number of included energy sectors in the database (Table 3.1). This allows modellers to choose the sectoral scope that is most appropriate for the modelling exercise at hand. For example, if a modeller is only interested in the electricity sector, then running the ACES-7D-1S database may be the most appropriate. In general, adding sectors increases the time for the mode to solve.

Table 3.1: The sectors included in each ACES database.

Number of Sectors	Included Sectors
1	Electricity
3	Electricity, Transportation, Buildings
6	Electricity, Transportation, Buildings, Industry, Agriculture, Waste

These databases represent the entire Atlantic Canada region. There are also four provincial databases that only consider the province in question. These are outlined in [APPENDIX A](#).

The ACES-Testing.sqlite database is a simplified version of the electricity database with reduced resolution, allowing for relatively quick solve times. The resulting reduced complexity of this database makes it unsuitable for thorough analysis of the Atlantic Canada energy system, but useful for performing test runs of the model and prototyping, as seen in [Running ACES Cloud](#).

Additional versions of testing and bespoke databases with your desired scope are available upon request.

3.1 Spatial Representation

Determining the spatial representation of an energy system model is critical. The representation must reflect the availability and granularity of any input data and will 1) determine which questions the model is apt to answer and 2) the computational size of the model and therefore the time and computer memory required for it to be solved.

The ACES model represents Atlantic Canada as five distinct regions:

1. New Brunswick (NB)
2. Nova Scotia (NS)
3. Prince Edward Island (PEI)
4. Newfoundland (NL)
5. Labrador (LAB)

The five regions are included in all ACES databases. Using provinces as the model regions is a natural choice. Most relevant data sources are tabulated by province and the bulk of energy-related policies are made in provincial legislatures. Despite this, Newfoundland and Labrador are modelled as separate and

distinct regions since their electricity systems are asynchronous and, in modelling the dynamics of their electricity interconnection, the Labrador Island Link is of relative importance¹.

To reduce the computational burden of the ACES model, simplifications are made to the Labrador region where appropriate. These simplifications include a relatively limited technology portfolio available to the region. For instance, several electricity generation technologies, including nuclear, are not available to Labrador. These limitations are documented in the data documentation Excel workbooks.

The five regions are interconnected by existing electricity transmission lines, which can be supplemented by new transmission capacity (with the exception of the Labrador Island Link) if deemed cost-optimal for the region's energy system by the model. Each region is modelled as a single node. Spatial dynamics and constraints within a single region (e.g., Nova Scotia) are not considered, with the following exceptions:

1. Intra-regional electricity transmission and distribution is approximated by applying an efficiency loss and a variable cost to electricity transmitted within a region².
2. The wind resource of each region is subdivided into several resource groups. These resource groups are based off the data presented in the [Pan-Canadian Wind Integration Study](#) and are further described in the 3.3 Electricity **Sector**.

The ACES model assumes that Newfoundland operates in the same time zone as all other regions. Further, it includes a simplified representation of Quebec and Maine to allow electricity exports and imports to and from these regions via New Brunswick and Labrador. More on this in [Interconnections](#).

3.2 Temporal Representation

The model's temporal representation is a key dimension which partially determines the model's relative accuracy and computational burden. The modeller must make three decisions in relation to the model's temporal representation:

1. What is the model's time-horizon?
2. Which years within the model's time-horizon are to be explicitly modelled?
3. How should each of these years be disaggregated into several time slices?

The ACES model uses a time-horizon of 2020-2050, which allows for an analysis of what is required to transition today's energy system to one that is characterized by net-zero GHG emissions by 2050. Within this time-horizon, every fifth year is explicitly modeled, i.e. {2020, 2025, 2030, ..., 2050}. Using this approach, Temoa makes a simplifying assumption that the dynamics occurring in each of these years is repeated five times to ensure model outputs, such as costs, are sensible³. The ACES-Testing database has been simplified to only model 2020, 2030, 2040, and 2050 time periods.

¹ The provincial database for Newfoundland and Labrador, "ACES-7D-6S-NLLAB.sqlite", also represents the two regions separately.

² For more information, please refer to the "E_TRANS-DIST" technology in the input databases or electricity sector Excel workbook.

³ More information on Temoa's temporal structure is available within its [official documentation](#).

The choice of sub-year temporal resolution is influenced by dynamics within the electricity sector. Hourly dynamics such as peak electricity demands and the variability of wind and solar resources determine the system's optimal operational decisions, which in turn inform the portfolio of cost-optimal capital investments. On this basis, including hourly resolution for the entire year would be preferable. This approach, however, results in model sizes that are far too large for most computers to solve⁴.

To manage the tradeoff between level of temporal resolution and computational complexity, the ACES model uses a system of weighted representative days that together constitute a full year. In all of the databases, seven days characterized at hourly resolution are included in the model and each of those seven days is assigned a weighting factor (except for ACES-Testing, where only three days are included for reduced computational complexity). Intuitively, the weighting factor represents how frequently that day occurs in a given year. The days and their assigned weights are selected in a fashion that best approximates the variability and average values of the system's electricity demand, wind resource and solar resource and follows the methodology outlined in [Kris Poncelet's 2018 study](#). Further detail on how this is implemented in the model can be found in the [Technical Documentation](#). Using representative days is a common approach taken in long term energy system models – see, for instance, the [Net-Zero America Project](#) or the [Open Energy Outlook](#).

Although using a representative days approach enables accurate modelling of intra-day dynamics – e.g., thermal generator ramp rates of intra-day battery storage – it does a poor job of modelling inter-day dynamics, e.g., seasonal energy storage. This is because Temoa assumes that the representative days occur in a block sequence, meaning that each representative day is repeated consecutively (with the number of times being repeated dictated by its weighting factor). A description of this phenomenon is presented in [Kotzur et al., 2018](#).

The temporal representation, much like all other model inputs, is completely flexible and users can make adjustments as they see fit. Interested readers can visit [Temoa's official documentation](#) to see how the temporal resolution is formally structured within the input database and Temoa codebase.

3.3 Electricity Sector

The electricity sector for each region includes a representation of end-use demands, new and existing generation and storage technologies as well as the transmission technologies that link neighbouring regions. Note that the inclusion or exclusion of certain technologies is not a statement of our support or lack thereof, but rather an outcome of data quality and availability.

3.3.1 Demands

Temoa represents end-use demands using two parameters: the “Demand” parameter establishes total annual demand and the “DemandSpecificDistribution” parameter establishes how the demand is distributed throughout the year, i.e., the demand profile⁵. Defining the electricity demand depends on which sectors are included in the model.

⁴ On the order of several hundred GB of RAM.

⁵ Please refer to Temoa's official documentation for more information on the “Demand” and “DemandSpecificDistribution” parameters.

For the database containing only the electricity sector, i.e., ACES-7D-1S.sqlite, the demand for electricity is exogenously defined and contains assumptions around electrification, energy efficiency, and demand side management. Creating load forecasts is thus a complex task. Fortunately, electric utilities provide load forecasts as part of their integrated resource planning. The ACES model uses these publicly available load forecasts to define the “Demand” parameter in each region out to 2050.

The publicly available load forecasts do not, however, provide hourly demand data from which the “DemandSpecificDistribution” parameters can be deduced. Consequently, the ACES model uses historical hourly electricity demand data to determine the demand profiles for each region. The model assumes no change in the demand profiles over time – that is, the demand profiles in year 2050 are assumed to be identical to those in 2020.

As more sectors are included in the model, the approach with which electricity demand is modelled must be revamped. This is because all of the explicit assumptions around technology adoption in the load forecasts published by the electric utilities are endogenized by the ACES model. In other words, the ACES model itself determines the adoption levels of technologies based on a multitude of factors. In this sense, the “electricity demand” is replaced with the residual electricity demand from all sectors not explicitly included in the model.

In general, the following approach is used to calculate the residual electricity demand in a given region for a multi-sector model:

1. Determine the total electricity demand for the year 2020.
2. Determine the actual electricity consumed in each of the modelled sectors in 2020.
3. Subtract 2 from 1 to determine the residual electricity demand in 2020 – i.e., the electricity demand from all sectors not explicitly included in the model.
4. Calculate the “Demand” and “DemandSpecificDistribution” parameters from the residual demand.

It is worth noting that although the included sectors do not include an explicit electricity demand, they still consume electricity to meet their end-use demands, such as residential space heating. The sector-specific end-use demands are outlined in detail in their respective sections.

3.3.2 Interconnections

Existing inter-regional electricity interconnections are included in the model: 560 MW of transmission capacity between New Brunswick and Prince Edward Island; 350 MW between New Brunswick and Nova Scotia; 500 MW between Nova Scotia and Newfoundland⁶; and 900 MW between Newfoundland and Labrador. The model is given the option of purchasing additional transmission capacity along these corridors.

Electricity trade with export markets is available between New Brunswick and Quebec, New Brunswick and Maine, and Labrador and Quebec. Accurately modelling such trade is challenging in energy systems

⁶ This assumes that all 500MW of the Maritime Link are fully operational in 2020. While this does not reflect the exact timeline, we chose to include it in this time-period because otherwise it could not be included until the subsequent 2025 time-period, and it is set to be fully operational prior 2025.

models when export markets are not included as explicit regions. As this is the case with Quebec and Maine in the ACES model, some simplifying assumptions were made. Trade between New Brunswick and its export markets is exogenously set using [historical data](#) – i.e., the amount and price of electricity traded in future years is determined by the amount and price of electricity traded in past years, informing the capacity factor. Due to the absence of historical data for trade between Labrador and Quebec, Labrador is free to trade electricity with Quebec at exogenously defined prices.

