The views expressed in this paper are those of the authors and do not necessarily reflect those of Environment and Climate Change Canada or the Government of Canada. Results are preliminary and expected to change significantly as work on this project is completed.

Pumped Hydro Storage (PHS) and Battery Energy Storage Systems (BESS):

An Assessment of Energy 2020 Initial Response and Identification of Possible Improvements

By Environment and Climate Change Canada

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Introduction

The Economic Analysis Directorate (EAD) of Environment and Climate Change Canada (ECCC) has been using the Energy 2020[1] model for internal policy analysis and development of baseline energy, GHG and air pollutant emissions projections since early 2000s. To conduct this analysis EAD uses the Energy 2020 model linked to the Informetrica model (a macroeconomic model for Canada), and together these two models formed an integrated hybrid modeling framework Energy, Emissions and Economy Model for Canada (E3MC) (see Section 1 for the description of the modelling framework).

Since the late 2000s, EAD developed and published GHG emissions projections annually, with the first publication of an Emissions Trends Report coming out in 2011 (see Section 3.a.v.).

E3MC has a highly detailed representation of the electricity sector, and is a well-proven tool for the analysis of electricity-related issues; a number of electricity sector regulations and equivalency agreements have been analyzed using E3MC (see Section 3.a.v.).

Energy 2020 was selected as the modeling tool for the Energy Modeling Initiative (EMI) project presented in this report. The project team consisted of professionals from two groups within ECCC: the Electricity and Combustion Division, which has expertise on electricity-related technologies, and the Analysis and Modeling Division, which has expertise in energy, emissions and economic modeling for Canada. The project examines the modeling results of including two potential technologies for electricity storage (pumped hydro and batteries) in the Canadian grid. The results presented in the report (Section 2) should be considered preliminary, as several areas of model improvements are identified that could have material impacts on the results. While the impacts could change significantly as a result of model improvements, some observations discussed in the Results section deserve some attention, and could provide some insights into policy development around energy storage.

