net-zero
atlantic

ACES Model User Guide for Version 2.0: ACES Desktop

Contents

1. Introduction

Long-term energy system optimization models allow users to analyse potential energy system transition pathways with regards to system cost, GHG emissions and other key performance indicators. These models provide comprehensive, technology-specific descriptions of possible scenarios for an energy system transition and 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 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, are 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.

This document serves as a user guide for Version 2.0 of the ACES Model. The structure of this document is as follows: The ACES Model Framework; The ACES Databases; Running ACES. These sections outline the model architecture, the model data, and instructional tutorials for running the model, respectively. The Technical Documentation contains additional information for ACES beyond the scope of this document. For instructions on running the Cloud version of ACES, please refer to the ACES Cloud version of the use guide. Version 2.0 of the ACES Model and User Guide were publicly released in February 2023. 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, a modified version of Temoa, and 3) output files which present feasible model solutions.

ACES Model Architecture
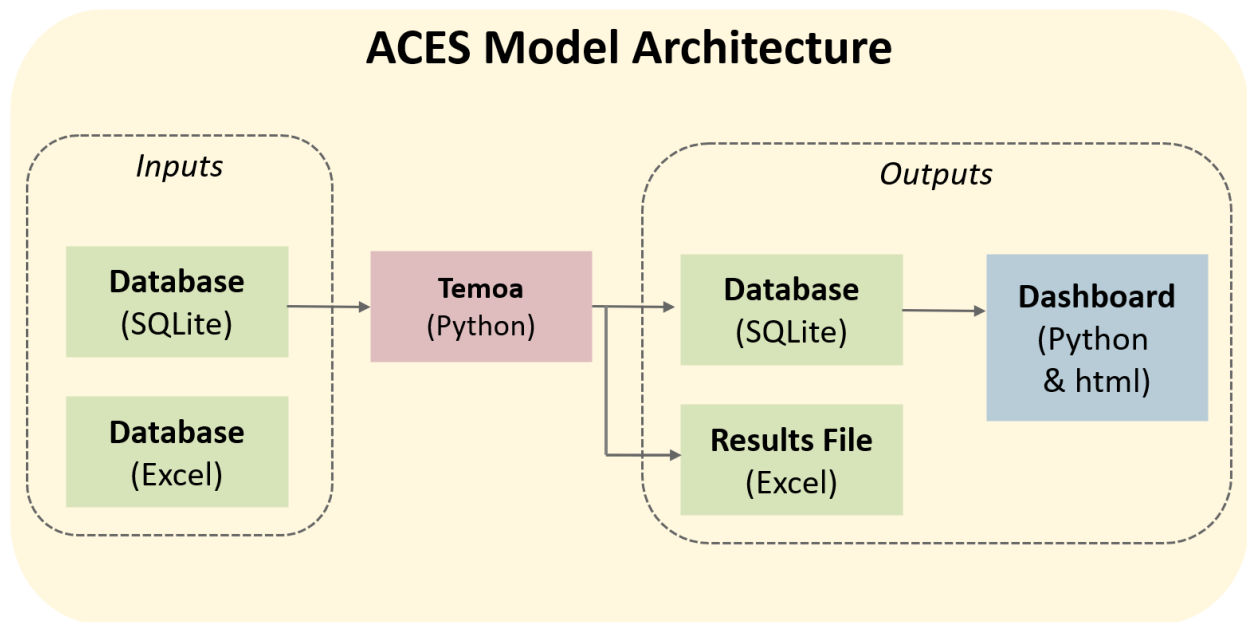
Figure 2.1: The ACES model architecture.

2.1 Inputs

The inputs contain all data necessary to fully characterize the energy system in question. This includes information and assumptions around the existing energy system, new technology options, commodity prices 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, 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.

The SQLite databases are located within the data_files/ directory and the Excel workbooks are located within the data_documentation/ directory.

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 – and colleagues 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 modelled. 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).
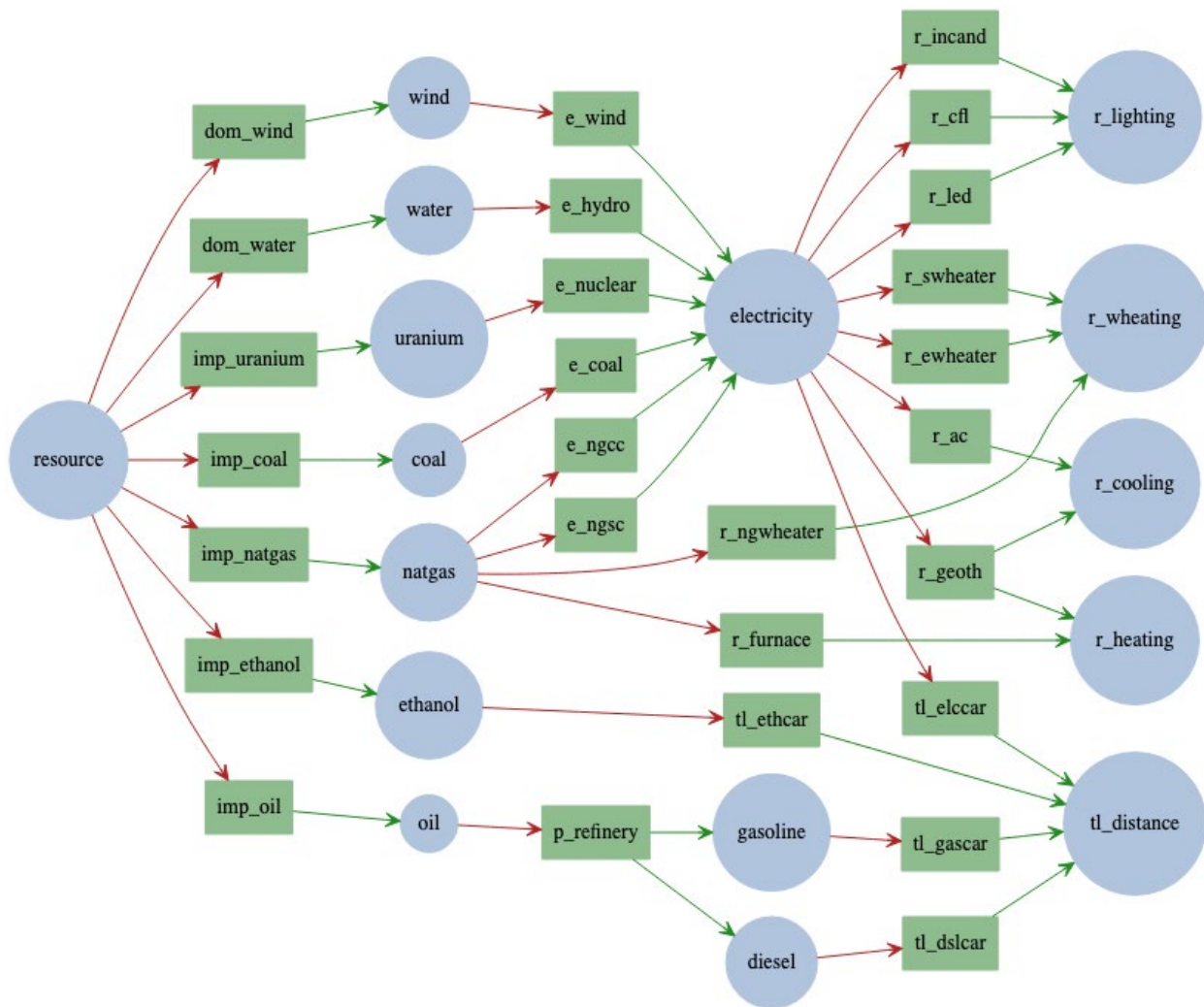
Figure 2.2: An energy system network diagram produced by Temoa for an example energy system. Technologies (green boxes) convert input commodities (blue circles) to output commodities that ultimately satisfy end-use demands. Image source:
https://github.com/TemoaProject/oeo/blob/master/OEO_Roadmap.md. Image 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. A complete list is provided in the Technical Documentation.

Technology-Specific Characterization	Name in Temoa	Definition
Capital Cost	CostInvest	The upfront investment cost.
Fixed Cost	CostFixed	Fixed operations and maintenance costs.
Variable Cost (annual average)	CostVariable	Variable operations and maintenance costs.
Variable Cost (Intra-annual)	CostVariableVariable	Intra-annual variations to the CostVariable parameter. This is optionally defined for commodity prices that exhibit a high degree of intra-annual price variability, such as natural gas.
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 (Annual Average)	Efficiency	The fraction of the technology's useful output per unit of input.
Efficiency (Intra-annual)	EfficiencyVariable	Intra-annual variations to the Efficiency parameter. This is optionally defined for technologies exhibiting a high degree of intra-annual variability to their efficiency (i.e., temperature dependent), such as heat pumps.
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).
Capacity Factor (Vintage-specific)	CapacityFactorProcess	Similar to the CapacityFactorTech parameter, but with an additional index for vintage. This allows users to incorporate learning rates – i.e., wind turbine capacity factors might improve as technologies mature.

Maximum and Minimum Annual Capacity Factor	MaxAnnualCapacityFactor; MinAnnualCapacityFactor	Upper and lower limits to the technology's annual capacity factor.
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. This is enforced for all timesteps.
Input Split (Annual)	TechInputSplitAverage	Similar to the TechInputSplit, but is only applied as an annual average.
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. This is enforced for all timesteps.
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 New Capacity	MinNewCapacity; MaxNewCapacity	The minimum and maximum amount of new capacity that can be added in a given year for a given technology. Note: this is distinct from the MinCapacity and MaxCapacity parameters in that those parameters limit the aggregate amount of installed capacity across all vintages.
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.

In addition to technology-specific parameters, Temoa includes the notion of *technology groups* which can be used to define technology group-specific parameters (Table 2.2). Technology groups are distinct sets of technologies over which users might want to constrain certain features.

These technology group-specific parameters are most easily explained by way of an example. Imagine you would like to set some specific constraints within the light-duty vehicle segment, which includes gasoline, diesel, battery electric, and hydrogen fuel cell vehicles. You might want to define two relevant technology groups: "LDV_Segment", to which you would assign all four vehicle types, and "LDV_ZeroEmissions", to which you would assign the battery electric and hydrogen fuel cell vehicles. By doing this, you could create a scenario that would force the model to ensure that a certain percentage of the light-duty vehicle segment is comprised by zero emission vehicles by a year. Table 2.2 lists all technology group-specific parameters and includes examples of how they might be applied to the "LDV_Segment" and/or "LDV_ZeroEmissions" technology groups.