New Brunswick and Nova Scotia have a firm supply of natural gas via the Maritimes and Northeast pipeline. Both regions can import up to 440 million cubic feet (0.481 PJ) of natural gas per day. This limit is enforced using the “MaxSeasonalActivity” constraint. The remaining regions do not have a firm supply of natural gas and as a result, natural gas is not used as an energy vector in those regions.

3.3.3 Existing Generation

The ACES model includes existing electricity generation capacity. The details of the existing generation fleet are provided in the database documentation and are summarized here.

Nova Scotia: The existing fleet of thermal generators are modelled as separate technologies in order to capture their specific techno-economic parameters. The mapping of existing generators to their database name, e.g., the Lingan Generating Station-> “E_COAL-BIT_EX-1”, in addition to all relevant parameters can be found in the database documentation. The parameters characterizing electricity technologies include the existing nameplate capacity, retirement dates⁷, efficiency, emission activity, fuel type and fixed and variable costs. The ACES databases assume that all coal-fired power plants retire by 2030, which is in line with the federal governments coal phaseout.

The existing wind fleet is represented as a single technology in the ACES model (“E_WIND-ON_EX”). Temoa does include technology vintaging, however, whereby pre-existing technology vintages are distinguished by time-period. For instance, by inspecting the “ExistingCapacity” table in the SQLite input database, you will notice that there is 33.85 MW of wind built in 2005, 386.1 MW built in 2010, 36 MW built in 2012 and a further 140 MW built in 2015. Unlike thermal generators whose output is governed by their efficiency, wind generation is governed by capacity factors. Each wind technology is assigned hourly capacity factors, which are values between 0 and 1.0 and represent its power output as a fraction of its installed capacity. The ACES model uses the [Renewables.ninja](#) tool⁸ to derive hourly capacity factors for wind generation. The hourly values are scaled to ensure the wind fleet’s annual capacity factor is consistent with historically reported data from Nova Scotia Power (35.2%). A detailed overview of how capacity factors for wind technologies are derived is included in the [Technical Documentation](#).

Nova Scotia’s existing hydroelectric system is represented as two distinct technologies, which follows the modelling approach taken in Nova Scotia Power’s 2020 Integrated Resource Plan⁹. The 212 MW Wreck

⁷ Temoa does not include a retirement data parameter. Instead, the retirement date is determined by taking a technology’s vintage and specifying its technical lifetime. See Temoa’s [official documentation](#) for more information.

⁸ This is a commonly used tool in energy systems modelling. A webpage with its documentation and a list of selected publications using the tool is [available here](#).

⁹ The details can be found in section 2.2.2 of [this document](#).

Cove hydroelectric system is modelled as a *dispatch-limited* facility (“E_HYDRO-LIMDSP_EX” in the ACES database) in that its operation is constrained by seasonal hydrodynamics which enforce daily energy budgets (Table 3). Daily energy budgets follow seasonal electricity production profiles and are implemented in the ACES model by setting the “MaxSeasonalActivity” and “MinSeasonalActivity” constraints to the same value. More information on these constraints can be found on page 252 of [Nova Scotia Power’s Integrated Resource Plan](#).

Table 3.2: Operational constraints for the Wreck Cove Hydroelectric System.

Facility	Capacity	Month	Daily Energy Budget
Wreck Cove (“E_HYDRO-LIMDSP_EX”)	212 MW	[December – March]	1,100 MWh/day
		[April - May]	800 MWh/day
		[June]	500 MWh/day
		[July – November]	800 MWh/day

The remainder of the province’s hydroelectric system (162 MW) is assumed to be from entirely dispatchable reservoirs (so long as an annual energy budget is respected) as the individual assets are assumed to have sufficient pondage to reliably meet an event of any duration, according to page 252 of [Nova Scotia Power’s Integrated Resource Plan](#).

New Brunswick: The existing fleet of thermal generators are modelled as separate technologies to capture their specific techno-economic parameters. Detailed information, including each generator’s techno-economic parameters, are provided in the database documentation. The ACES model assumes that all coal-fired power plants retire by 2030, which is in line with the federal government’s coal phaseout. The Point Lepreau nuclear generating station is assumed to retire in 2040 and is not given the option for refurbishment, although implementing refurbishment decisions is possible in the Temoa framework.

New Brunswick has 329 MW of existing wind generation capacity with an annual capacity factor of 24.9%. Hourly capacity factors are calculated using the same approach outlined for Nova Scotia.

New Brunswick’s existing hydroelectric system (913 MW) consists of the 668 MW Mactaquac Generating Station and several other smaller generating stations. Over 90% of the hydroelectric capacity is along the Saint John River and is characterized by limited operational flexibility. The ACES model represents the system as a single limited-dispatch technology (encompassing both the Mactaquac Generating Station and several other smaller generating stations) characterized by daily energy budgets derived from [historical generation data](#) (Table). The standardised seven representative days in the existing database do not reflect all 12 months, but these days can be changed by users to reference the energy budgets if desired.

Table 3.3: Daily energy budgets by month for hydroelectric generation in New Brunswick (GWh).

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
7.05	5.99	7.19	14.79	14.66	9.19	6.26	5.21	4.81	6.48	9.41	8.59

Prince Edward Island: Most electricity consumed in PEI is imported from New Brunswick. PEI has 204 MW of wind capacity that, at an average capacity factor of 39.2%, accounts for well over 95% of its on-island generation. Hourly capacity factors are calculated using the same approach outlined for Nova Scotia. On-island firm capacity is provided by a total of 104 MW of diesel combustion turbines which the ACES model groups as a single technology.

Newfoundland: Newfoundland’s generation capacity is primarily hydro (Table 3.). The bulk of its hydro assets have large reservoirs enabling operational flexibility. The ACES model groups these facilities together into a single 1,204 MW hydro asset. Due to their flexibility, the only operational constraint placed on the asset is an annual energy budget of 6.04 TWh, equalling the fleet’s average annual generation¹⁰. This constraint is implemented by setting the “MaxActivity” and “MinActivity” constraints for this technology equal to 6.04 TWh.

Table 3.4: Newfoundland’s hydroelectric generators¹¹. Reservoirs are considered entirely dispatchable.

Facility Name	Capacity	Facility Type	Average Annual Generation (GWh)
Bay d’Espoir	613.4	Reservoir	2650
Deer Lake	129	Reservoir	678
Cat Arm	137	Reservoir	755
Upper Salmon	84	Reservoir	556
Hinds Lake	75	Reservoir	354
Granite Canal	40	Reservoir	246
Star Lake	18	Reservoir	141
Exploits	95.6	Reservoir	615
Paradise River	8	Dispatch-Limited	35
Rattle Brook	4	Dispatch-Limited	15

The ACES model also includes the region’s 275 MW of gas turbines and 54 MW of wind capacity. The model *does not* include the 490 MW Holyrood thermal generating station as it is slated for decommission in 2021.

Labrador: Labrador is home to two large hydroelectric facilities: the 5,428 MW Churchill Falls generating station and the 824 MW Muskrat Falls generating station.

Electricity generated from Churchill Falls is provided to the Newfoundland and Labrador electricity systems through two existing power purchase agreements. The “TwinCo Block” provides a firm 225 MW block of power and energy, capable of supplying 1,971 GWh per year. The “Recapture Energy” contract supplies 300 MW of capacity and 2,352 GWh of energy per year. Although the two contracts expire in 2041, the model assumes they extend beyond 2050.

¹⁰ This is consistent with the information outlined Section 4.2.2.2 of [this analysis](#).

¹¹ Data taken from

<http://www.pub.nf.ca/applications/NLH2018ReliabilityAdequacy/application/From%20NLH%20%20-%20Reliability%20and%20Resource%20Adequacy%20Study%20-%20November%202018%20-%202018-11-16.PDF>

Churchill Falls is modelled as a 525 MW run-of-river hydro facility due to the nature of the Recall Energy and TwinCo contracts. It is therefore not dispatchable and its hourly generation is set to 495 MW via Temoa’s “Capacity Factor” parameter (this assumes a 100% utilization factor of the TwinCo block and 90% utilization factor of the Recall Energy block).

Muskrat Falls is modelled as an 824 MW limited dispatch hydroelectric facility. Monthly generation data are taken from Figure 3.1 to determine its average daily energy budgets.