[1] https://www.energy2020.com/energy-2020

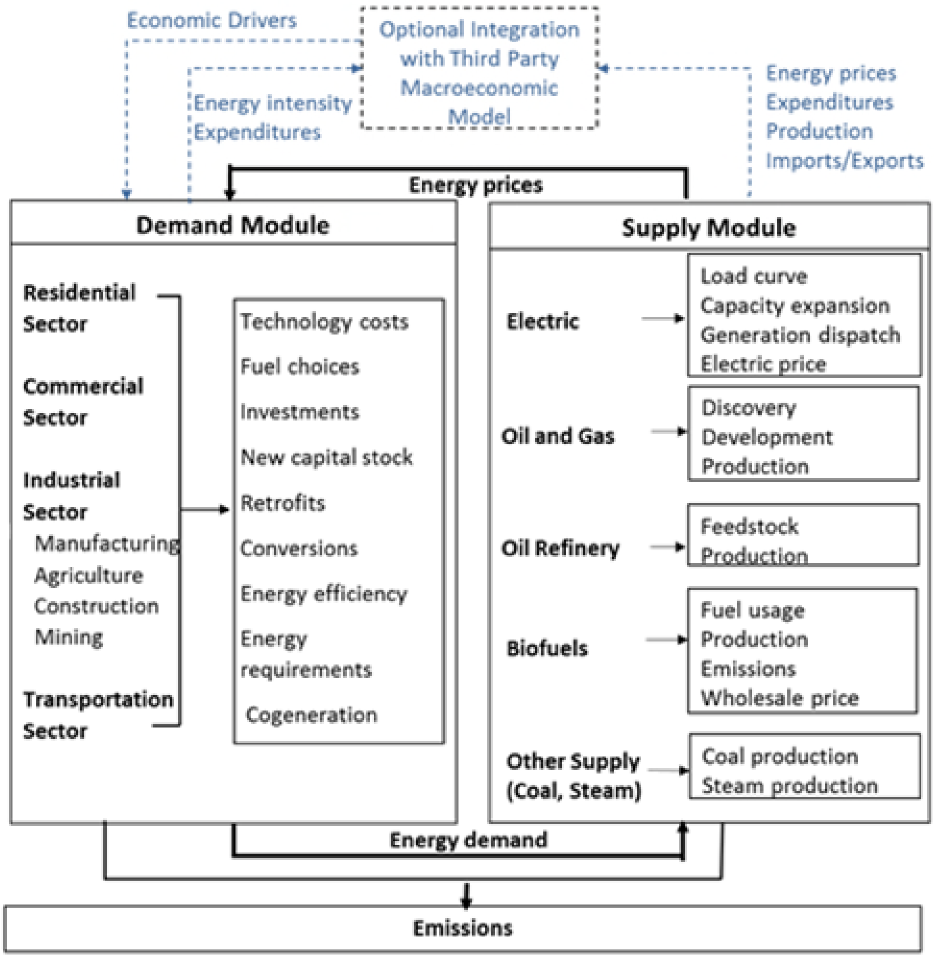
Section 1. Energy 2020 Model

a. Its Nature

Energy 2020 is a bottom-up end-use energy model that in combination with a top-down macroeconomic model forms an integrated hybrid modeling framework Energy, Emissions and Economy Model for Canada (E3MC). Energy 2020 is an integrated regional, multi-sector energy analysis system that simulates energy supply, price and demand across thirty-five detailed fuel types. When coupled with the macroeconomic model, the modeling framework simulates macroeconomic feedback, i.e. the energy supply and demand sectors feed impacts of policies to the macroeconomic model, which then sends economic impacts to the demand sector. Indirect impacts from the macroeconomic model are sent to the supply sector through changes in energy demand.

Energy 2020 uses economic drivers to drive energy demand, which must be met by energy supply (local or imports). Figure 1 illustrates the overall structural design of Energy 2020. The energy demand module consists of four sectors (residential, commercial, industrial, and transportation). Energy demands are calculated and sent as input to the supply module consisting of six energy producing sectors – electricity, oil and gas, refinery, biofuels, coal, and steam. The supply module produces the energy required to meet the energy demand, calculates energy prices, and sends energy prices back as feedback to the demand sector. Both energy and non-energy related emissions are tracked covering eighteen separate greenhouse gas (GHG) pollutants and air pollutants.

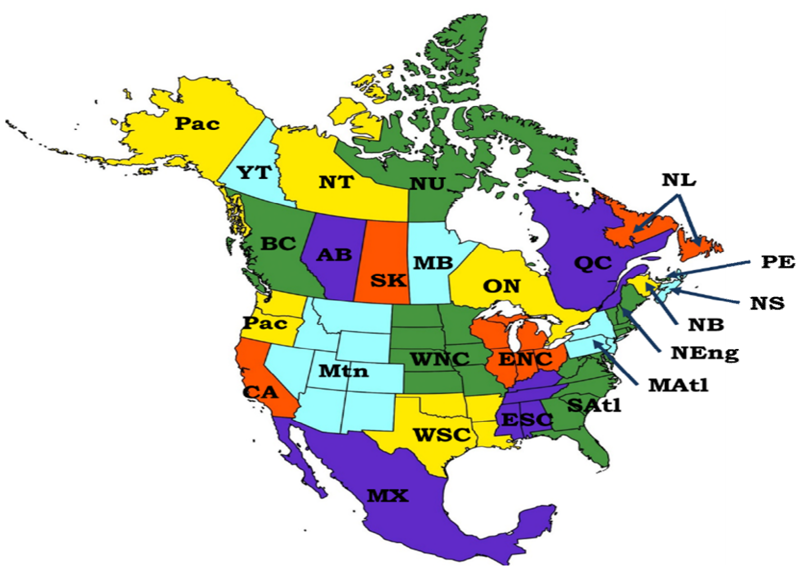
Figure 1. Energy 2020 Model Structure



i. Regions

The currently-defined areas in the model are shown on the map in Figure 2. Each Canadian province/territory is simulated individually within the model; on the United States (U.S.) side the current configuration aggregates the states into ten U.S. regions with California being split out from the Pacific region (for purposes of modeling the Western Climate Initiative's cap-and-trade system); and Mexico is represented at an aggregate national level.