Table 2.2 Descriptions of technology-group specific parameters that can be utilized to characterize technologies in ACES

Technology Group-Specific Parameter	Name in Temoa	Definition
Minimum and Maximum Activity	MinActivityGroup; MaxActivityGroup	The minimum or maximum amount of aggregate activity across all technologies in a given group in a given year. *Example:* A MinActivityGroup constraint is set on the "LDV_ZeroEmissions" technology group in PEI

		for 2030 to ensure zero emission vehicles account for at minimum 100 million vehicle kilometres.
Minimum and Maximum Capacity	MinCapacityGroup; MaxCapacityGroup	The minimum or maximum amount of aggregate capacity across all technologies in a given group in a given year. *Example:* A MinCapacityGroup constraint is set on the "LDV_ZeroEmissions" technology group in New Brunswick for 2035 to ensure there are at least 200,000 zero-emission vehicles on the road in that year.
Minimum and Maximum New Capacity	MinNewCapacityGroup; MaxNewCapacityGroup	The minimum or maximum amount of new aggregate capacity across all technologies in a given group in a given year. *Example:* A MinNewCapacityGroup constraint is set on the "LDV_ZeroEmissions" technology group in Newfoundland for 2030 to ensure there are at least 15,000 zero emissions vehicles purchased in that year.
Minimum and Maximum Capacity Share	MinCapacityShare; MaxCapacityShare	The minimum or maximum share of capacity a given technology from a given group can account for (relative to the aggregate group capacity). *Example:* A MinCapcaityShare constraint is set on the "LDV_Segment" technology group in Nova Scotia for 2040 to ensure a minimum of 70% of vehicles belonging to that group are battery-electric.
Minimum and Maximum New Capacity Share	MinNewCapacityShare; MaxNewCapacityShare	The minimum or maximum share of new capacity a given technology from a given group can account for (relative to the new aggregate group capacity). *Example:* A MinNewCapcaityShare constraint is set on the "LDV_Segment" technology group in PEI for 2040 to ensure that at least 80% of new vehicle purchases across that segment are battery electric.

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 (see Table 2.3).

Table 2.3 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	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. 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 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, year, and sector.
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 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

Once a particular input database is solved by Temoa, the model results are printed to an SQLite database and to a dedicated Excel workbook. You will instruct Temoa which SQLite database you would like the results saved to in the configuration file – typically users will use the same database for input and output. By convention, Temoa will save the Excel workbook in the following directory: data_files/<input_database_name>_<scenario_name>_model/ where <input_database_name> and <scenario_name> are the same as those provided in the configuration file.

2.4 Configuration File

A configuration file contains the remainder of the information required by Temoa to solve a particular scenario. The configuration file is located in the temoa_model/ directory with the filename config_sample. The file instructs model users on how to change the relevant input parameters, such as:

1. The file location of the input database.
2. The file location of the output database.
3. The file location of the output Excel workbook.
4. The scenario name.
5. Which solver to use.

See how to edit the configuration file when running the model in [Set Up Configuration File.](#)

2.5 Data Visualizations

Model users can create bespoke data visualizations using the model output files. The ACES model includes a beta version of a results dashboard, a screenshot of which is included in Figure 2.3. Instructions on how to use the dashboard are provided in [How To Use the Results Dashboard (beta)](#).
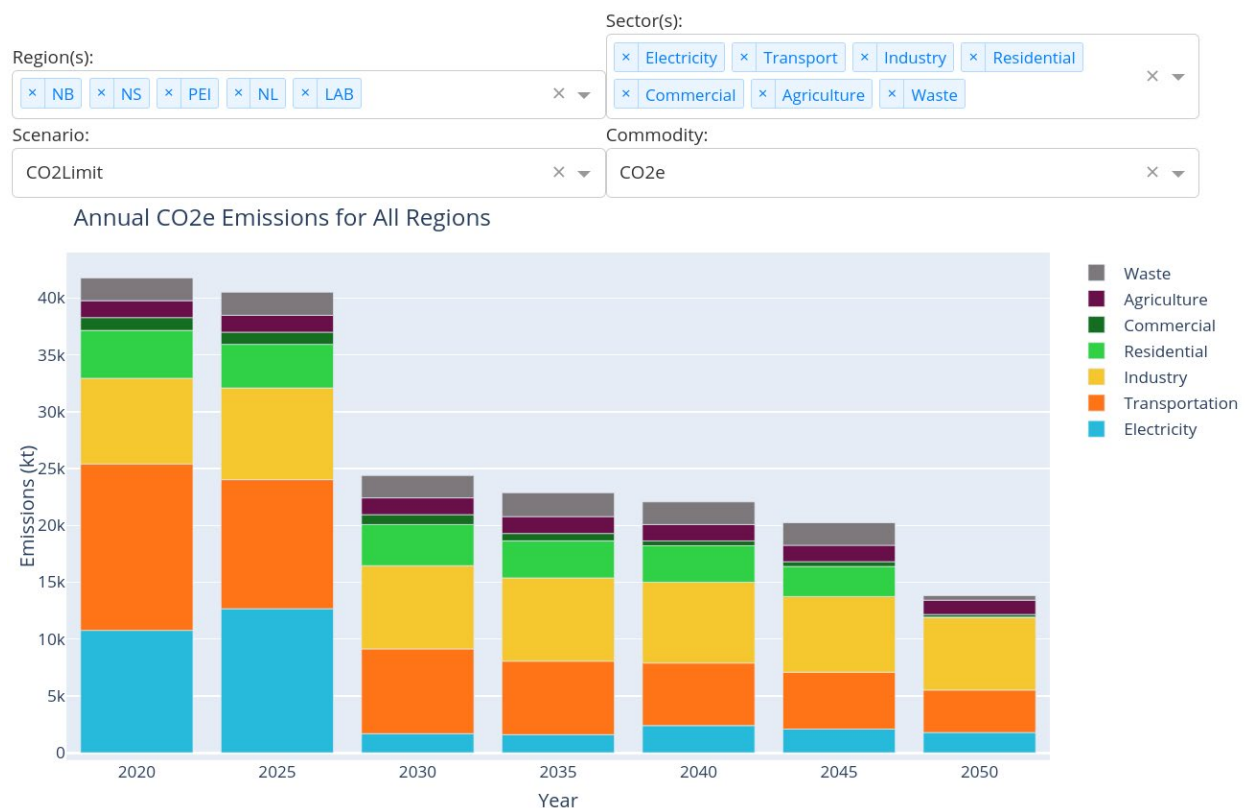
Figure 2.3: A screenshot of the ACES model results dashboard.

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 and computer memory required to solve the model.

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.

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 as 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 regions since their electricity systems are asynchronous and, in modelling the dynamics of their electricity interconnection, the Labrador Island Link is of relative importance[1].

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

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

region. For instance, several electricity generation technologies, including nuclear, are not available to Labrador. These limitations are documented in the 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 are approximated by applying an efficiency loss and a variable cost to electricity transmitted within a region[2].
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 Section 3.3.

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 sensible[3]. The ACES-Testing database has been simplified to only model 2020, 2030, 2040, and 2050 time periods to decrease solve times.

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

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[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.

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 solve[4].

To manage the tradeoff between the 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 this approach enables accurate modelling of intra-day dynamics – e.g., thermal generator ramp rates and 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 that it is 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

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[4] On the order of several hundred GB of RAM.

distributed throughout the year, i.e., the demand profile[5]. Defining the exogenous electricity demand depends on which sectors are included in the model.

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 revisited. 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 such as electric vehicles based on a multitude of factors. In this sense, the electricity demand from the modelled sectors is endogenized and subtracted from the exogenously defined bulk electricity demand.

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 (e.g., residential buildings).
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 electricity demand from these sectors is therefore *endogenized.* The sector-specific end-use demands are outlined in detail in their respective sections.

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[5] Please refer to Temoa's official documentation for more information on the "Demand" and "DemandSpecificDistribution" parameters.

3.3.2 Interconnections

Existing inter-regional electricity interconnections are included in the model: 300 MW of transmission capacity between New Brunswick and Prince Edward Island; 330 MW between New Brunswick and Nova Scotia; 475 MW between Nova Scotia and Newfoundland[6]; and 900 MW between Newfoundland and Labrador. The model is given the option of purchasing additional transmission capacity along these corridors.

Existing transmission corridors to export markets, namely Quebec and Maine, are also included in the model. The Technical Documentation provides details around price forecasts and emission intensities of imported electricity.

New Brunswick and Nova Scotia can import natural gas via the Maritimes and Northeast pipeline. Due to pipeline constraints, 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. The Technical Documentation provides details around natural gas price assumptions.

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 and retirement dates. 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 dates[7], 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

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[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.

[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.

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](#) tool[8] 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 Plan[9]. The 212 MW Wreck 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.

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[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](#).

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 3.3). 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 144 MW of diesel combustion turbines which the ACES model groups as a single technology.

Newfoundland: Newfoundland's generation capacity is primarily hydro (Table 3.4). 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 generation[10]. 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 generators[11]. 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

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[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

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 276 MW of gas turbines, the 490 MW Holyrood Thermal Generating Station and 54 MW of existing wind capacity.

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.

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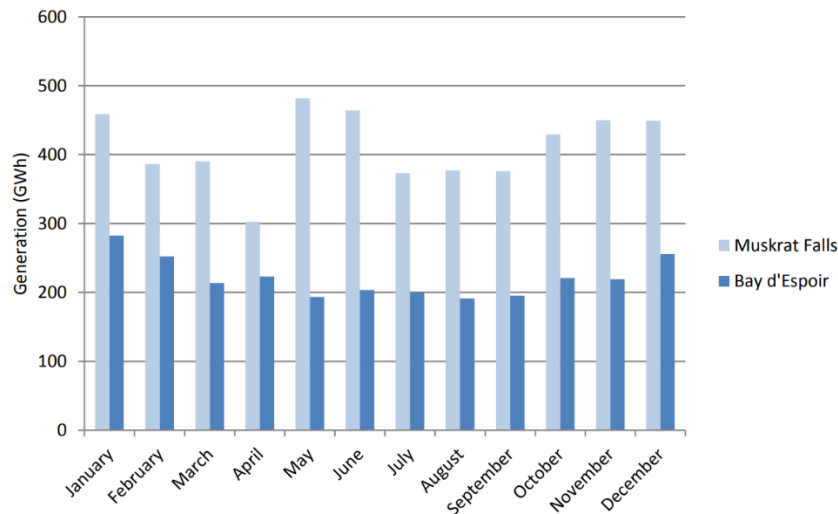
Figure 3.1: Muskrat Falls and Bay d'Espoir monthly generation data, taken from this Newfoundland Hydro report.