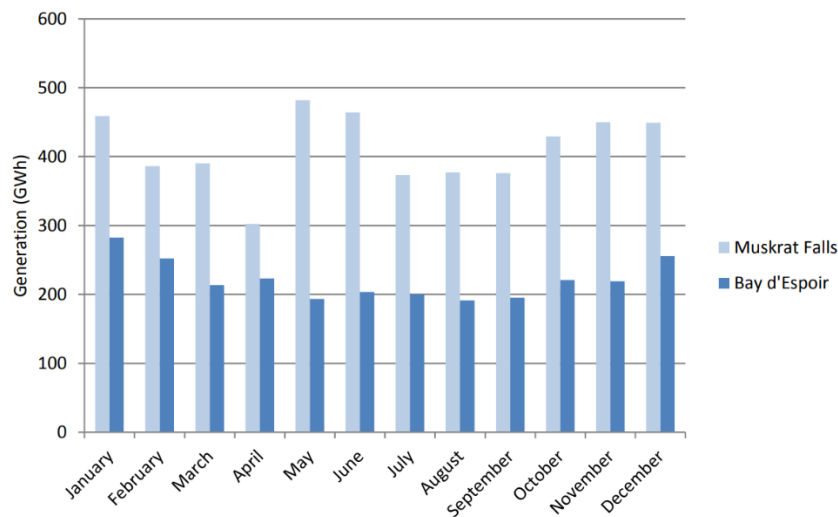


Figure 3.1: Muskrat Falls and Bay d'Espoir monthly generation data, taken from this [Newfoundland Hydro report](#).

The ACES model does not include a representation of the many small communities in Labrador that are not connected to the region’s high voltage electricity grid. This limitation is the result of the computational complexity that including each additional off-grid community would add to the model. Additional work, and perhaps a different modelling framework, is needed to better capture dynamics within small off-grid communities in Labrador.

3.3.4 New Generation Options

Each region can build new generation to replace retiring capacity and meet its future electricity demand (Table 3.5). Thermal generators available to the model include natural gas combined cycle plants, natural gas combined cycle plants with carbon capture and sequestration (CCS), natural gas combustion turbines, biopower plants, biopower plants with CCS, nuclear power plants, and hydrogen combined cycle plants. Techno-economic data for these technologies are largely taken from the [2021 NREL Annual Technology Baseline](#) (ATB). Detailed information can be found in the database documentation. Due to a lack of firm natural gas supply, natural gas technologies are not available in Prince Edward Island, Newfoundland, or Labrador.

Table 3.5: New generation options for each region. Note that Labrador does not have any options for new generation.

Generation Option	NB	NS	PEI	NL
Land-Based Wind	x	x	x	x
Offshore Wind	x	x	x	x
Utility-scale Solar PV	x	x	x	x

Residential Solar PV	x	x	x	x
Biopower	x	x	x	x
Biopower with CCS	x	x	x	x
Natural Gas (Combined Cycle)	x	x		
Natural Gas (Combined Cycle with CCS)	x	x		
Natural Gas (Combustion Turbine)	x	x		
Geothermal				
Nuclear (Advanced Light Water Reactor)	x		x	x
Hydrogen Combined Cycle Turbine	x	x	x	x
Battery Storage (2-hour)	x	x	x	x
Battery Storage (4-hour)	x	x	x	x

Renewable generation options available to the model include land-based wind, fixed-bottom offshore wind, utility scale solar (with 1-axis tracking), and residential solar. The techno-economic parameters of each of these technologies are sourced from the 2021 NREL ATB dataset.

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. To avoid a high concentration of wind capacity in resource rich regions, a cap of 625 MW per region is applied. A summary of the wind regions in each province is provided in Table 3.6. The [Technical Documentation](#) provides a detailed overview of the wind resources and how the values in Table 3.6 are derived.

Table 3.6: Modelled capacity factors for the different wind resources in each region.

Region	Resource 1	Resource 2	Resource 3	Resource 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%	--	--

The locations and resource availabilities for the fixed-bottom off-shore wind technologies are based on a Geological Survey of Canada [analysis](#). 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](#), and the most populated city in each region is used as the basis for the residential solar resource. The [NREL PVWatts Calculator](#) is used to derive the hourly capacity factors for the utility-scale and residential solar technologies. These capacity factors are outlined in Figure 3.7. Further information is available in the [Technical Documentation](#).

Table 3.7: Capacity factors for offshore wind, utility-scale solar and residential solar for each region.

Region	Off-Shore 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%

3.3.5 Hydrogen

Included within the Electricity Sector are several pathways for the production, storage, and combustion of hydrogen. Hydrogen can be produced via water electrolysis (both proton-exchange membrane and alkaline based electrolyzers are included) or steam methane reforming with carbon capture and sequestration. The gas can be stored in geological formations and combusted in a combined cycle turbine to generate electricity. Additionally, hydrogen can be used to meet end-use demands in the transportation sector.

3.3.6 Storage

Electricity storage options include 2-hour and a 4-hour lithium-ion batteries whose representations are based off data (costs, efficiency, etc.) from the 2021 NREL ATB. Carbon dioxide captured by the CCS technologies can either be sequestered at a cost or used as a feedstock to several processes in the industry sector.

3.4 Transportation Sector

In line with the classifications used by Natural Resource Canada in its [Comprehensive Energy Use Database](#), the transportation sector is sub-divided into several subsectors. Each subsector is characterized by an existing fleet of vehicles and a selection of new vehicle options that are together used to satisfy its exogenously defined end-use demand.

Annual end-use demand for each subsector is calculated from the data provided in the Comprehensive Energy Use Database tables. Demand growth is assumed to increase in line with the [forecast population growth](#) for each region. Electric vehicle charging profiles for the “Cars”, “Passenger Light Trucks”, “Freight Light Trucks”, and “Medium Trucks” subsectors are sourced from Bistline et al., 2021. “Heavy Trucks” and “Urban Transit” are assumed to have a constant charging profile throughout the year.

Data characterizing the existing fleet of vehicles, e.g., the existing stock’s vintages and efficiencies, is taken from the Comprehensive Energy Use Database. Each subsector provides a suite of technology options primarily characterized by their fuel type. Table 3.8 and Table 3.9 summarize the new technology options available for on-road and off-road transportation segments, respectively. Data for new technologies is taken from an array of data sources and is outlined in the database documentation.

Table 3.8: On-road transportation subsectors with available technology options. PHEV = plug-in hybrid electric vehicle; CNG = compressed natural gas.

	Gas	Diesel	PHEV	Electric	CNG	Hydrogen	Diesel Hybrid
Cars	X	X	X	X		X	
Passenger Light Trucks	X	X	X	X	X		
Freight Light Trucks	X	X		X	X		
Medium Trucks	X	X	X	X			
Heavy Trucks		X		X		X	
Urban Transit	X	X		X	X		X

Table 3.9: Off-road transportation subsectors with available technology options. LNG = liquefied natural gas.

	Marine Gasoil	Residual Fuel Oil	Liquid Hydrogen	Jet Fuel	Aviation Biofuel	Diesel	Biodiesel	LNG
Marine	X	X	X					
Airplanes				X	X			
Rail						X	X	X

The ACES model also includes explicit technologies for electric vehicle charging stations, hydrogen refueling stations, and hydrogen compression and liquefaction. Biodiesel and aviation biofuel production is included as part of the industry sector. All other transportation subsectors not included in Table 3.8 and Table 3.9 which make up a relatively small fraction of total transportation end-use demand -- namely motorcycles, school buses, inter-city buses, and off-road vehicles -- are grouped together in an “other” category and included in the ACES model as a generic technology¹² to preserve their energy use and emissions activity.

3.5 Buildings Sector

The ACES model represents the residential sector and commercial buildings sectors separately. This division, in addition to the classification within the residential and commercial sectors, follows the classification system used in Natural Resource Canada’s [Comprehensive Energy Use Database](#).

Residential space heating and residential water heating are modelled in detail whereas other residential subsectors, namely those for electrical appliances, lighting, and space cooling, are grouped together in an ‘other’ category and included in the ACES model as a generic technology to preserve their energy use and emissions activity. Similarly in the commercial sector, commercial space heating is modelled in detail whereas all other commercial subsectors are grouped together in an ‘other’ category and represented by a generic technology.

The annual end-use demands for space heating and water heating are derived using data from the Comprehensive Energy Use Database and hourly demand profiles are taken from NREL’s [Electrification Futures Study](#)¹³. No demand growth is assumed over the model time-horizon as improvements to building efficiencies are assumed to counteract any increase in demand due to other factors.

The existing technology stock is characterized using data from the Comprehensive Energy Use Database. Techno-economic characterizations of new technology options (Table 10) are taken from a variety of data sources outlined in the database documentation.

¹² “Generic technologies” are modelled in a highly stylized approach with the sole purpose of accounting for energy flow in and out of the process as well as process related emissions. Generic technologies therefore do not have associated costs, lifetimes, or other techno-economic parameters.

¹³ Using the “Maine” region.

Table 3.10: New technology options for residential space heating and water heating.

Residential Space Heating	Residential Water Heating	Commercial Space Heating
Electric Furnace	Electric Water Heating	Heat Pump (Roof Top Unit)
Natural Gas Furnace	Natural Gas Water Heat	Natural Gas (Roof Top Unit)
Propane Furnace	Propane Water Heater	Propane (Roof Top Unit)
Heating Oil Furnace	Heating Oil Water Heater	Heating Oil (Roof Top Unit)
Electric Heat Pump	Heat Pump Water Heater	

The constraints governing the operation of technologies within the building sector are somewhat different to those within the electricity sector. In the electricity sector, generators are optimally dispatched to minimize system costs. For instance, coal generation will be low in times of high wind and solar output and will be high in times of low wind and solar output. By contrast, it does not make sense for a region's fleet of electric furnaces to be dispatched around wind and solar output. If house A owns a natural gas furnace and house B owns an electric furnace, both furnaces should be used similarly throughout the year. Temoa's "DemandActivityConstraint" is used to ensure this dynamic is reflected in the model. Interested readers can consult [Temoa's official documentation](#) for further information.