Figure 2. Default Demand Areas in Energy 2020



ii. Demand Sectors

The demand module provides long-range projections of total energy demand (end-use, cogeneration, and feedstock), emissions, energy efficiency, and investments for each of the residential, commercial, industrial, and transportation sectors. Energy demands are projected for all economic categories (household types, building types, industry types, and transportation modes), end-use technologies, and areas represented in the model. The specific economic categories, or types of consumers, represented in the model currently include: three residential and twelve commercial classes, fifty industries, and eight transportation economic categories.

iii. Supply Sectors

Energy 2020's supply module simulates the production of electricity, oil, gas, biofuels, refined petroleum products, coal, and steam to meet the fuel demands required by the demand sector. The model has the capability to produce an endogenous forecast for each of these sectors, use an exogenous forecast, or a combination of both depending on model switches set by the user.

Since the focus of this project report is on the electricity sector, details on the Electricity Module within Energy 2020 Model are provided below.

Electricity Sector

Energy 2020 model has a unit-by-unit representation of the electricity sector and contains:

- Over 1,500 individual generating units in Canada;
- Over 900 aggregated electric generating units in U.S.; and
- Ten aggregated electric generating units in Mexico.

Generating units are specified by defining characteristics, including a name, the node in which they are located, the type of plant, the heat rate, the online and retirement years of the unit, its generating capacity, and fixed and variable costs. These units may be flagged as "industrial" meaning their primary purpose is providing electricity for an industrial facility. Units may also be flagged as "must run", meaning the unit always runs. In addition to the units entered manually in the model, Energy 2020 can build "endogenous" units if needed to meet electricity demand during projection years.

Energy 2020 currently represents twenty-three plant types (see Table 1 below):

- Seven conventional plant types, thirteen non-emitting and/or renewable types, and three other.

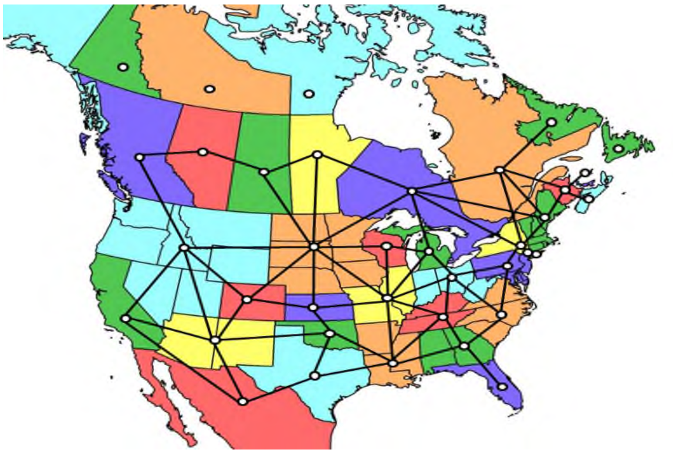
Table 1. Electricity Plant Types

Conventional	Non-Emitting and/or Renewable		Other
Gas/Oil Peaking (OGCT)	Nuclear	Solar PV	CHP/Other
Gas/Oil Combined Cycle (OGCC)	Base Hydro	Solar Thermal	Fuel Cells
Small OGCC	Peak Hydro	Geothermal	Other Storage
Gas/Oil Steam	Pumped Hydro	Onshore Wind	
Coal	Small Hydro	Offshore Wind	
Coal with CCS	Wave	Landfill Gas	
Waste	Biomass		

The transmission network consists of a set of nodes connected by transmission lines. Electric transmission nodes:

- U.S. - 22 electric supply nodes
- Canada - 14 nodes, one for each province and territory plus Labrador
- Mexico - 1 node

Figure 3. Default Transmission Nodes



Energy 2020 determines the amount of electricity needed at each node by minimizing the costs to meet demand (from all residential, commercial, industrial, and transportation demand sectors) across the entire network.

iv. Modeling Approach

Energy 2020 is a behavioral model; it uses algorithms that simulate a realistic decision-making process for each economic actor and associated real-world factors. For instance, in the real world, utilities dispatch electricity to minimize system costs with the help of a linear program. The algorithms within Energy 2020 mimic this process when simulating the dispatch for plants into the future. Consumers making decisions regarding purchasing a new appliance or car, however, generally do not act optimally, but rather make decisions based on limited information available combined with personal preferences. Energy 2020 utilizes Qualitative Choice Theory (QCT) to reproduce the consumers' decision-making process by simulating actual (rather than optimized) responses, allowing it to capture the nuances of technology selections.