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, small modular reactors, diesel combustion turbines and hydrogen combustion turbines. Techno-economic data for these technologies are largely taken from the 2022 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 (Small Modular Reactor)	x	x	x	x
Hydrogen Combustion 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 2022 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	57.6%	49.3%	42.2%	44.23%
New Brunswick	42.8%	41.3%	46.2%	43.3%
Prince Edward Island	54.9%	55.0%	50.1%	50.1%
Newfoundland	51.8%	47.1%	--	--

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	58.8%	16.4%	13.9%

New Brunswick	41.1%	18.0%	13.8%
Prince Edward Island	54.4%	17.8%	13.6%
Newfoundland	50.5%	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 electrolysis or steam methane reforming with carbon capture and sequestration. The gas can be stored in geological formations and combusted in a combustion turbine to generate electricity. Additionally, hydrogen can be utilized in other sectors such as transportation and industry.

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 2022 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.

3.3.7 Policies

The ACES model includes several policies relevant to the electricity sector:

- The federal coal phaseout legislation which requires all that all provinces and territories phase out coal by 2030.
- New Brunswick's 40% renewable portfolio standard, which requires, as of 2020, 40% of electricity sold in New Brunswick to have been generated using renewable energy (electricity imports that have been generated using renewable energy can be counted towards this standard).
- Nova Scotia's renewable electricity standard (40% until 2030; 80% thereafter), which requires 40% of electricity sold in Nova Scotia until 2030 (and 80% thereafter) to have been generated using renewable energy (electricity imports that have been generated using renewable energy can be counted towards this standard).
- The federal carbon tax and the output-based pricing system (OBPS).
  - o The federal carbon price starts at $50/tonne CO_2e in 2022 and increases by $15/tonne CO_2e until it reaches $170/tonne CO2e in 2030. We assume this value increases by 2% annually from 2031 to 2050 in order to preserve the real dollar value of the tax. The federal carbon price, both in nominal and 2018 dollars[12], is presented in Figure 3.2.
  - o The federal OBPS sets an emissions intensity limit for each type of generator in the supply mix. These limits act as a performance standard for generators in each class (e.g., liquid fuels or solid fuels) and are presented in Figure 3.3. The effective carbon levy, then, for a

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[12] The ACES model presents all costs in 2018 Canadian dollars.

given generator is the carbon tax (\$/tonne CO_2e) multiplied by the total production (GWh) and by the difference between its emissions intensity and the output-based standard:

$$Carbon\ Tax = Tax\ Rate\ \left(\frac{\$}{tonne\ CO2e}\right) * Electricity\ Production\ (GWh) *$$
$$\left(Emission\ Intensity\ \left(\frac{tonnes\ CO2e}{GWh}\right) - Output\ Based\ Standard\ \left(\frac{tonnes\ CO2e}{GWh}\right)\right)$$

While not technically a policy, an operational constraint limiting the maximum instantaneous penetration of electricity generation from variable renewables is included. This constraint is modelled after the "Max Instantaneous Wind/Solar Penetration Constraint" outlined in the Nova Scotia Power 2022 Evergreen IRP and is a proxy for several renewable integration constraints that are not able to be properly represented in a linear planning model such as this. The constraint itself limits the share of electricity generation from wind and solar in each timestep for a given region to: 70% for 2025-2030; 90% for 2031-2040; and 100% from 2041 onwards. More information on this particular constraint ("MaxAsynchronousShare") can be found in the Technical Documentation.
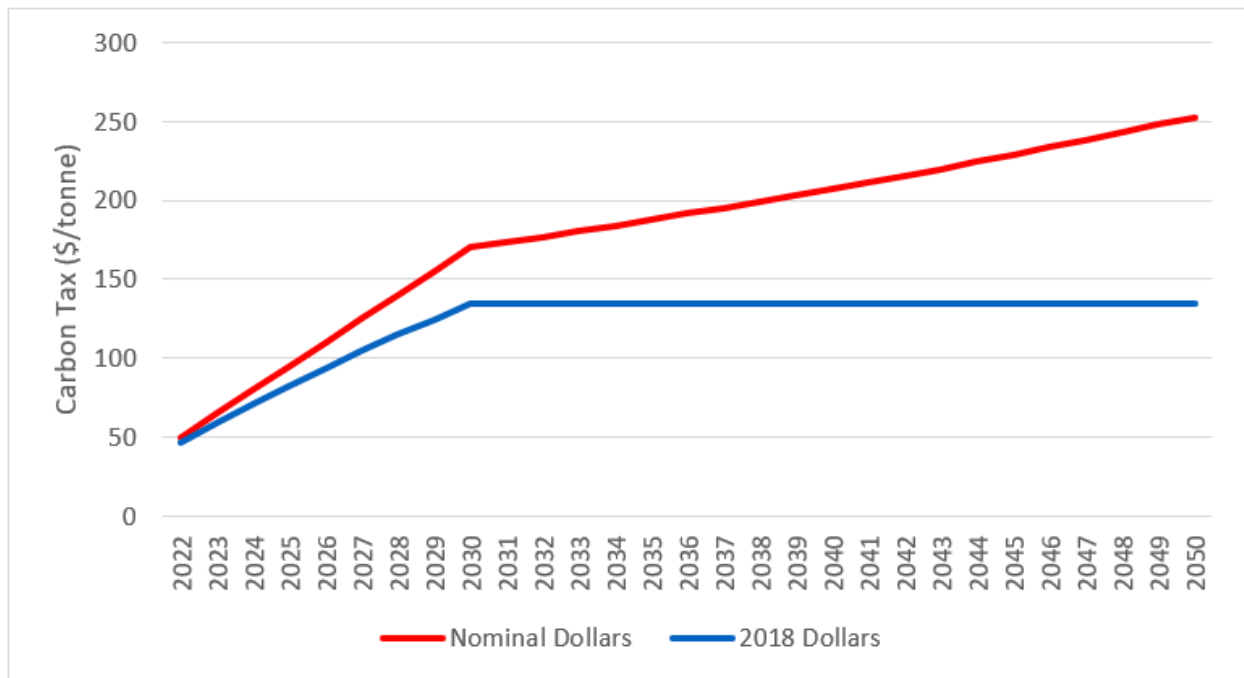

Figure 3.2 Federal carbon price in nominal and real dollars (2018) between 2022 and 2050
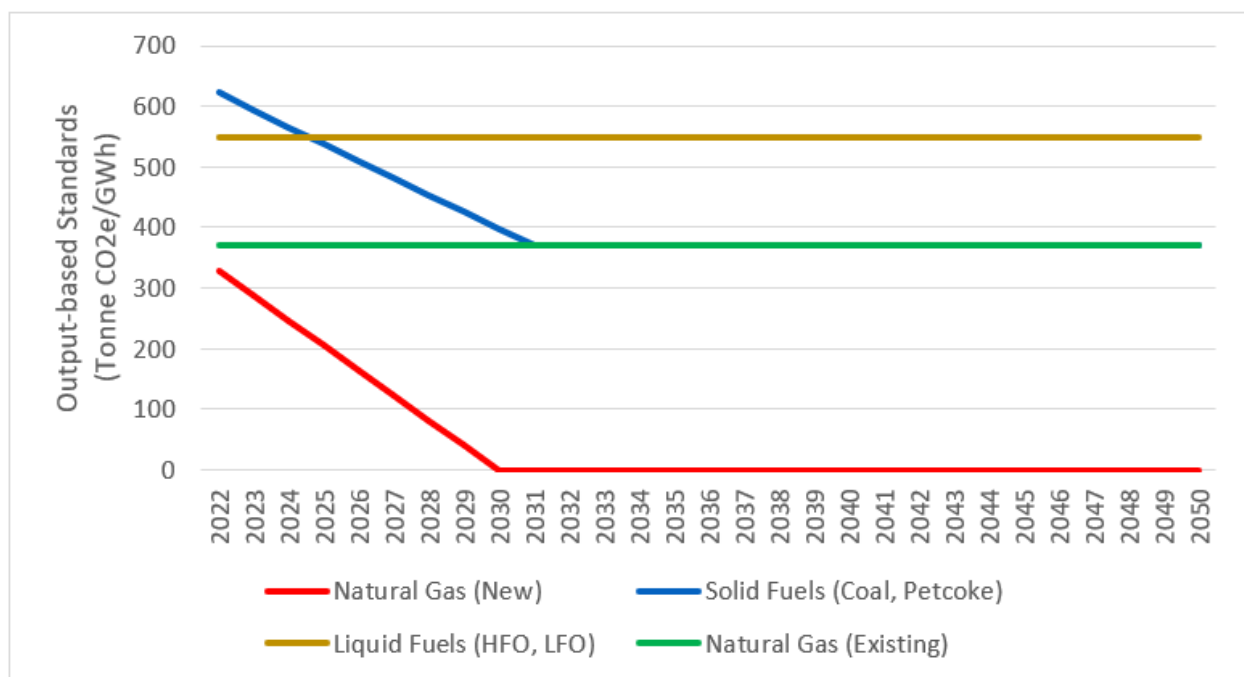
Figure 3.2 Output-based performance standards for electricity generators across different fuel classes between 2022 and 2050

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 forecasted population growth for each region. Electric vehicle charging profiles have been derived in consultation with staff from Natural Resources Canada.

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	Active Trans.
Cars	X	X	X	X		X		X
Passenger Light Trucks	X	X	X	X				X
Freight Light Trucks	X	X		X				
Medium Trucks	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 technology[13] to preserve their energy use and emissions activity.

"Active Transportation" is included as a vehicle substitute for the following vehicle classes: Cars and Passenger Light Trucks. It has no cost nor any emissions associated with its use. The default model configuration does not allow the use of "Active Transportation" by setting its "MaximumActivity" constraint to zero. Model users may relax this constraint to model the effects of increased adoption of

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[13] "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.

"Active Transportation". Relaxing this constraint should be done with caution, however, as the solver will select as much active transportation as possible given it has no cost.

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. 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 ResStock and ComStock tools.[14]. 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 such as population growth.

The existing technology stock is characterized using data from the Comprehensive Energy Use Database. Techno-economic characterizations of new technology options (Table 3.10) are taken from a variety of data sources outlined in the Database Documentation.

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)
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

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[14] Using the "Maine" region.

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 constraints[15].

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 3.11.

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 technology options (based off Keith et al., 2018) distinguished by their financial assumptions and/or fuel type are included.
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 CO_2 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.**

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

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 refining[16]; 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 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 cattle[17]. 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,

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[16] The ACES model makes the assumption that the Come By Chance Refinery in Newfoundland is not operational.
[17] Swine and other livestock produce methane via enteric fermentation, although at much lower levels.

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.

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. 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. Running ACES

Now that you have a good understanding of the model details, you are ready to run ACES. Here, we provide a walkthrough of a complete model run, how to use the dashboard for results visualization, how to modify input databases, and some additional tips for customizing your model databases.