Natural gas technologies are limited to regions with access to natural gas distribution infrastructure. Therefore, no natural gas space heaters or water heaters are available to Prince Edward Island, Newfoundland, or Labrador. Furthermore, only a portion of Nova Scotia's and New Brunswick's housing stock have access to such technologies. Finally, the model assumes that the existing stock is used until its end-of-life. Otherwise, the model would determine it cost optimal to retrofit inefficient existing heating systems with new, more efficient systems. Since Temoa does not currently have the functionality to economically retire technologies this results in a surplus of heating technologies. The database documentation can be consulted for more information around these constraints¹⁴.

3.6 Industry Sector

The industry sector is nominally split into "new industry" and "industry" sectors. The new industry sector includes several technologies that do not belong to other sectors and are not currently part of Atlantic Canada's industrial sector. The key technologies within this sector are summarized in Table 11.

Table 3.11: Overview of the technologies available in the "New Industry" sector.

Technology	Details
Direct Air Capture	This technology removes carbon dioxide from the atmosphere. The captured CO ₂ can be used as a feedstock to other industrial processes or geologically sequestered. Several technologies (based off Keith et al., 2018) distinguished by their financial assumptions and/or fuel type are included.

¹⁴ As with all model functionalities, model users are free to remove or edit assumptions around existing technologies and constraints.

Synthetic Fuel Production	This technology produces synthetic natural gas in a process that combines hydrogen and captured CO ₂ . Its representation is taken from the Open Energy Outlook .
Transesterification	This technology produces biodiesel from fish oil and/or greasy residues. Its representation is taken from the Open Energy Outlook .
Fischer-Tropsch Process	This technology produces biodiesel and/or aviation biofuel from agricultural residues, forestry residues and dedicated crops. Its representation is taken from the Open Energy Outlook .

The new industry sector also includes **a dummy direct air capture technology**. This technology, characterized by an ability to remove CO₂ from the system at a prohibitively expensive cost, is included only to ensure modelled scenarios with ambitious emission limits that cannot otherwise be met with available technologies are computationally feasible. **It is critical to note that scenarios in which this technology (“CO₂_CAPTURE-DUMMY”) appears in the results should be interpreted as infeasible.**

Due to data limitations, existing industrial sectors are currently modelled using a highly stylized approach. Each of the subsectors outlined the Natural Resource Canada’s [Comprehensive Energy Use Database](#) for which there is activity in Atlantic Canada -- namely the construction; pulp and paper; smelting and refining; petroleum refining¹⁵; cement; other manufacturing; forestry; and mining, quarrying and oil and gas extraction sectors – are included.

Each subsector is modelled in a generic fashion to match reported energy use from the Comprehensive Energy Use Database. The activity in each subsector is assumed to increase in line with the forecast population growth reported in the Canada Energy Regulator’s [Canada’s Energy Future study](#) with two exceptions: the total activity in the oil and gas extraction subsector (i.e., Newfoundland’s offshore oil platforms) is indexed to the forecast demand for [crude oil production in Newfoundland](#), and the total activity in the petroleum refining subsector is indexed to the forecast demand for [refined petroleum products](#). In addition to accounting for emissions from fuel use, the model also accounts for other types of industrial emissions when applicable, such as those from venting and flaring in the oil and gas extraction subsector.

It is worth noting that the activity within the petroleum refining subsector is not linked to other sectors within the ACES model. Outputs from the petroleum refining subsector, such as gasoline or propane, are not directly linked to the transportation or buildings sectors. Therefore, scenarios with high levels of transportation and building electrification do not automatically translate to lower activity within the petroleum refining subsector. This is because most refined petroleum products are exported to markets outside of Atlantic Canada.

Although no technical mitigation options are provided for the industry subsectors, model users currently have two mechanisms by which to influence sectoral emissions. The first is to simply adjust the exogenously defined subsector activity (this is set via the “Demand” parameter in Temoa). The second is

¹⁵ The ACES model makes the assumption that the Come By Chance Refinery in Newfoundland is not operational.

to simulate fuel switching (e.g., electrification) by adjusting the relative share of fuel inputs for a given subsector (this is set via the “TechInputSplit” parameter).

3.7 Agriculture Sector

The modelling of the agriculture sector is done using a stylized approach. The sector is sub-divided into several emitting processes: enteric fermentation; manure management; soil management; liming and urea application; and on-farm fuel use.

We assume that methane emissions from enteric fermentation are entirely attributed to cattle¹⁶. Each region has a specified demand for cattle which is set equal to the current number of cattle in each region as reported by [Statistics Canada](#). The existing stock of cattle is assumed to have a lifetime of five years, after which it is replaced by “new” cattle. The emission activity of cattle in each region is determined by dividing the total amount of existing cattle in the region by the region’s [reported emissions via enteric fermentation](#). The model includes two mitigation options for emissions via enteric fermentation. The first is reduced demand for cattle; the second is an [anti-methanogen vaccine for cattle](#), which is characterized by higher costs, higher cattle productivity, and reduced methane emissions.

The manure management process is modelled as a generic technology whose activity and emissions are in proportion to the region’s number of swine and cattle. There are two mitigation options for emissions via manure management: the first is by reducing the demand for manure management, which in effect is analogous to reducing the number of swine and cattle; the second is a [small-scale digester](#) which is characterized by higher costs and a 50% reduction in non-CO2 emissions.

The manure management and enteric fermentation processes are not currently linked in the ACES model. Therefore, a reduction in the demand for cattle does not also result in a reduction in demand for manure management – these reductions must be manually entered separately.

The soil management, urea and liming application, and on-farm fuel use processes are modelled as generic processes, whose fuel use and emissions are consistent with amounts reported by [Statistics Canada](#) (2018) and [Environment and Climate Change Canada](#) (2019), respectively. The only mitigation option for these activities is demand reduction.

3.8 Waste Sector

Much like the agriculture sector, the modelling of the waste sector is done using a stylized approach with a focus on emissions accounting. The federal government’s [National Waste Characterization Report](#) is used to characterize the composition and management of solid waste in each region. This includes the volume of solid waste, the amount sorted for compost, the amount sorted for recycling, and current landfilling practices. Data from the report is used in conjunction [with data of reported emissions](#) to determine the emissions intensity of existing landfills in each region.

¹⁶ Swine and other livestock produce methane via enteric fermentation, although at [much lower levels](#).

Nova Scotia and New Brunswick are characterized by a relatively high rate of composting and recycling. The bulk of their solid waste is sent to landfills with landfill gas (LFG) recovery. The only technical mitigation option for solid waste disposal in these regions is an anaerobic digester.

Prince Edward Island also has systems in place for composting and recycling. The remainder of its solid waste is either incinerated at a waste-to-energy facility or sent to landfill. Technical mitigation options available in PEI are anaerobic digesters and landfills with LFG recovery.

Neither Newfoundland nor Labrador have composting systems in place and are therefore characterized by higher emission intensities for their solid waste management. Technical mitigation options available in Newfoundland and Labrador are anaerobic digesters and landfills with LFG recovery.

The ACES model includes generic processes for wastewater treatment and the landfilling of industrial wood waste to include their associated emissions within the model. No technical mitigation options are provided for these processes.

3.9 Sector Links

The six sectors are interlinked by the commodity flows summarized in Table 3.12.

Table 3.12: A summary of the sector linkages by commodity flows.

Sectors	Linkages
Electricity & Buildings	Technologies in the buildings sector (residential and commercial) consume electricity produced in the electricity sector.
Electricity & Transportation	Technologies in the transportation sector consume electricity and hydrogen produced in the electricity sector.
Electricity & Industry	Technologies in the industrial sector consume electricity produced in the electricity sector.
Industry & Transportation	Technologies in the transportation sector consume biodiesel and aviation biofuel produced in the industrial sector.
Industry & Electricity	Technologies in the electricity sector consume synthetic natural gas that is produced in the industrial sector.

Sectors can be considered linked by their competition for scarce resources. When system-wide emission limits are introduced, the sectors are interlinked via competition for emission credits. Similarly, different sectors in New Brunswick and Nova Scotia compete with one another for access to the limited supply of natural gas.

4. Using the ACES Cloud Application

Now that you have a good understanding of the model details, you are ready to run ACES. This section includes details on the set-up process, creating scenarios, queueing model runs, and generating plots.

4.1 Setting Up

This section outlines the different steps you will need to complete prior to using the ACES Cloud. You can also watch an instructional video on our website.

4.1.1 Download ACES Model Databases

To use the Cloud application, you will need an ACES database to upload to the server. Please refer [The ACES Databases](#) section for an overview of the available databases. These can be downloaded from the acesmodel.ca website on the Run the Model page.