Decisions made by the agents within the model are made on the margin. For example, a new vehicle would have a higher efficiency than an existing one, the average intensity of the fleet would change gradually as more and more efficient cars are entering the fleet, and as the stock of vehicles turns over.

The electric supply sector is simulated with individual electric generating units sending electricity over transmission lines connected by a set of electricity nodes. Inputs such as total electricity demand, generating unit characteristics, transmission costs and constraints are used to find an optimal solution (minimizing costs) of generation dispatch. Outputs include projections of future capacity, generation, flows including imports and exports, and the resulting nodal prices. The entire geographic area of the model is dispatched as a single system. Generating units are dispatched by month (or season) across six time periods (from low load hours up to one peak hour) and for three representative day types in the month (peak, minimum, and average).

Imports and exports are endogenously determined from the dispatch routine; however, users are able to specify contract amounts that force the flow of electricity between specific nodes if there are known minimum contracted flows in or out of specific regions.

The load curves output from the demand module are used as input to the supply module's electric supply sector which builds new generating capacity, if required. The fuel used to generate electricity by the electric utility industry is then calculated along with resulting emissions from electricity generation and delivered price of electricity.

Energy 2020 simulates both generating and retail (load serving entities) companies. The current model configuration defines generating and retail companies as a one-to-one correspondence with the areas in the model. Each generating company is assigned a set of generating units, a capacity expansion strategy, a bidding strategy, and contracts with retail companies. Retail companies have contracts with generating companies, sales to demand areas, and a retail cost structure.

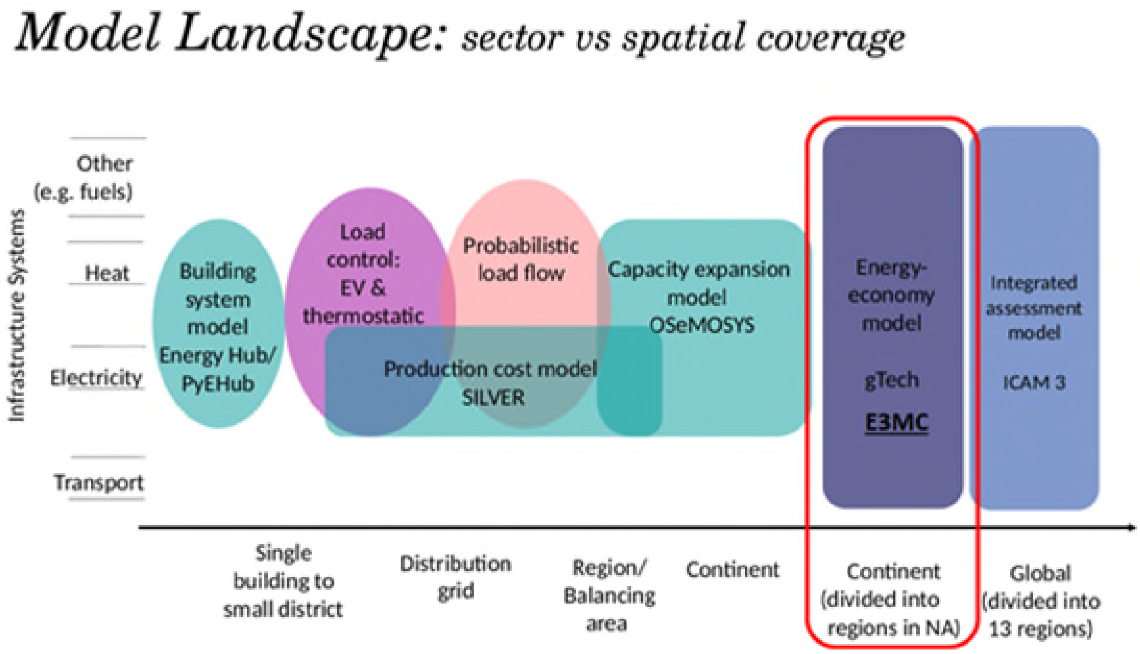
Table 2. Inputs and Outputs for the Electricity Sector