4.1 Installation

4.1.1 What You Will Need

Links and instructions for each step are described in the section below.

1. **Windows Subsystem for Linux***
   o Windows Subsystem for Linux is a compatibility layer for running the Linux operating system on Windows. This will enable you to use faster solvers, speeding up the model run time.
2. **Ubuntu Terminal***

- o Ubuntu is a desktop operating system based on Linux, used to run the commands to run the model.
3. Anaconda
   - o Anaconda is a program that distributes Python to simplify packages and overall use.
   - o ACES uses Python coding; using Anaconda streamlines this process.
4. ACES Model Files
   - o The ACES folder has all the files needed to run the ACES model.
5. Text editor application
   - o E.g., Notepad for Windows users, or TextEdit for Mac users.
   - o This will be helpful for editing code in text files.
6. DB Browser for SQLite
   - o DB Browser is a tool to create, design and edit database files compatible with SQLite.
   - o SQLite is a relational database management system, where the files to run and edit the model are formatted. You can think of DB Browser as similar to Microsoft Excel.

*Windows users only.

4.1.2 Steps for ACES Model Installation – Windows

1. INSTALLING WINDOWS SUBSYSTEM FOR LINUX (WSL) AND TERMINAL
   - o Search your Windows machine for the **Command Prompt** application. When you see the icon, select the **Run as administrator** option.
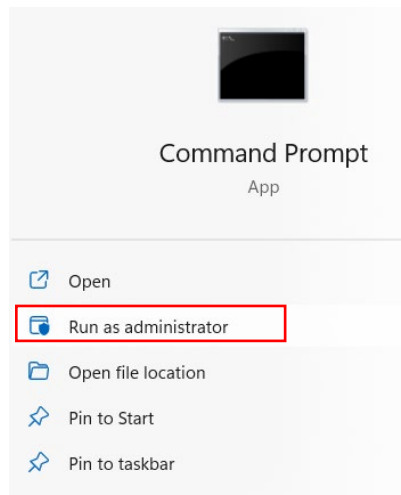
   - o You may be asked if you want to allow this application to make changes to your device – select "yes". This will open a terminal. Type the following command and press **enter**:

     ```
     wsl --install
     ```

   - o This will begin to install Windows Subsystem for Linux. To complete the installation, you will see a message that says you will need to restart your device. Restart your computer.
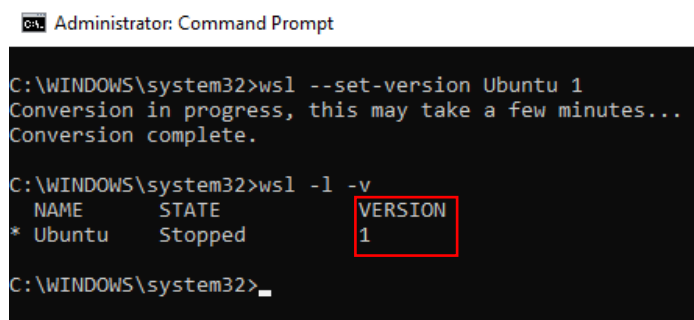   - o Note: if you already have WSL installed, install Ubuntu by typing: `wsl --install -d Ubuntu`

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- o When your computer restarts, it will automatically begin installing Ubuntu. When it is complete, it will ask you to create a UNIX username. Use only lowercase letters and no spaces. Press enter. Create a password. The password line will appear blank when you type, but the text is just hidden for privacy. Type in your chosen password, press enter, re-type it in the following prompt, and press enter again. When done, you should see Installation successful!, a few additional lines, and finally a new command line.
- o In a new Command Prompt window, type the following to change the version of WSL installed:

```
wsl --set-version Ubuntu 1
```
- o To check if it worked, type:

```
wsl -l -v
```
Like the image below, your window should indicate you are now running Version 1:

2. DOWNLOADING ANACONDA FOR LINUX
   - o You can install Anaconda for Linux from your Ubuntu terminal. There are many versions of Anaconda; you can see a list of releases at https://repo.continuum.io/archive. The one you will be using is **Anaconda3-5.3.1-Linux-x86_64.sh**, if you have a 64-bit operating system (this is most likely). If you have a 32-bit operating system, you will likely use the **x86.sh** version. **You do not need to download it from here**, as you will be doing this from your terminal in the next step.
   - o In your Ubuntu terminal, you should have a command line ready. Please remember that any commands you type are **space- and case-sensitive**, and to press enter after each new command you type.
   - o Copy the following and paste into the terminal by right-clicking next to the command prompt, OR manually type (as one line):

```
wget https://repo.anaconda.com/archive/Anaconda3-5.3.1-
Linux-x86_64.sh
```
(or the version of Anaconda that works for you).

When that has loaded, a new command line will appear. Install Anaconda by typing:

```
bash Anaconda3-5.3.1-Linux-x86_64.sh
```

You will be asked to review the license agreement – press enter. Continue to press enter until the entire license agreement appears. The last line will say Do you accept the license terms? [yes|no]. Type **yes** into the prompt. It will then tell you the location that it will install Anaconda3, press enter to continue, then wait for it to install (this will take some time).
You will also be asked if you wish to initialize Anaconda3. Again, type **yes** into the prompt. When the installation is complete, it may ask if you would like to install VSCode. Type **no**.

o Close the terminal and reopen Ubuntu. You should see a command line. To test that it worked, type **which python**. It should print a pathway that has anaconda in it, such as /home/username/anaconda3/bin/python.

3. UPDATING CONDA
   o To update the conda distribution paste or type the following command in Ubuntu:
   ```
   conda upgrade –n base –c defaults --override-channels conda
   ```
   o Press enter. You will receive a prompt asking Proceed ([y]/n)?, type You'y and let the update complete. A command line will appear when done.

4. OBTAINING THE ACES FILES
   o Go to the ACES Model website (acesmodel.ca > Run The Model) and select "Download ACES Desktop Folder" on the side bar.
   o Find the ACES zip you downloaded. Open the zip file and find the ACES folder inside. If your device does not automatically have an extracting tool, you can use a free extracting tool from the internet, such as 7-zip. Once the internal file is extracted, **place the ACES folder in your C-drive**.

5. CREATING THE PROJECT ENVIRONMENT
   o Creating a virtual environment will separate your current project to make it distinct from other Python projects. The environment.yml file is in the ACES folder. It is a text file that lists all the required packages and functions, telling your system what it needs to set up the environment.
   o Open your ACES folder. To set the directory in the Linux Terminal, **Shift+right click** in the ACES folder space. This should give you an extended list of options, including Open Linux Shell Here. Alternatively, you can manually set the pathway in your Ubuntu terminal by typing:
   ```
   cd /mnt/c/ACES
   ```
   This tells the terminal to navigate your current directory (cd) to your C-drive, in the ACES folder. This pathway will only work if the folder is in the C-drive, otherwise put your correct pathway (e.g., `cd /mnt/downloads/ACES` if your ACES folder was in downloads). Press enter.
   o To create the environment, type:
   ```
   conda env create
   ```

- o Let the environment solve and download packages. This will take a while! It can take over an hour but will vary a lot depending on your computer. Leave it alone while it does this, feel free to work on other things in the meantime.
- o When it is finished, a new command line will appear. Activate the modelling environment with:

```
conda activate ACES
```
  You should see a new command prompt starting with (ACES) which has replaced (base), signifying that the environment has been activated.
- o To test that the environment is working, invoke the following command (as one line):

```
python data_processing/MakeGraphviz.py -i
./data_files/ACES-Testing.sqlite
```
  Note: there is a space before and after the "-i"
- o A network diagram of the energy system should appear under the ACES-Testing_input_graphviz directory in your ACES folder in your C-drive. When you open the file, you should get something like this:
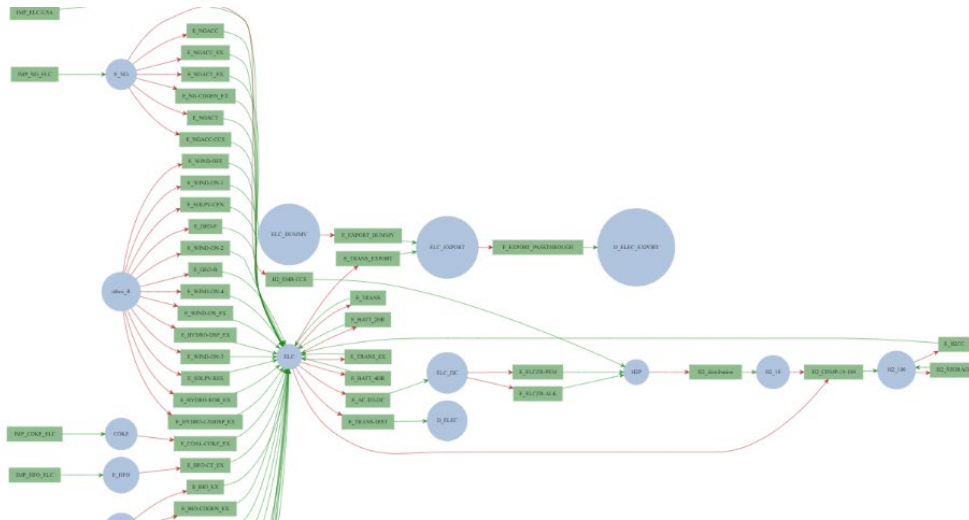
6. DOWNLOADING DB BROWSER FOR SQLITE
- o DB Browser will be helpful for changing the parameters to run different model scenarios.
- o Download here, selecting the Standard installer for 64-bit Windows:
  https://sqlitebrowser.org/dl/
- o Open the downloaded file, agree to the terms, and continue until it is installed. If you get a pop-up asking if the program can make changes to your computer, select yes.

When the above steps are complete, continue to Your First Model Run.

4.1.3 Steps for ACES Model Installation – Mac
1. OBTAINING THE ACES FILES

- Go to the ACES Model website (acesmodel.ca > Run the Model) and select "Download ACES Desktop Folder" on the side bar. Download the folder and copy it to your Documents folder for easy access.
- You will need to extract the ACES folder within the zip. If you double-click the zip file, you should find the ACES folder inside and can move this to your Documents folder. Alternatively, you can right-click the zip file and select Extract All. If your device does not automatically have an extracting tool, you can use a free extracting tool from the internet, such as 7-zip. Once the internal file is extracted, you may delete the zip file.

2. DOWNLOADING ANACONDA
- Go to https://www.anaconda.com/products/individual to download Anaconda for MacOS. When the file is downloaded, open the .pkg file and begin the install process for Anaconda3, following the steps in the install prompt.