4.1.2 Install DB Browser

The databases are in SQLite file format. To read them and make modifications to set scenario parameters, you will need to download **DB Browser for SQLite**. Follow the steps below:

- Visit sqlitebrowser.org/dl to download and install the application. Select the option best suited for your device with the standard installer.
- Once installed, select an SQLite database you want to use. Right click and select the “open with” option. You may have to search through your computer programs to find DB Browser. Select it to open the file in this application.
- Explore the DB Browser tool. In the “Browse Data” tab, you will be able to look through numerous tables used to characterize the energy system. For more information on these tables, refer to the Technical Documentation.
- Refer to the “technologies” table in the database to find the descriptions for each technology abbreviation used in the database.

4.1.3 Creating an ACES Cloud Account

You will need to create an account on the ACES Cloud Application to perform model runs. Follow the steps below:

- Go to aces.netzeroatlantic.ca.
- Select “Sign up” option to create your account. Type in your email, create a password, and type it again to confirm it. Hit the “Register” button.
- An email will be sent to that account to start the verification process. You will receive an automatic email letting you know that a verification email will be sent by Net Zero Atlantic to verify your account. **This process is done manually by Net Zero Atlantic and can take up to one business day.**
- You will receive an email with a waiver. When you agree to that waiver, you will be notified when your account has been activated by Net Zero Atlantic. You can then log in to the ACES Cloud.

4.2 Modifying the Input Databases

The open-source nature of ACES allows you to create a model scenario and test your own energy system assumptions. As outlined in [The ACES Model Framework](#) section, input files are constructed as SQLite relational databases. You may wish to modify existing input databases or construct your own databases from scratch. You can do this in several ways.

You can directly modify the SQLite database using the DB Browser for SQLite application. This is recommended when making small modifications (i.e., editing a small selection of parameters). **It is prudent to make a copy of the original database before making any changes, to make sure you can revert**

to the original values if needed. Modifying the SQLite databases is covered in [this tutorial](#) by the lead author of Temoa, Joe DeCarolis (jump to 12:11 for the relevant section).

For more substantial modifications and additions, working directly with the text-based sql file is encouraged. [Temoa's official documentation](#) outlines the relevant steps of creating and modifying sql databases and converting them to the binary SQLite file. More details are provided in [this online tutorial](#). The ACES model provides its input databases in both sql and SQLite format.

After modifying a database and creating your scenario, you may follow the steps in [Running ACES Cloud](#). For a walkthrough of example scenarios, please see [Tutorials](#).

4.3 Running ACES Cloud

Now that you have set up your ACES Cloud account, downloaded your ACES databases and the DB Browser application, you are ready to run the ACES Model. This section will walk-through the process of uploading scenarios, producing model results, and creating model visualizations.

4.3.1 Upload a Scenario

You can upload your databases in your ACES Cloud account by organizing them based on project and scenario. Follow the steps below:

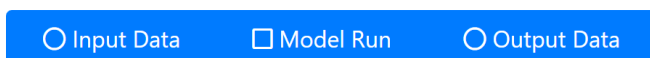
- When you log into the Cloud, start by creating a project by selecting the “Create Project” button. A project is a space to keep multiple scenarios and database uploads. You can create as many projects as needed.
- Enter a project name, and a description if desired. Press the “Create” button when ready.
- You should now see the new project you created in the “Projects” list. The column furthest to the right, called “Actions”, has a blue “eye” icon that you can press to open your project, seen below. The red trashcan button will delete your project from your account.



- When you open your project, select “Manage Scenarios”, then “Create Scenario”. Set a scenario name (e.g., BaseCase).
 - **The name must start with a letter, followed by optional numbers. Symbols and spaces are not accepted.**
- Click the box below to explore your computer’s files and select the SQLite database you want to upload. Starting with ACES-Testing is a good choice for your first scenario. Select your chosen database and allow it to upload to the site.
- Note that the database can be up to 2GB in size.
- Select the “Back to Scenarios” button to see your new scenario in the list. Select the “eye” icon in “Actions” to open the scenario and view your options.

4.3.2 Input Data

When you open your scenario, you will see a blue bar at the top of the page with your options: Input Data, Model Run, and Output Data.



The “Input data” option allows you to make a **network diagram** of your energy system data.

- Select “Input Data” on the blue bar. The page allows you to set your network diagram options.
- Select your region of interest from the drop-down menu. Diagrams can be created per region.
- Choose to create your diagram in colour or grey scale.
- You can select a **commodity or technology type** from a drop-down menu. You can select “NONE” to show a diagram for all technologies and commodities. Selecting “commodity” or “technology” will prompt another drop-down menu to select your chosen parameter for your diagram.
 - For example, selecting “commodity” will prompt a menu with ACES model commodity values such as CO2e, D_ELEC (electricity demand), etc. Selecting “technology” will prompt a menu with ACES model technologies in your chosen database such as E_WIND-ON (onshore windmills), E_NGACC (natural gas), etc.
- The Output Format options for the diagram only includes SVG; you can leave this as is.
- Select the “Render Network Diagram” option and see that the task was added to the asynchronous queue.
- You will likely see a notification pop up on the screen in the top right corner, indicating that your diagram is complete (these generate quickly). The screen will return to the previous page where you will see a **unique name created for your new scenario action**, with the mode listed as “Input Diagram”. You can open this action with the “eye” icon and select the “Result Download” button to download your resulting input diagram (Figure 4.1) in a .zip file.
- Press the “Back to Actions” button when done.

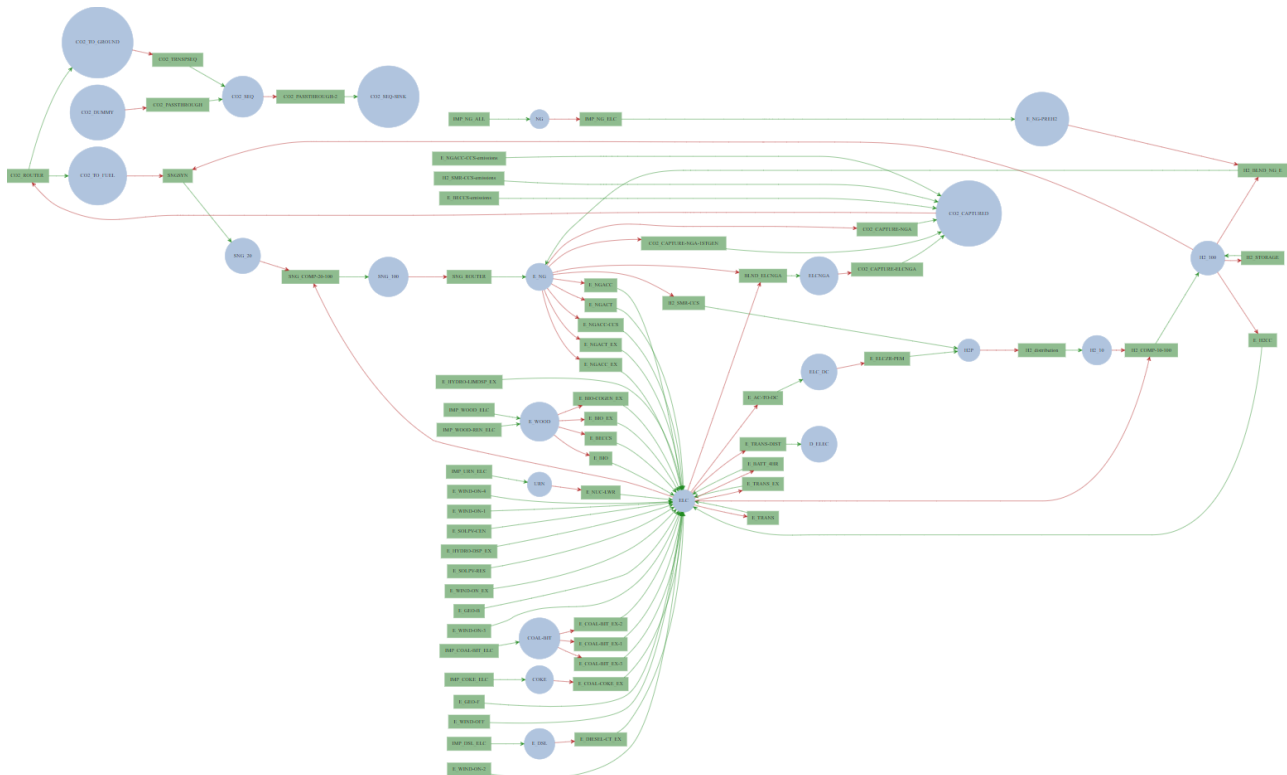


Figure 4.1. An input network diagram of the entire Nova Scotia energy system, generated with ACES Cloud.

4.3.3 Model Run

The second option on the action bar is “Model Run” which is how you produce your feasible scenario results.