Sector	Outputs	Inputs from Energy 2020	Exogenous Inputs
Electricity Supply	Electricity capacity, generation, transmission flows, imports and exports Fuel usage required to generate electricity (energy demand for Electric Utility Generation industry) Emissions from electric generation Electricity prices Spending on fuel expenditures and emissions reduction permits	Consumer demand for electricity (residential, commercial, industrial, transportation) Peak, average, minimum load by season and time period	Existing and new plant characteristics (location, capacity, plant type, costs, historical generation, fuel demands, heat rates, etc.) Technology innovation curves Emissions coefficients or inventories Emissions caps or reduction requirements

b. Energy 2020's place in the modelling landscape / ecosystem

There exists a variety of energy models with different capabilities, which depend mainly on the issues or problems the models are trying to address. During the Western Workshop of the Energy Modeling Initiative (EMI) in an attempt to classify and categorize the various energy models a Model Landscape (Figure 4) has been presented, which is very useful for describing where the E3MC would fit, and how it compares to other models.

Figure 4. Model Landscape



Source: Energy Modeling Initiative – Western Workshop (Sep. 27, 2019) - An Overview of Energy Models

E3MC is an energy-economy model (similar to the gTech model), which is not focused only electricity sector but also includes all other sectors of the economy. This makes it possible to analyze a large variety of policies across all sectors affecting both energy demand and supply.

c. How it compares with other models with similar objectives

Energy-economy models, could be sub-divided into two main groups of models: partial equilibrium models (systems dynamics or simulation models) and computable general equilibrium (CGE) models. CGE models include MARKAL, G-Tech, etc. Partial equilibrium models or System Dynamics (SD) Models include models such E3MC and U.S. NEMS model. Both CGE and SD models are used for similar purposes, however, one important distinction between these two types of models is how an equilibrium is achieved within the model. Unlike CGE models, the E3MC model does not fully equilibrate government budgets and the markets for employment and investment. That is, the modeling results reflect rigidities of the economy such as unemployment and government surpluses and deficits.

E3MC is a recursive model, which means that the decisions of the agents in the model about savings and investments are based only on previous and current period variables. Recursive models such as E3MC have no foresight.

On the other hand, Computer General Equilibrium (CGE) models are based on perfect foresight assumptions, i.e. saving and investment decisions are determined by a life-time optimization behaviour that takes into account all future economic conditions[i]. CGE models generally belong to a "forward-looking" class of the models.

Energy 2020 is a recursive system dynamics model that simulates the feedback effect between supply and demand for over thirty five specific types of fuels and the resulting effects on greenhouse gas emissions and criteria air contaminants. Energy 2020 has continuous end-use technologies, which facilitate a better long run forecast, since in the long run exact timing of a discrete technology would be unknown. Other models, like optimization models such as MARKAL and simulation models such as NEMS, are limited to the technologies, which are known at the present time. Energy 2020 has discrete technologies in some sectors, e.g. in electricity supply, with an explicit individual representation of all existing or planned electric generating units.

Since U.S. NEMS model is one of the closest to E3MC, Table 3 describes the key similarities and differences between the two models.

Table 3. Similarities and Differences between E3MC and U.S. NEMS

Key Similarities	Key Differences
Overall structure: Macroeconomic driver, residential, commercial, industrial, and transportation demands, electric, oil, natural gas, and coal energy supplies.	**Technology representation**: NEMS has more detailed technologies with projections of discrete technologies. Energy 2020 has less detailed technologies with projections of continuous technologies.
Basic methodology: Economic drivers drive energy demand, which must be met by energy supplies or imports. Energy is also exported.	**Demand sector methodologies**: Energy 2020 methodologies are the same across all demand sectors. NEMS uses different methodologies across sectors.
Capital stock vintaging: Vintaging of energy capital stocks based on retirements, replacements, and new additions.	**Commercial/industrial fuel choice:** NEMS uses varied methods within commercial and industrial sectors. Energy 2020 uses logistic function from consumer choice theory across all sectors.
Residential/transportation fuel choice: Both systems use logistic functions from consumer choice theory to simulate fuel choice in residential and transportation sectors	**Development, maintenance, and data support:** NEMS significantly more time intensive to maintain due to separate models, methodologies, and technology detail.
Electric dispatch of generating units: Individual electric generating unit representation with linear program dispatch to minimizing system costs.	