3. CREATING THE PROJECT ENVIRONMENT
- Creating a virtual environment will separate your current project to make it distinct from other Python projects. The environment.yml file is in the ACES folder. It is a text file that lists all the required packages and functions, telling your system what it needs to set up the environment.
- Open your ACES folder. Hold the Shift button and right-click, and select "New Terminal at Folder" from the dropdown list. Alternatively, you can manually set the pathway by opening your Launchpad and clicking the Terminal icon. When the Terminal opens, navigate to your Documents by typing: `cd documents` then press enter. Now navigate to your ACES folder by typing: `cd ACES` then press enter. This tells the terminal to set your current directory (cd) to the ACES folder.
- To create the environment, type: `conda env create`
- Let the environment solve and download packages. This will take some time. Leave it alone while it does this, feel free to work on other things in the meantime.
- When it is finished, a new command line will appear. Activate the modelling framework with: `conda activate ACES`
- You should see a new directory starting with (ACES) which has replaced (base), signifying that the environment has been activated.
- To test that the environment is working, invoke the following command (as one line): `python data_processing/MakeGraphviz.py -i ./data_files/ACES-Testing.sqlite`
  Note: there is a space before and after the `-i`

o   A network diagram of the energy system should appear under the ACES-Testing_input_graphviz directory in your ACES folder in your Documents. When you open the file, you should get something like this:
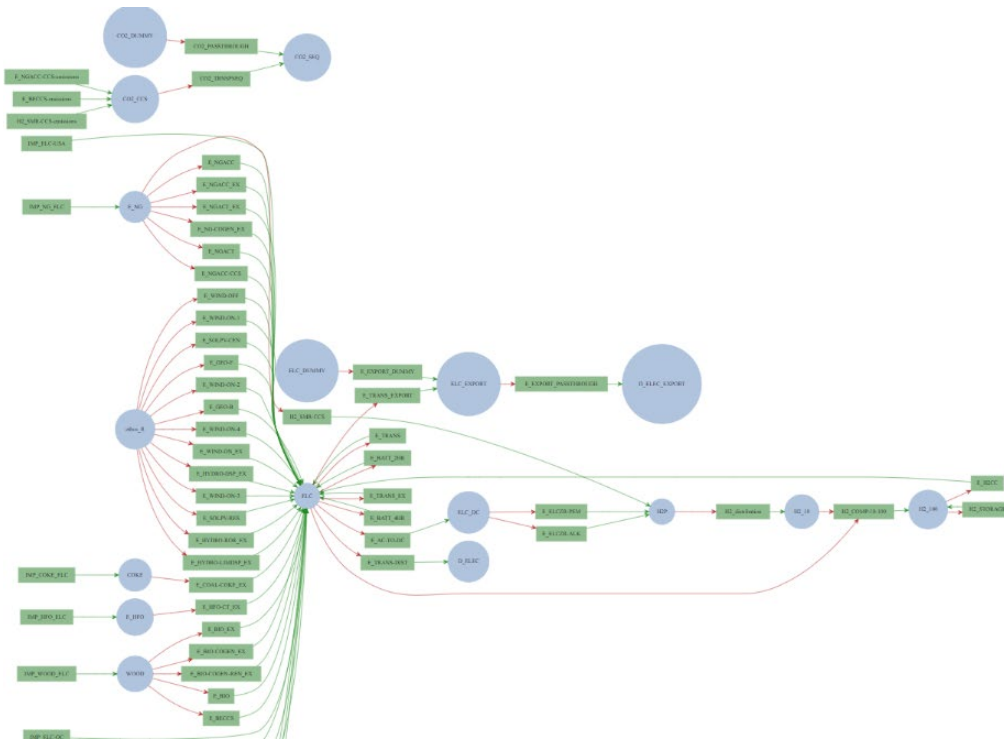
4. DOWNLOADING DB BROWSER FOR SQLITE
   o   DB Browser will be helpful for changing the parameters to run different model scenarios.
   o   Download here, selecting the Standard installer for Mac: https://sqlitebrowser.org/dl/
   o   Open the downloaded file, agree to the terms, and continue until it is installed. If you get a pop-up asking if the program can make changes to your computer, select yes.

4.2 Your First Model Run

This section provides a walkthrough of a complete model run to illustrate the different components of the ACES model framework. This tutorial is designed for a Windows operating system and assumes that you have already followed the instructions outlined in the Installation section. In this walkthrough, we will be using the ACES-Testing.sqlite database – a reminder that the simplified nature of this database makes it suitable for performing test runs of the model, but not for thorough analysis of the Atlantic Canada energy system.

4.2.1 Set Directory and Activate Environment

- First, open the /ACES-Model directory.
- Second, open a Linux shell by holding the Shift button and right-clicking in the /ACES-Model directory and selecting "Open Linux shell here" from the dropdown list (Figure 4.1).
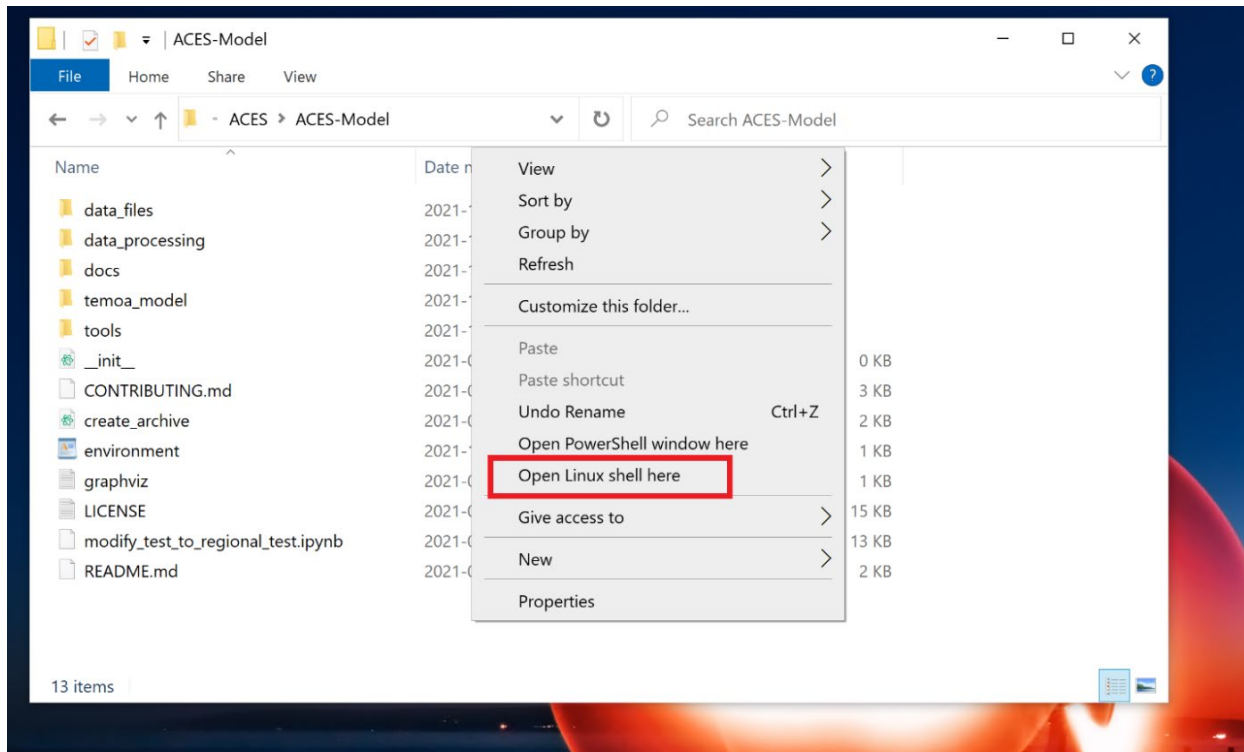

Figure 4.1: Screenshot of Windows pop-up to open Linux shell from ACES-Model directory.

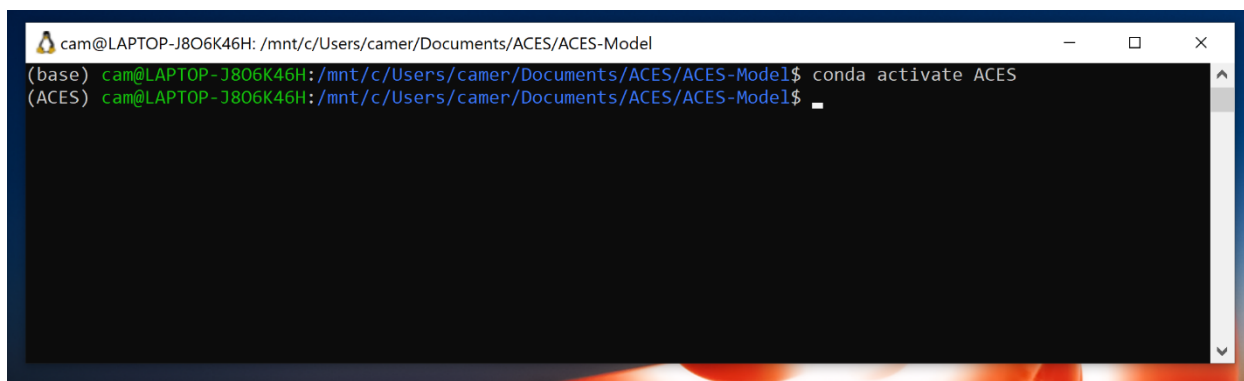- In the Linux shell, activate the ACES environment (Figure 4.2) by invoking the following command:

```
conda activate ACES
```


Figure 4.2: Screenshot of Linux terminal after activating ACES Python environment.

4.2.2 Set Up Configuration File

- The configuration file (temoa_model/config_sample) contains some important settings for your model run. Open this in a text-editing application (Atom, Notepad, etc.), and update the information by following these steps:

1. First, instruct Temoa that we will be using the "ACES-Testing.sqlite" database. To do this, ensure line 11 of the configuration file reads:

   --input=data_files/ACES-Testing.sqlite

2. Next, instruct Temoa where to save the outputs. Although not necessary, it is common practice to save the outputs to the input database. This way, all model information is contained in a single database. To do this, ensure line 15 of the configuration file reads:

   --output=data_files/ACES-Testing.sqlite

   Alternatively, a designated output database can be created and set as your output file. This can be done by copying and pasting the original input database into the folder, renaming it to indicate it as the output file (e.g., ACES-Testing-Out.sqlite), and setting it as your output file in the configuration file. This is an optional, but cautious way to separate databases.