- Select “Model Run” on the blue bar. The page allows you to select all the file formats you want your results to be saved as. The results will always save into your SQLite database that you uploaded, and you can also have your results prepared as a downloadable Excel spreadsheet, a text file, and an LP file. You can leave the settings as “yes” for all the options, or select “no” for ones you do not want.
- There is currently only one solver option, so you can leave this as is.
- If you are an advanced Python user, you may choose to enter a custom flag.
- Select “Run Model” for the task to be added to the asynchronous queue. **Depending on the database you are running, and the complexity of your scenario, solve time will vary.** Refer to [Approximate Solve Times](#) for what you can expect for model run completion.
- If you already have multiple tasks running in the queue, this will also impact the solve time.
- To check the status of the model run, you can open the task with the “eye” icon. The status will be set to “IN_PROGRESS” if the model is currently solving.
- You will receive an email notification when your task is complete, and your results are ready. You can open the task via the “eye” icon again and should see that the results are ready to download. You will also be able to download the SQLite database next to “Database File”. The SQLite database can be opened in DB Browser where you can view the results in the Output tables. The Excel spreadsheet will be organized similarly but will allow more flexibility with how you choose to organize your results. For example, you can move columns, delete rows, create plots, etc.

4.3.4 Output Data

The third option on the action bar is “Output Data” which will allow you to generate plots and diagrams of the results of your model run. These options will not be functional until you have completed a model run, as the figures are generated based on model results.

Network Diagram

- Select “Output Data” on the blue bar. The page will open up on the “Network Diagram” generator, which will allow you to customize a network diagram of your scenario results.
- Select the region you would like to create the diagram for. Again, there is currently only the option to create plots of individual regions at a time.
- Select the scenario you wish to create the diagram for. The scenario you created and ran will be in this drop-down menu, as well as any other scenarios you may have run using the same database.
 - For example, if you downloaded your results SQLite database, used it to create a new scenario, and re-uploaded it for another model run, then you would have results for two separate scenarios in the database and both would be listed in this drop-down menu.
- Once a scenario name is selected, you can choose a Date Range for the diagram based on the time periods included in the dataset (e.g., 2020, 2025...2050).
 - For example, you could create your first diagram for the 2020 time period, then another for 2050 to compare changes to the system over time.

- You may choose to select a specific commodity or technology type to base your diagram on, same as discussed for Input Data. You can also choose “NONE” and create the diagram for the whole dataset.
- Again, select a colour scheme and leave your output format as SVG.
- Select “Render Network Diagram” for the task to be added to the asynchronous queue. Open the action and download the result when it is ready.

Output Plots

- Select “Output Data” on the blue bar. Then select the “Output Plots” tab next to “Network Diagram”.
- Select the region of interest from the drop-down menu.
- Select the scenario you wish to create the plots for.
- You can choose between Capacity, Output Flow, and Emissions in the plot type drop-down menu.
 - **Capacity plots** will show the technology build-out in each time period included in the dataset based on your scenario (Figure 4.2).
 - **Output Flow plots** will show the active use of technologies in each time period based on your scenario (Figure 4.3). This varies from capacity, as it shows what is being deployed to meet end-use demands.
 - **Emissions plots** show changes in multiple pollutants in each time period based on your scenario (Figure 4.4)
- Select the sector to generate the plot of. Only the sectors included in your database will be included. You can select “all” to show results for all sectors in a single plot, or an individual sector.
 - Due to varying units, it will be best to make plots of individual sectors (e.g., electricity or transportation, not combined) for Capacity and Output Flow plots.
- It is recommended to check the “**Group technologies by category**” box to generate a cleaner looking plot.
- Select “Generate Output Plot” for the task to be added to the asynchronous queue. Open the action and download the result when it is ready.

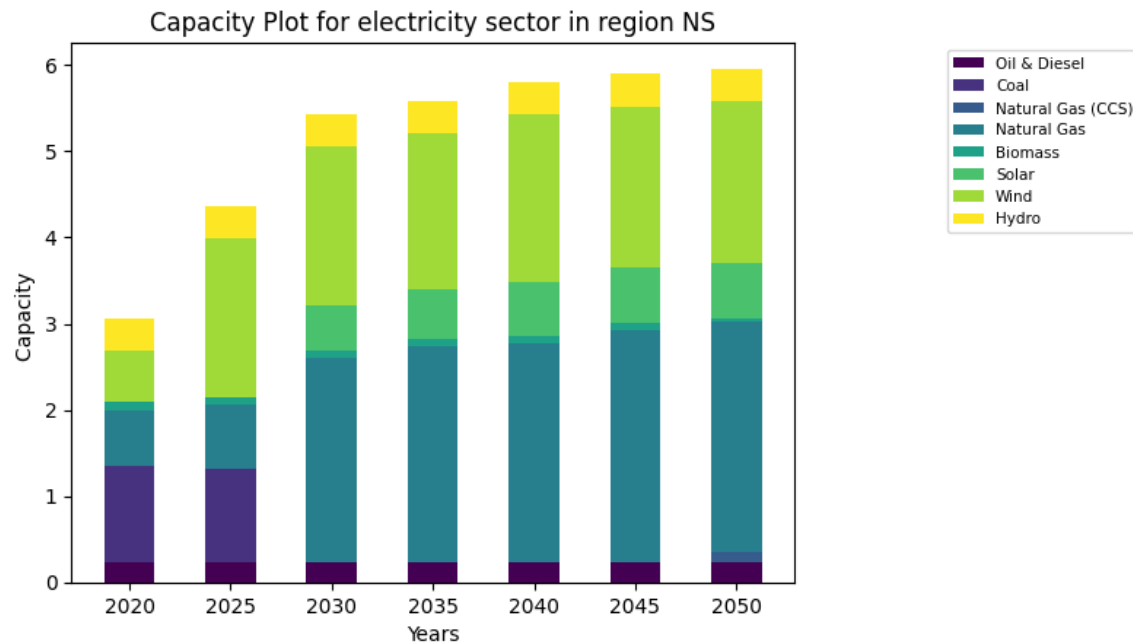


Figure 4.2. An example of a Capacity plot generated by ACES Cloud for the electricity sector in Nova Scotia under a federal carbon tax scenario.

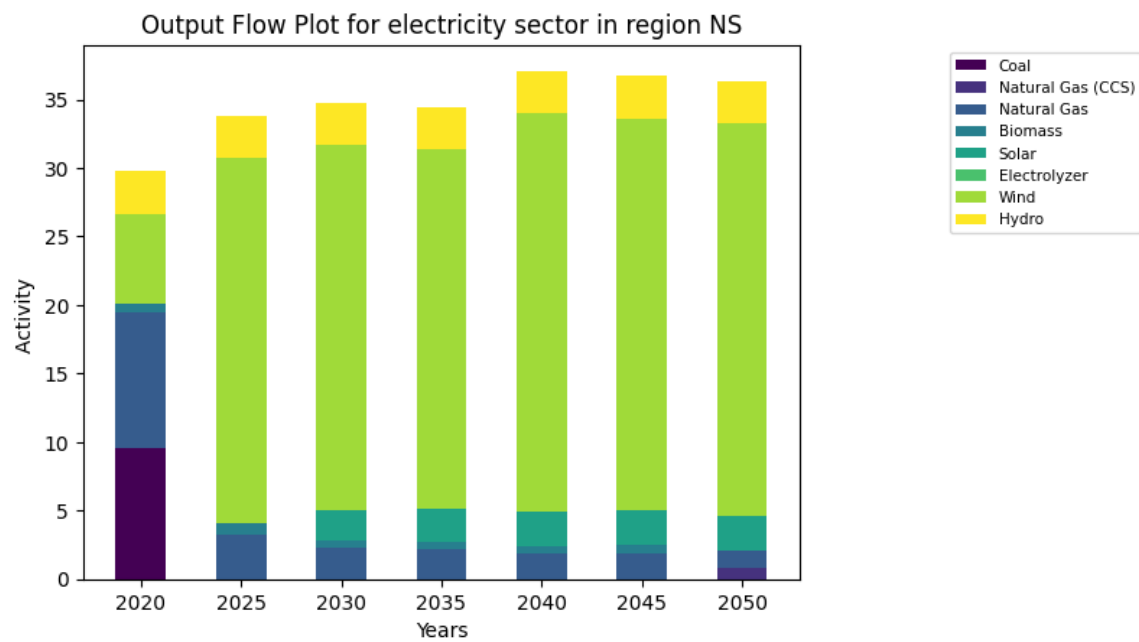


Figure 4.3. An example of an Output Flow plot generated by ACES Cloud for the electricity sector in Nova Scotia under a federal carbon tax scenario.