d. The state of development and evolution roadmap

Energy 2020 was developed by Jeff Amlin and George Backus in 1981. It was an outgrowth of the system dynamics models used by the U.S. government to analyze its national energy plans developed during the U.S. energy crisis in 1977. The initial model, FOSSIL1 (developed by Roger Naill's work at the Dartmouth Resource Policy Group), simulated four sectors with no regional or industry level detail. FOSSIL1 quickly evolved into FOSSIL2 with enhanced supply technology detail. The U.S. Department of Energy used FOSSIL2 from the late 1970s to the early 1990s for energy planning as well as for policy analysis related to greenhouse gas emission reduction efforts. FOSSIL2 subsequently evolved into IDEAS (Integrated Dynamic Energy Analysis Simulation) with an enhanced transportation and electric supply sector and incorporated "optimized" consumer decision-making.[ii]

By 1981, U.S. national level energy planning efforts were diminishing, interest in least-cost planning had increased, and energy policy making was shifting to the regional level. Energy 2020 was developed to fill that need and provided individual energy firms and state agencies with a multi-fuel energy model with a similar design to the DOE's FOSSIL2/IDEAS model.[iii] Energy 2020 also built on the foundation of Andy Ford's EPPAM model, a dynamic simulation of the U.S. electricity sector[2]. Energy 2020 provided clients the ability to perform regional analysis and simulation of detailed energy-demand, energy-supply, and pollution-accounting sectors.

Ongoing development of Energy 2020 has evolved directly from client needs - the model has changed dramatically over the years due to the specific policy interest of the clients. These developments have included:

- In the 1980s, Energy 2020 added increasing level of detailed industries and end uses. Additionally, the energy efficiency representation was split into two types - process and device energy efficiency. The demand sector methodology was enhanced with consumer choice methodology to simulate realistic consumer decisions.
- During the 1980s and into the 1990s, Energy 2020 evolved to provide electric utility level financial detail and simulation of retail and generation companies allowing for simulation of electric industry deregulation. Energy 2020 could automatically configure itself to simulate individual and collections of over 3000 electric utility companies.
- During the 1990s, Energy 2020 also evolved to include electric unit detail and optimization routine for electric dispatch. Numerous examples of use of the model by Kansas Gas and Electric Company, Wisconsin Power and Light's company, Minnesota

[2] http://www.energycrisis.com/hubbert/SystemDynamicsEnergyModeling/

Power, State of Illinois, Southern California Edison, Central Maine Power in application to the electricity sector over 1980-90s.

- During the 1990s, automated linkages were created that would allow integration between Energy 2020 and any desired third party macroeconomic model in order to obtain economic feedback of policies.
- In the 1990s, Energy 2020 added ability to simulate multiple geographic areas in a single model, added data for all the states to the model, and added Canada to the model.
- All types of GHG and air pollutants were added to the model in 1998 for analysis of the Kyoto protocol in 1998.
- Model development continues to occur on an annual basis, primarily driven by the policy analysis needs of Environment and Climate Change Canada. Recent examples of model development would include the development of the oil and gas production module, the endogenous waste module, the biofuel production module.

Prior to 2004, all Energy 2020 projects and development efforts were a joint effort between Policy Assessment Corporation (Backus) and Systematic Solutions Inc. (Amlin) along with occasional project partners, such as the Canadian Energy Research Institute, Rocky Mountain Institute, NewEnergy, ICF, Inc, and Accenture. As of 2005, Systematic Solutions Inc. became the sole entity offering Energy 2020 services and model development.