3. Next, provide a scenario name. Model outputs are categorized by scenario names, which conveniently allows for multiple scenarios to be run (by modifying input values, e.g., the cost of a certain technology) with results kept in a common database. We will use the scenario name "BaseCase", as we are not making any changes to the file. To do this, ensure line 19 of the configuration file reads:

   --scenario=BaseCase

4. Finally, select your solver of choice. We recommend using the "cbc" solver, which is free to use and performs relatively strongly against other open-source solvers[18]. To do this, ensure line 37 of the configuration file reads:

   --solver=cbc

---

[18] Temoa uses the Pyomo optimization library and can be used with a number of open-source and commercial solvers, such as Gurobi and CPLEX.

5. Save the configuration file. You can ignore the remainder of the file options.

4.2.3 Produce Model Results

- Initiate the model run by invoking the following line in the Linux shell:

```
python temoa_model/ --config=temoa_model/config_sample
```

- Your Linux shell will now print out a summary of the model configuration (Figure 4.3). To continue with the model run, press the Enter key. This commences the four-step process of solving the model:
  1. Reading the data files.
  2. Creating the Temoa model instance.
  3. Solving the model instance.
  4. Calculating and reporting the results.

Figure 4.3: Screenshot of Linux terminal after model has solved.

- As you can see in Figure 4.3, the process takes approximately four minutes from start to finish (this is indicated by the time in seconds printed in square brackets on the left-hand side). This will vary based on your computer's specifications.

- The results are printed to two locations:
    1. The Excel results file, located in the new directory data_files/ACES-Testing_BaseCase_model. By convention, the Excel results are printed to the directory data_files/XXX_YYY_model, where XXX is the output SQLite database name and YYY is the scenario name.
    2. The ACES-Testing.sqlite database in the Output tables (or the separate Output database if you created one).

Congratulations! You have successfully completed your first model run. You can also use the dashboard visualization to analyze results, using the instructions below.

4.2.4 Approximate Solve Times

The time it takes for the model to solve depends on several factors: the solver you use; varying size and complexity of the databases; the parameter settings of your scenario; and your computer's RAM and processor. Table 4.1 displays the approximate solve times for each database on two example machines. All times provided were completed using cbc – a free programming solver. Cbc is the default solver used in the ACES model configuration files. The default settings for the Cbc solver are as follows: `crossover=off, dualTolerance=1e-6, primalTolerance=1e-6, zeroTolerance=1e-12`. Users can adjust these settings in lines 405 to 408 in `temoa_model/temoa_run.py`.

Table 3.1. Approximate model solve times per database on three machines with different RAM capacity and processors.

Machine	Database	Approx. Solve Time	RAM Requirement
1. 32GB RAM 11th Gen Intel Core i7-11850H 2.50GHz, Windows	ACES-7D-6S	6-8 hrs	11 GB
	ACES-7D-3S	5-7 hrs	10 GB
	ACES-7D-1S	3-5 hrs	5 GB
	ACES-Testing	5-10 mins	< 5 GB
	ACES-7D-6S-NB	10-15 mins	
	ACES-7D-6S-NLLAB	5-10 mins	
	ACES-7D-6S-NS	20-25 mins	
	ACES-7D-6S-PEI	10-15 mins	
2. 8GB RAM Intel Core i7-6500U 2.50GHz, Windows	ACES-Testing	10-15 mins	
	ACES-7D-6S-NB	15-25 mins	
	ACES-7D-6S-NLLAB	15-20 mins	
	ACES-7D-6S-NS	20-30 mins	
	ACES-7D-6S-PEI	15-20 mins	

Note that Machines 2 and 3 do not have sufficient RAM to run the 6S or 3S databases. You can use the ACES Cloud Application to run these databases if your computer does not have sufficient RAM.

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Additionally, it is noted that some solvers do not support the M1 chip on some newer Mac devices. If your computer has an M1 chip, you may need to use a different solver or the ACES Cloud.

4.3 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 repeat the steps outlined in Your First Model Run with a new scenario name. For a walkthrough of an example scenario, please see Tutorials.

4.4 How To Use the Results Dashboard (beta)

The ACES model includes a beta version of an interactive results dashboard. To begin, open a Linux shell in the /ACES-Model directory, and activate the ACES environment via the `conda activate ACES` command. You can launch a dashboard for any database that contains output results, using the following syntax:

```
python data_processing/Dashboard_beta.py -i
./data_files/<results_database> -p <plot_type>
```

where `<results_database>` is the database whose results you wish to analyze (e.g., ACES-Testing.sqlite or any designated output database) and `<plot_type>` is the plot type, which must be either "capacity", "emissions", or "flow". For example:

```
python data_processing/Dashboard_beta.py -i ./data_files/ACES-Testing-
Out.sqlite -p capacity
```

Here, we provide an overview of how to use the dashboard to analyze the ACES-7D-6S-results.sqlite database. This database includes three pre-solved scenarios:

1. The "BAU", or business-as-usual, scenario characterized by no GHG policies.

2. The "CO2Limit" scenario with region-specific GHG limits.
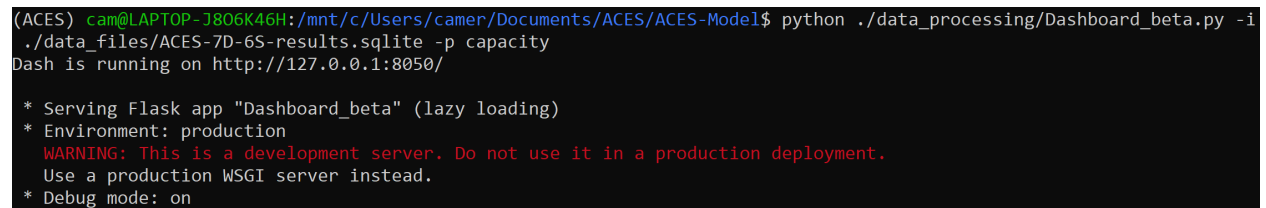3. The "CO2Tax" scenario with the federal carbon tax.

The details of these scenarios are not of importance – we simply wish to illustrate the ability of the dashboard to compare scenario outcomes.

4.4.1 Capacity and Activity Dashboard

The capacity dashboard allows you to analyze the installed capacity and total activity of technologies by toggling through combinations of regions, sectors, subsectors, and scenarios. This is accomplished by invoking the following command in the Linux shell:

```
python data_processing/Dashboard_beta.py -i ./data_files/ACES-7D-6S-
results.sqlite -p capacity
```

Your terminal output should look like what's pictured in Figure 4.4:


```
(ACES) cam@LAPTOP-J8O6K46H:/mnt/c/Users/camer/Documents/ACES/ACES-Model$ python ./data_processing/Dashboard_beta.py -i
 ./data_files/ACES-7D-6S-results.sqlite -p capacity
Dash is running on http://127.0.0.1:8050/

 * Serving Flask app "Dashboard_beta" (lazy loading)
 * Environment: production
   WARNING: This is a development server. Do not use it in a production deployment.
   Use a production WSGI server instead.
 * Debug mode: on
```

Figure 4.4: Screenshot of the Linux shell after invoking the command to launch the results dashboard.

To activate the dashboard, copy the provided URL (in this case "http://127.0.0.1:8050/") into your web browser. The resulting webpage should be the interactive dashboard, as shown in Figure 4.5.
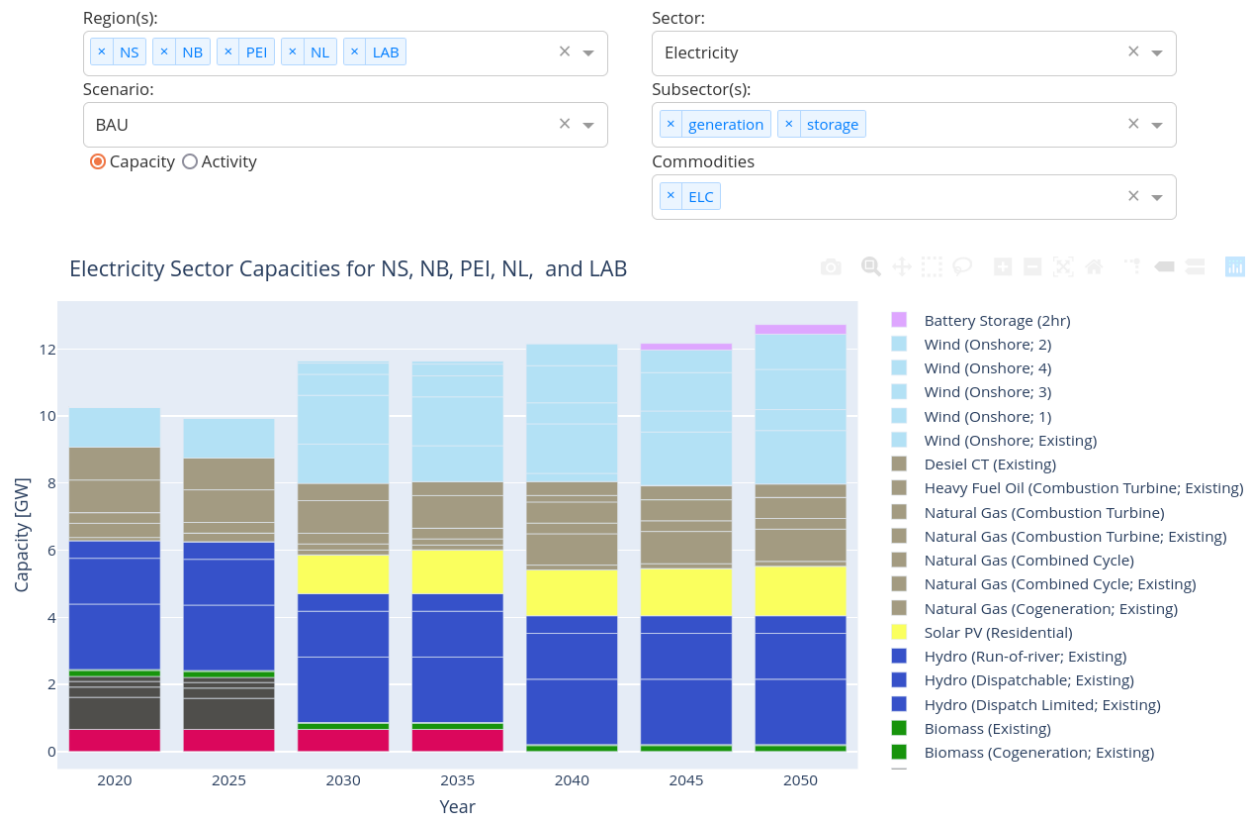
Figure 4.5: Screenshot of the results dashboard displaying technology capacities in the electricity sector.

Here, we discuss the different parts of the dashboard:

- The dropdown "Region(s)" menu allows you to select any combination of regions to analyze. You'll notice that it also provides the "linked" regions over which transmission technologies are defined. That is, you can select the "NB-NS" region if you would like to plot its new and existing transmission capacity.