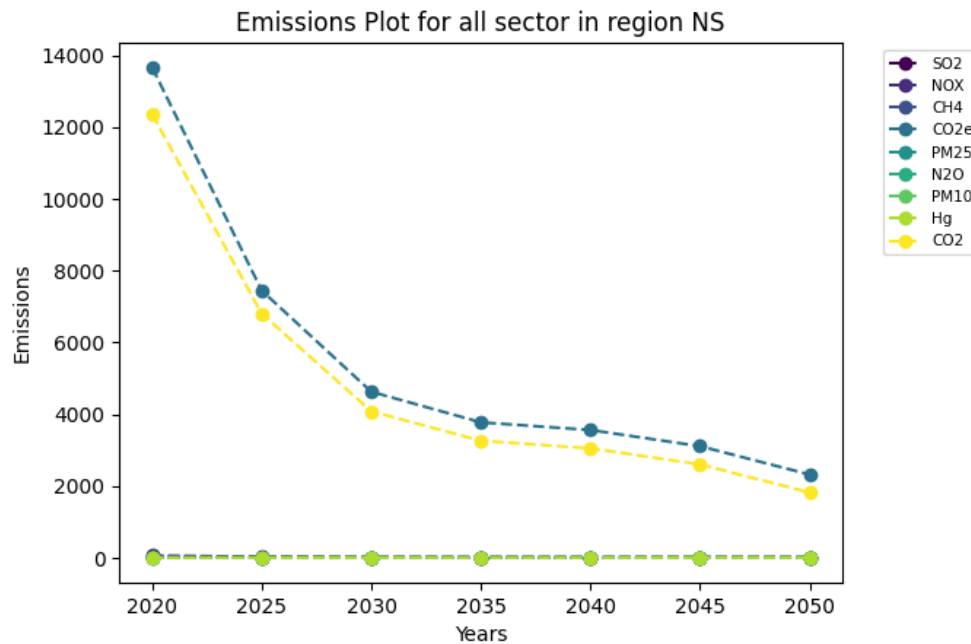
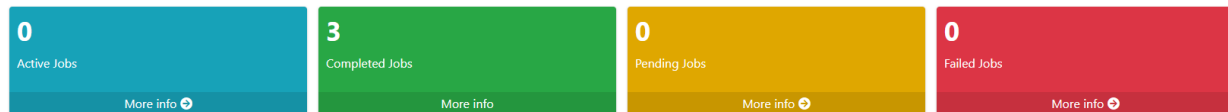


Figure 4.4. An example of an Emissions plot generated by ACES Cloud for all sectors in Nova Scotia under a federal carbon tax scenario.

4.3.5 Live Dashboard

You can track the progress of your tasks in the ACES Cloud Live Dashboard. You will see the Live Dashboard on the left side-bar. Opening this will show all your tasks for the current date. This is organized by columns of Active Jobs, Completed Jobs, Pending Jobs, and Failed Jobs. This is useful for monitoring how many tasks are in the queue.



4.3.6 Approximate Solve Times

The time it takes for the model to solve depends on several factors: the number of model runs you have in the queue; varying size and complexity of the databases; and the parameter settings of your scenario. Table 4.1 displays the approximate solve times for each database on ACES Cloud.

Table 4.1. Approximate model solve times per database on ACES Cloud.

Database	Approx. Solve Time
ACES-7D-6S	6-8 hrs
ACES-7D-3S	5-7 hrs
ACES-7D-1S	4-6 hrs
ACES-Testing	5-10 mins
ACES-7D-6S-NB	5-15 mins
ACES-7D-6S-NLLAB	5-10 mins
ACES-7D-6S-NS	10-20 mins
ACES-7D-6S-PEI	5-10 mins

4.4 Tutorials

These tutorials outline how to modify or add to an existing input database. All tutorials use the ACES-Testing.sqlite database.

4.4.1 Modifying an Existing Technology

The following steps outline how to run a model scenario based around aggressive cost reductions in solar prices.

1. Make a copy of the ACES-Testing.sqlite database and rename it to ACES-Testing-Tutorial.sqlite. This is done so that you do not overwrite the original database.
2. Consult [Temoa's official documentation](#) to determine the input parameter of interest. In this case, the relevant parameter is "CostInvest".
3. Open the database in DB Browser for SQLite.
4. Navigate to the "CostInvest" table by first selecting the "Browse Data" tab, then selecting the "CostInvest" table on the dropdown menu.
5. Filter the table by entering "E_SOLPV-CEN" into the "tech" filter¹⁷.
6. Update the investment costs to reflect the data in Table 4.2. Do this for NS, NB, PEI and NL.

Table 4.2: Investment costs for utility-scale solar in units of M\$/GW.

	2020	2030	2040	2050
Original Costs	1862.3778	966.0848	852.2819	750.153
Updated Costs	1862.3778	600.0	400.0	300.0

7. Save the updated SQLite database by pressing CTRL+S.
8. Open the ACES Cloud website and upload this database to your new scenario, then complete your model run as outlined in [Running ACES Cloud](#).

When the model run is complete, you can download your results files (ACES-Testing-Tutorial.sqlite and Excel results file) to view and analyze. The installed solar capacities in New Brunswick for the LowPV and BaseCase¹⁸ scenario is provided in Table 4.3. We see the cost reductions for the utility-scale solar technology result in increased buildout in New Brunswick. You will also likely see these changes reflected in your output plots.

Table 4.3: Summarized solar capacities (in MW) in New Brunswick for the BaseCase and LowPV scenarios.

Scenario	2020	2030	2040	2050
BaseCase	0	0	0	0
LowPV	0	0	538	586

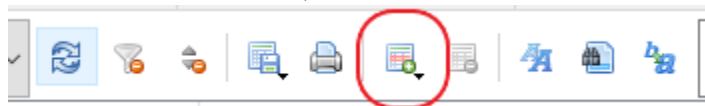
¹⁷ You may first want to navigate to the "technologies" table to determine the technology name, i.e. E_SOLPV-CEN, for utility-scale solar.

¹⁸ This scenario was solved as part of the [Running ACES Cloud](#) section.

4.4.2 Adding a New Technology

You may want to add a new technology to the database for the model to consider. To implement this into the model, we need to add the technology itself as well as the associated data and assumptions within the model parameters. The following steps are taken to add a technology into the model:

1. Make a copy of the ACES-Testing.sqlite database and rename it to ACES-Testing-Tutorial.sqlite. This is done so that you do not overwrite the original database.
2. Open the database in DB Browser for SQLite.
3. Navigate to the “technologies” table by first selecting the “Browse Data” tab, then selecting the “technologies” table on the dropdown menu.
4. Add a new entry by clicking on the icon pictured below. Complete the new entry with the following data:
 - “tech” = your designated name for the technology following the model nomenclature.
 - “flag” = “p”. Note: the flag must be one of the options listed in the “technology_labels” table.
 - “sector” = the sector this technology is assigned to, e.g., “electricity”. Note: the flag must be one of the options listed in the “sector_labels” table.
 - “subsector” = the subsector this technology is assigned to, e.g., “storage”. Note: the flag must be one of the options listed in the “subsector_labels” table.
 - “tech_desc” = the description of the technology or nomenclature.
 - “tech_category” = the category of the technology. This entry is optional and is used in by the dashboard to group distinct technologies with the same “tech_category” together.
 - “cap_units” = units of the technology’s capacity, e.g., “GW”.
 - “color” = the assigned colour to represent the technology on the dashboard. This field is optional.
 - “plot_order” = a number assigned to choose the order the technology will appear on the dashboard. This field is optional.



5. Navigate to the other tables in the database from the dropdown menu that you have designated assumptions for this new technology.
6. In each table, add your new entries by clicking the icon pictured below. Complete the new entry with the following data: {“regions” = one entry for each region the technology exists in; “periods” = one entry for each time-period the technology exists in per region; “tech” = the designated name assigned to the technology following the model nomenclature in the “technologies” table; “vintage” = the time period the new technology was implemented; the column for assigning the data values, e.g. “cost_fixed”; the units column; the notes column, typically used for citing the source of the data}.



7. Save the updated SQLite database by pressing CTRL+S.

- Open the ACES Cloud website and upload this database to your new scenario, then complete your model run as outlined in [Running ACES Cloud](#).

4.4.3 Modifying a Constraint

Here, we consider a case where we wish to restrict the limit on new wind capacity beyond those imposed in the BaseCase scenario (625 MW). To implement this scenario in the model, we can arbitrarily reduce the limit to 400 MW. This may be done to reflect one of several factors such as local community opposition, intra-regional transmission congestion not captured by the ACES model, or a limited amount of land suitable for wind development. These steps update the relevant constraint and solve the model:

- Make a copy of the ACES-Testing.sqlite database and rename it to ACES-Testing-Tutorial.sqlite. This is done so that you do not overwrite the original database.
- Consult [Temoa's official documentation](#) to determine the relevant input parameter. In this case, the relevant parameter is "MaxCapacity".
- Open the database in DB Browser for SQLite.
- Navigate to the "MaxCapacity" table by first selecting the "Browse Data" tab, then selecting the "MaxCapacity" table on the dropdown menu.
- Filter the table by entering "E_WIND-ON" into the "tech" filter.
- Update the entries that read 0.625 to 0.4 to reflect the desired modification.
- Save the updated SQLite database by pressing CTRL+S.
- Open the ACES Cloud website and upload this database to your new scenario, then complete your model run as outlined in [Running ACES Cloud](#).

When the model run is complete, you can download your results files (ACES-Testing-Tutorial.sqlite and Excel results file) to view and analyze. Table 4.4 shows a summary of the installed capacities for the different wind technologies in Nova Scotia for the BaseCase scenario and the LowWindCap scenario.

Table 4.4: Summarized results for the BaseCase and LowWindCap scenarios.