- The dropdown "Scenario" menu allows you to toggle between results from different scenarios contained within the database.

- The "Capacity" or "Activity" selector determines whether the plot displays the technology capacities or annual activities.

- The dropdown "Sector" menu allows you to select which sector to plot.

- The dropdown "Subsector(s)" menu allows you to select which subsector(s) to include. In the screenshot, we have "generation" and "storage" technologies selected. Please refer to the "technologies" table in the SQLite database to see which sector and subsector specific technologies belong to.

- The dropdown "Commodities" menu allows you to filter technologies within the selected subsector by their output commodity when the plot type is set to "Activity".

You can also edit the overall appearance of the dashboard in the following ways:

- You can change the plot colour of technologies by editing their "color" in the "technologies" table of the SQLite database. Note: colours are informed by their Hex code (This online colour picker can be used to get custom colours and hex codes).
- You can change the order in which technologies are stacked by editing their "plot_order" in the "technologies" table of the SQLite database.
- You can change the label that appears in the legend by editing a given technology's "tech_desc" in the "technologies" table of the SQLite database.
- You can change the sector and subsector classification of technologies by editing their "sector" and "subsector" labels.

To reflect these changes in the dashboard, you must first save the SQLite file and restart the dashboard.

Figure 4.6 and Figure 4.7 highlight the flexibility of the dashboard:

- Figure 4.6 is the result of changing the sector to "Transport", subsector to "LDV-Car", and regions to "NS".
- Figure 4.7 is the result of changing the scenario to "CO2Limit" and switching from the "Capacity" to the "Activity" plot.
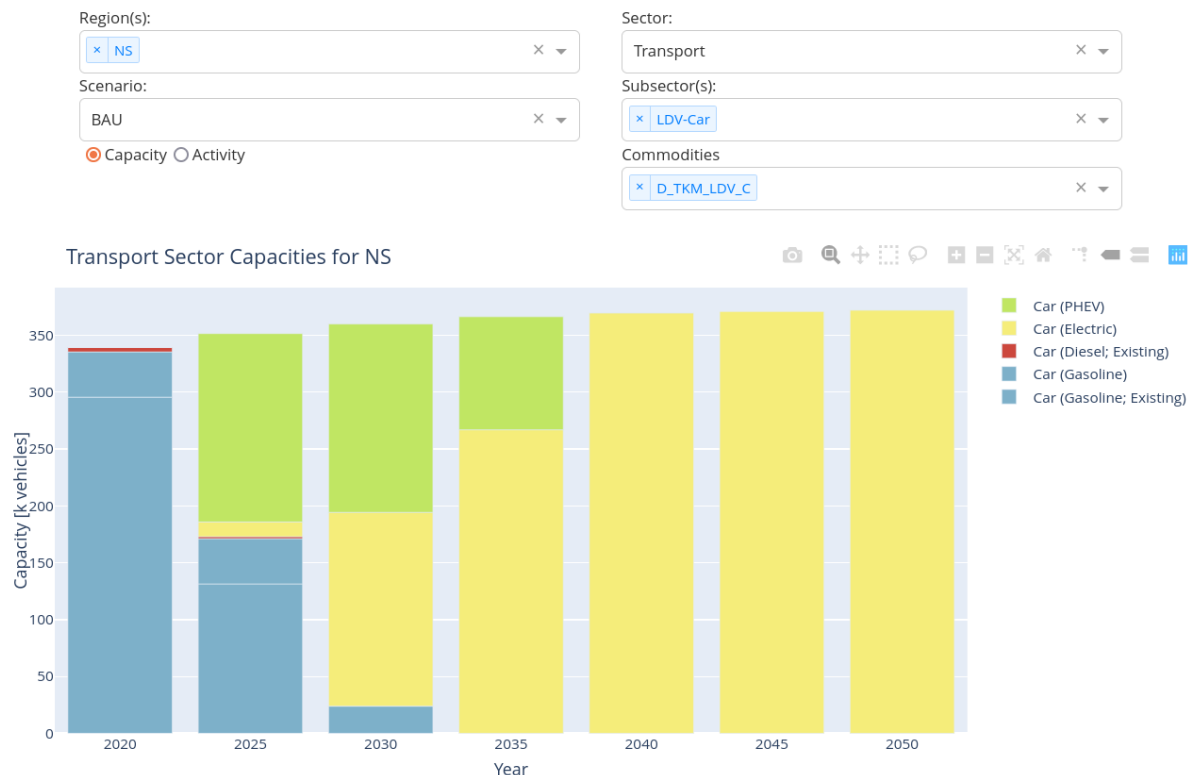

Figure 4.6: Screenshot of the results dashboard displaying technology capacities in the transportation sector and LDV-Car subsector.
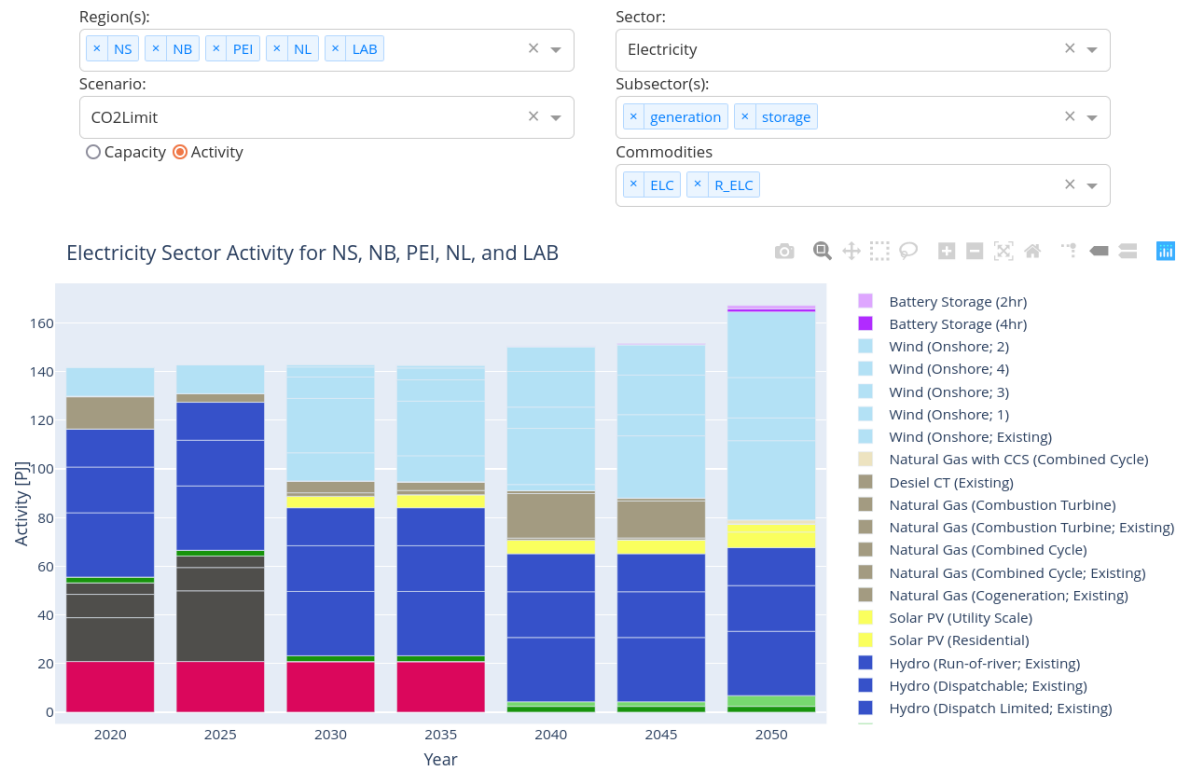
Figure 4.7: Screenshot of the results dashboard displaying technology activity in the electricity sector.

Similar technologies can be grouped together[19] within the capacity plots to simplify the visual output. You can do this by including the optional --super flag in the shell command. For instance, Figure 4.8 displays the dashboard after invoking the following command:

```
python data_processing/Dashboard_beta.py -i ./data_files/ACES-7D-6S-
results.sqlite -p capacity --super
```

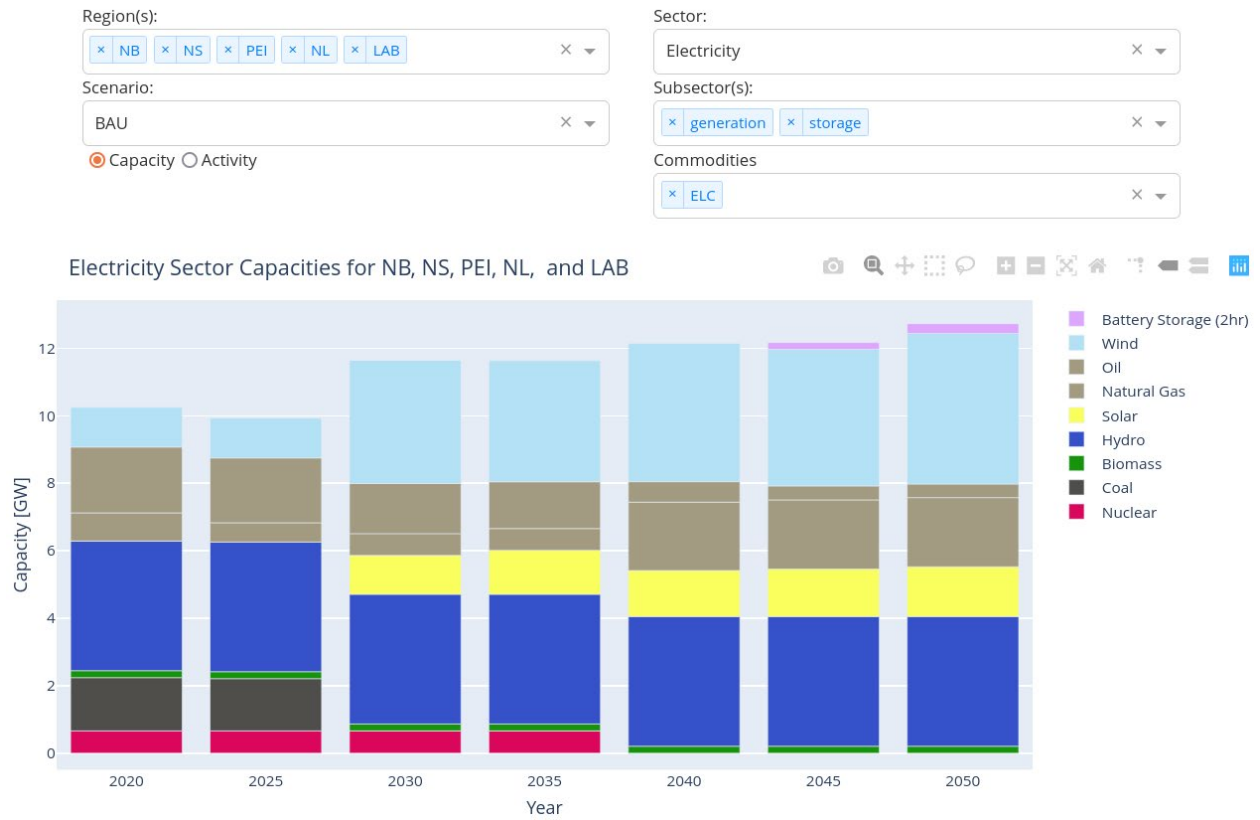[17] The groupings are dictated by the "tech_category" column in the "technologies" table in the SQLite database.