Scenario	Technology	Installed Capacity [MW]			
		2020	2030	2040	2050
BaseCase	E_WIND-ON-1	0	625	625	625
	E_WIND-ON-2	0	546	625	625
	E_WIND-ON-3	0	0	0	0
	E_WIND-ON-4	0	0	384	451
LowWindCap	E_WIND-ON-1	0	400	400	400
	E_WIND-ON-2	0	400	400	400
	E_WIND-ON-3	0	0	400	400
	E_WIND-ON-4	0	348	400	400

4.4.4 Adding a Novel Constraint

Imagine a scenario where we want to constrain the pace that new wind capacity can be built in Nova Scotia. We may want to model such a scenario if we find that installing 625 MW of new wind capacity in a single region by 2030 is unrealistic. To implement this constraint, we can use the [“GrowthRateConstraint”](#) rule in Temoa following these steps:

1. Make a copy of the ACES-Testing.sqlite database and rename it to ACES-Testing-Tutorial.sqlite. This is done so that you do not overwrite the original database.
2. Consult [Temoa’s official documentation](#) to determine the relevant input parameters. In this case, the relevant parameters are “GrowthRateMax” and “GrowthRateSeed”. These parameters work in tandem to constrain the rate at which technologies can grow¹⁹.
3. Open the database in DB Browser for SQLite.
4. Navigate to the “GrowthRateSeed” table by first selecting the “Browse Data” tab, then selecting the “GrowthRateSeed” table on the dropdown menu.
5. Add a new entry by clicking on the icon pictured below. Complete the new entry with the following data: {“regions” = “NS”; “tech” = “E_WIND-ON-1”; “growthrate_seed” = 0.05; “growthrate_seed_units” = “GW”}.



6. Repeat step 5 for the E_WIND-ON-2, E_WIND-ON-3, and E_WIND-ON-4 technologies. Your table should be like the one pictured below:

regions	tech	growthrate_seed	growthrate_seed_units	growthrate_seed_notes
Filter	Filter	Filter	Filter	Filter
NS	E_WIND-ON-1	0.05	GW	NULL
NS	E_WIND-ON-2	0.05	GW	NULL
NS	E_WIND-ON-3	0.05	GW	NULL
NS	E_WIND-ON-4	0.05	GW	NULL

7. Next, navigate to the “GrowthRateMax” table and add new entries until your table appears like the one pictured below:

¹⁹ In essence, the GrowthRateMax parameter sets the maximum rate at which a technology can grow from one period to the next and the GrowthRateSeed acts as an imaginary initial capacity for technologies with no existing capacity. Without the seed, any technology with zero capacity in the first time period would be restricted to zero capacity for the remainder of the time horizon. Please consult Temoa’s online documentation for a detailed explanation of how these parameters are defined.

regions	tech	growthrate_max	growthrate_max_notes ▼ ¹
Filter	Filter	Filter	Filter
NS	E_WIND-ON-1	2.0	NULL
NS	E_WIND-ON-2	2.0	NULL
NS	E_WIND-ON-3	2.0	NULL
NS	E_WIND-ON-4	2.0	NULL

8. Finally, navigate to the “MaxCapacity” table and remove the entries for E_WIND-ON-1, E_WIND-ON-2, E_WIND-ON-3 and E_WIND-ON-4 in Nova Scotia by selecting the appropriate entries and clicking on the icon pictured below:



9. Save the updated SQLite database by pressing CTRL+S.
9. Open the ACES Cloud website and upload this database to your new scenario, then complete your model run as outlined in [Running ACES Cloud](#).

To summarize, we have removed the “MaxCapacity” constraint limiting the total amount of wind capacity in Nova Scotia and have replaced it with a growth rate constraint that allows 100 MW of wind in year 2020 ($0.05 \text{ GW} * 2.0 = 0.1 \text{ GW}$) and allows a doubling of installed capacity in each consecutive period.

The model results are shown in Table 4.5, where you can see the effect of replacing capacity limits with growth rates.

Table 4.5: Summarized results for the BaseCase and WindGrowthRate scenarios.

Scenario	Technology	Installed Capacity [MW]			
		2020	2030	2040	2050
BaseCase	E_WIND-ON-1	0	625	625	625
	E_WIND-ON-2	0	546	625	625
	E_WIND-ON-3	0	0	0	0
	E_WIND-ON-4	0	0	384	451
WindGrowthRate	E_WIND-ON-1	100	200	400	800
	E_WIND-ON-2	100	200	400	559
	E_WIND-ON-3	25	51	102	76
	E_WIND-ON-4	10	200	400	300

Appendix A: Provincial Databases

In addition to the databases outlined in [The ACES Databases](#), we have provided four additional databases: one specific to each of the four Atlantic Canadian provinces. Relative to the Atlantic Canada database, the provincial databases require less computer memory and time to solve and can deliver province-specific insights. This comes at the expense of (1) not gaining insights into the operation and transformation of the energy systems elsewhere in Atlantic Canada and (2) a highly simplified representation of export markets, particularly with respect to electricity.

This section first outlines the general differences between the Atlantic Canada databases and the provincial databases, followed by a detailed overview of the four provincial databases.

In the Atlantic Canada database, each region is represented by a suite of resources, technologies and end-use demands. Further, each region is connected to neighbouring regions via transmission lines, which enable the trade of electricity. The model trades electricity between regions in a manner that minimizes total system cost while respecting a set of physical constraints. This involves the model calculating the value of electricity in each region in each time step. Determining this value is a complicated process that depends on a multitude of variables, many of which are themselves decision variables.

By contrast, the regional databases abstract the dynamics of the other Atlantic Canada regions by representing them as a single, simplified node with whom they can trade electricity – i.e., a single, simplified export market. The price at which the export market buys electricity from and sells electricity to the region in question is exogenously defined. Moreover, the current implementation of the ACES model only allows for a fixed price of electricity in each year – that is, although the import and export price can change from year to year, the cost is constant throughout a given year.

In summary, the key distinction between the Atlantic Canada databases and their provincial counterparts is the detail with which the value of electricity traded between regions is calculated. Additionally, the provincial databases do not currently permit the expansion of inter-regional interconnection capacity.

Below is a summary of each provincial database and how their electricity interconnections with export markets are represented.

Nova Scotia

- Nova Scotia is connected to New Brunswick via the existing 350 MW transmission line. There are no annual trading constraints.
- Nova Scotia is connected to Newfoundland via the 500 MW Maritime Link. We separate the link into two separate links, representing the two contracts governing electricity trade between the two regions.
 - The first link has a capacity of 153 MW and represents the “Nova Scotia block” and the “Supplemental Energy” contracts. This link must supply 950 GWh for 35 years, and an additional 240 GWh of electricity for five years.
 - The second link has a capacity of 347 MW and represents the “Market Energy” contract. Each year, Nova Scotia must import between 1.2 TWh and 1.8 TWh of electricity.

- These data are consistent with the [Nova Scotia Power 2020 IRP](#) and language in [Nalcor documents](#).

The cost at which electricity is traded is as follows. There is no cost for imports via the “Nova Scotia block” and “Supplemental Energy” contracts. This is because electricity is purchased through an existing contract, and Temoa does not pay down costs associated with existing infrastructure and contracts. The cost of imports via New Brunswick and the “Market Energy” contract with Newfoundland is set at 15.83 M\$/PJ, which is taken from the [NS Utility and Review Board 2020-2022 Fuel Stability Plan](#) (page 43). The cost of exports to both regions is set at -6.02 M\$/PJ, which is taken as the spot price for Quebec imports from the modelling work done by [Princeton’s Net Zero America](#) project. We choose to use different prices for imports and exports to limit the region’s reliance on external markets. This, of course, can be changed by model users.

New Brunswick

- New Brunswick is connected to Nova Scotia via the existing 350 MW transmission line. There are no annual trading constraints.
- New Brunswick is connected to Prince Edward Island via the existing 560 MW transmission line. There are no annual trading constraints.
- New Brunswick is connected to Quebec via the existing 1,130 MW transmission line. The operational constraints are the same as those outlined in the Atlantic Canada database.
- New Brunswick is connected to Maine via the existing 678 MW transmission line. The operational constraints are the same as those outlined in the Atlantic Canada database.

Similar to Nova Scotia, the cost of imports from each region is set to 15.83 M\$/PJ and the cost of exports to both regions is set at -6.02 M\$/PJ.

Prince Edward Island

- PEI is connected to New Brunswick via the existing 560 MW transmission line. There are no annual trading constraints. Similar to the AC model, this transmission line does provide 200 MW of firm capacity to PEI.

Similar to Nova Scotia, the cost of imports from each region is set to 15.83 M\$/PJ and the cost of exports to both regions is set at -6.02 M\$/PJ.

Newfoundland and Labrador

- Newfoundland is connected to Nova Scotia via the 500 MW Maritime Link. We separate the link into two separate links, representing the two contracts governing electricity trade between the two regions.
 - The first link has a capacity of 153 MW and represents the “Nova Scotia block” and the “Supplemental Energy” contract. This link must supply Nova Scotia with 950 GWh for 35 years, and an additional 240 GWh of electricity for five years.
 - The second link has a capacity of 347 MW and represents the “Market Energy” contract. Each year, Newfoundland must export between 1.2 TWh and 1.8 TWh of electricity to Nova Scotia via this link.

- Labrador is connected to Quebec via a 265 GW link. There are no annual trading constraints.
- Similar to the Atlantic Canada model, Newfoundland and Labrador are modelled as distinct regions.

Similar to Nova Scotia, the cost of imports from each region is set to 15.83 M\$/PJ and the cost of exports to both regions is set at -6.02 M\$/PJ.