Figure 4.8: Screenshot of the results dashboard displaying technology capacities in the electricity sector using the --super option to group similar technologies.

4.4.2 Emissions Dashboard

The emissions dashboard is created by invoking the following command in the Linux shell:

```
python data_processing/Dashboard_beta.py -i ./data_files/ACES-7D-6S-
results.sqlite -p emissions
```

Figure 4.9 shows the resulting dashboard, filtered by region, scenario, sector, and emissions commodity. The appearance of the dashboard can be edited in the following ways:

- The plot colours of the sectors can be changed by editing their "color" in the "sector_labels" table of the SQLite database.
- The order in which the sectors are stacked can be changed by editing the "plot_order" in the "sector_labels" table of the SQLite database.

Figure 4.9: Screenshot of the emissions dashboard.

4.4.3 Flow Dashboard

The final dashboard option plots the hourly dispatch of electricity generation technologies over the selected representative days for a given year. Activate this by invoking the following command in the Linux shell:

```
python data_processing/Dashboard_beta.py -i ./data_files/ACES-7D-6S-
results.sqlite -p flow
```

Figure shows the resulting dashboard. The drop-down menus and options by which you can change the appearance of the flow dashboard are nearly identical to those outlined in the 4.3.1 Capacity and Activity Dashboard.

It is advised that you only use the flow dashboard to analyse the electricity sector. The beta version does not yet properly render the flow plots for other sectors.
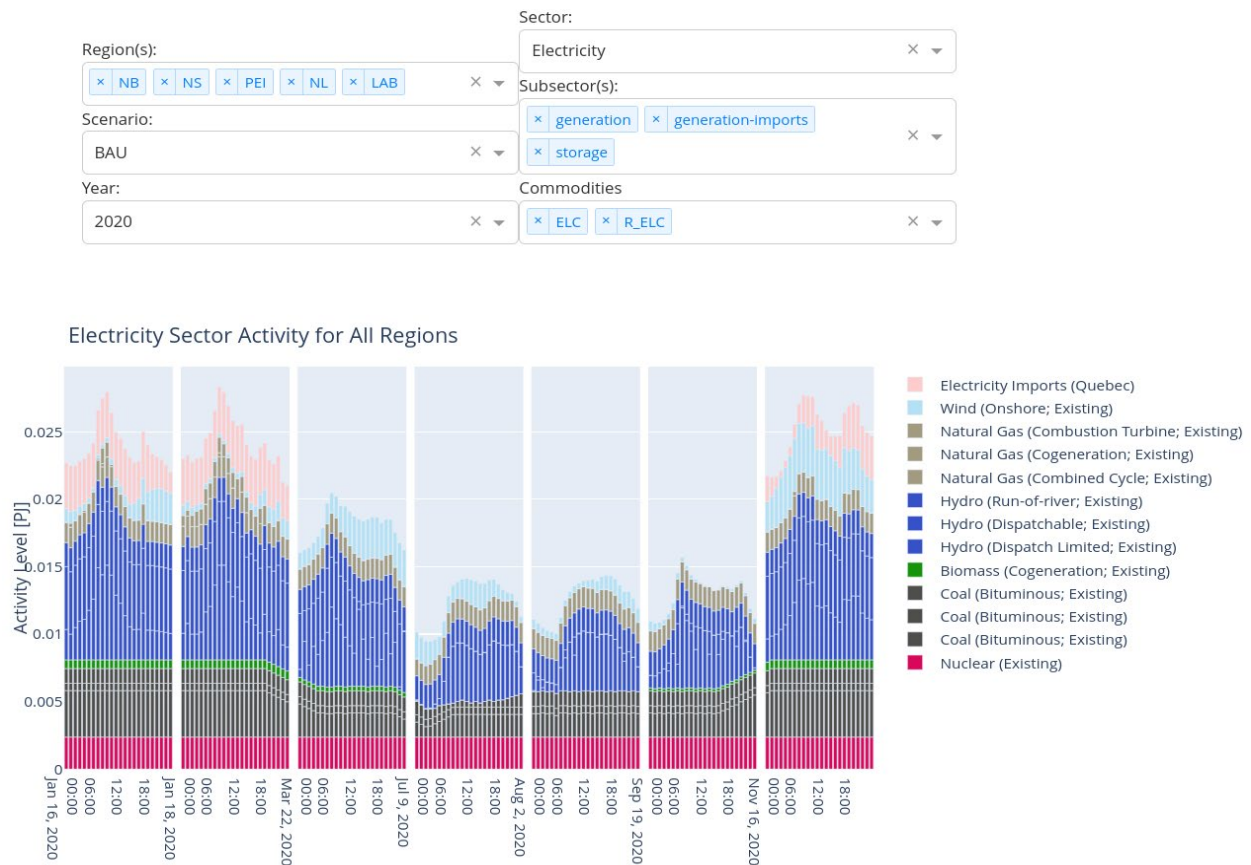
Figure 4.10: Screenshot of the flow dashboard.

4.5 Tutorials

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

4.5.1 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" filter[20].
6. Update the investment costs to reflect the data in Table 4.1. Do this for NS, NB, PEI and NL.

Table 4.1: 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 configuration file (/temoa_model/config_sample) and change the input and output databases to /data_files/ACES-Testing-Tutorial.sqlite and update the scenario name to LowPV. Save the file.
9. Open a Linux shell by holding the Shift button and right-clicking in the /ACES-Model directory and selecting "Open Linux shell here" from the dropdown list.
10. Solve the model by invoking the following command in the Linux shell:
```
python temoa_model/ --config=temoa_model/config_sample
```

You should now find the results printed to the ACES-Testing-Tutorial.sqlite and Excel results file to view and analyze. The dedicated Excel results are printed in data_files/XXX_YYY_model, where XXX is the output SQLite database name and YYY is the scenario name. In the folder, you will see two workbooks that contain the same data, one of which is in Pyam-compatible format. The installed solar capacities in New Brunswick for the LowPV and BaseCase[21] scenario is provided in Table 4.2. We see the cost reductions for the utility-scale solar technology result in increased buildout in New Brunswick.

Table 4.2: 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

4.5.2 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:

---

[20] You may first want to navigate to the "technologies" table to determine the technology name, i.e., E_SOLVPV-CEN, for utility-scale solar.
[21] This scenario was solved as part of the Your First Model Run section.

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:
   o "tech" = your designated name for the technology following the model nomenclature.
   o "flag" = "p". Note: the flag must be one of the options listed in the "technology_labels" table.
   o "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.
   o "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.
   o "tech_desc" = the description of the technology or nomenclature.
   o "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.
   o "cap_units" = units of the technology's capacity, e.g., "GW".
   o "color" = the assigned colour to represent the technology on the dashboard. This field is optional.
   o "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.

8. Open the configuration file (/temoa_model/config_sample) and change the input and output databases to /data_files/ACES-Testing-Tutorial.sqlite and update the scenario name to NewTech.
9. Open a Linux shell by holding the Shift button and right-clicking in the /ACES-Model directory and selecting "Open Linux shell here" from the dropdown list.
10. Solve the model by invoking the following command in the Linux shell:
    ```
    python temoa_model/ --config=temoa_model/config_sample
    ```

4.5.3 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:

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 parameter. In this case, the relevant parameter is "MaxCapacity".
3. Open the database in DB Browser for SQLite.
4. Navigate to the "MaxCapacity" table by first selecting the "Browse Data" tab, then selecting the "MaxCapacity" table on the dropdown menu.
5. Filter the table by entering "E_WIND-ON" into the "tech" filter.
6. Update the entries that read 0.625 to 0.4 to reflect the desired modification.
7. Save the updated SQLite database by pressing CTRL+S.
8. Open the configuration file (/temoa_model/config_sample) and change the input and output databases to /data_files/ACES-Testing-Tutorial.sqlite and update the scenario name to LowWindCap.
9. Open a Linux shell by holding the Shift button and right-clicking in the /ACES-Model directory and selecting "Open Linux shell here" from the dropdown list.
10. Solve the model by invoking the following command in the Linux shell:
    ```
    python temoa_model/ --config=temoa_model/config_sample
    ```

You should now find your results printed to the ACES-Testing-Tutorial.sqlite and Excel results file. Table 4.3 shows a summary of the installed capacities for the different wind technologies in Nova Scotia for the BaseCase scenario and the LowWindCap scenario.

Table 4.3: Summarized results for the BaseCase and LowWindCap scenarios.

		Installed Capacity [MW]

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

4.5.4 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 grow[22].
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"}.

---

[22] 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.

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:

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.
10. Open the configuration file (/temoa_model/config_sample) and change the input and output databases to /data_files/ACES-Testing-Tutorial.sqlite and update the scenario name to WindGrowthRate.
11. Open a Linux shell by holding the Shift button and right-clicking in the /ACES-Model directory and selecting "Open Linux shell here" from the dropdown list.
12. Solve the model by invoking the following command in the Linux shell:
```
python temoa_model/ --config=temoa_model/config_sample
```

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 GW * 2.0 = 0.1 GW) and allows a doubling of installed capacity in each consecutive period.

The model results are shown in Table 4.4, where you can see the effect of replacing capacity limits with growth rates.

Table 4.4: 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.

- o 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.
- o 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.
- o 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 the same as the cost of electricity from export markets in the full model (see the Technical Documentation for more details).

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.

The cost of imports via Nova Scotia, Maine or Quebec is the same as the cost of electricity from export markets in the full model (see the Technical Documentation for more details).

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.

The cost of imports New Brunswick is the same as the cost of electricity from export markets in the full model (see the Technical Documentation for more details).

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.

- o 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.
- o 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 MW link. There are no annual trading constraints.
- Similar to the Atlantic Canada model, Newfoundland and Labrador are modelled as distinct regions.

The cost of imports via Nova Scotia or Quebec is the same as the cost of electricity from export markets in the full model (see the Technical Documentation for more details).