Over the last 30 years Energy 2020 has been used for load forecasting, strategic planning, regulatory and business development. It has been used in over 20 different countries, but most of its work has focused on the U.S. and Canada.

e. Strengths and Limitations of E3MC

The major strengths of the Energy 2020 model combined with the macro-economic model (E3MC) are that it is integrated, comprehensive, causal model with feedbacks, stocks and flows, and behavioural responses. It uses a highly detailed representation of the Canadian energy system and the model response is calibrated to the Canadian experience. The model describes energy demand and supply at a level suitable for policy evaluation and GHG forecasts. Given that rich detail, the model has the capacity to model many types of policies, not just market based instruments. There is considerable flexibility in terms of parameter and model specification to capture the salient features of many types of policy instruments in the area of energy and environment, such as standards and regulations, incentives, pricing strategies, cap and trade or carbon tax systems.

A limitation of the model is that there are often trade-offs between scope, detail, execution time, data development and budget in order to simulate the complexities of the energy system.

As described above the Energy 2020 model is not forward looking, and the decisions are made for the most part based on the current information. For example, in a recursive structure agents cannot look ahead to see resource depletion and hence would, if allowed, produce and consume these resources at marginal cost of production until they suddenly ran out of them. Forward-looking agents look ahead and see the implications of over consuming depletable resources and hence allocate these scarce resources optimally over time. Banking and borrowing are particular aspects of forward-looking behavior that are important in modeling climate policies. It is argued that inter-temporal optimization with perfect foresight poorly represents the real economy where agents face high levels of uncertainty that likely lead to higher costs than if they knew the future with certainty. Babiker et al conclude that while the forward-looking model has value for some problems, the recursive model produces similar behavior in the energy sector and provides greater flexibility in the details of the system that can be represented.

In some cases, however, such as a decision to build new electric capacity, in order to account for construction delay, the model looks two years ahead to determine whether construction of new capacity is needed, in order to meet future electricity demands.

Section 2. The modelling results

The views expressed in this paper are those of the authors and do not necessarily reflect those of Environment and Climate Change Canada or the Government of Canada. Results are preliminary and expected to change significantly as work on this project is completed.

a. Introduction

Grid-level storage units are expected to become more common in Canada and to contribute to the generation of low-carbon electricity – for example by allowing for more dispatch from, and more construction of, variable renewable electricity (VRE) units like wind and solar. Since there is currently no large grid-level storage unit in Canada, the capacity to simulate this technology has not been fully deployed and tested yet in Energy 2020. This project aimed to assess the response of Energy 2020 to an introduction of grid-level electricity storage units across Canada and to identify areas of model improvements to better capture the range of resulting impacts.

We focussed this project on two different technologies for grid-level storage units:

- Pumped Hydro Storage (PHS), in which water is pumped to a higher-elevation reservoir, to be released later through turbines that generate electricity; and
- Battery Energy Storage System (BESS), in which energy is stored using a battery technology at utility scale.

Despite differences in technical specifications (see Methods below), both systems are conceptually similar. From an economic perspective, they buy low-price electricity from the grid during the baseload period and sell the electricity they generate during peak periods at higher prices. From a GHG perspective, reductions in emissions are expected to occur if the emission intensity of the electricity displaced by storage units (e.g. from peaking gas units) is higher than the emission intensity of the electricity used to recharge the storage units (e.g. from wind units).

b. Methods

The definitions and values of the technical specifications for PHS and BESS units are as follows:

- Generation time: fraction of time during which the unit is intended to generate electricity (i.e. a value of 15% means that storage units can generate during the peaking 15% of all demand periods);
- Outage rate: fraction of time during which the unit does not actually generate electricity, even though it is intended to do so (e.g. due to equipment failure); and
- Storage efficiency: ratio of the electricity generated by the unit and the electricity used to recharge the unit.

Table 4. Technical specifications for storage units

Parameter	PHS	BESS
Generation time (%)	15	15
Outage rate (%)	10	20
Storage efficiency (%)	78	86

Combining the generation time and the outage rate gives the total fraction of time during which the unit actually generated electricity. For PHS this was 15 * (1 – 0.1) = 13.5%, whereas for BESS this was 15 * (1 – 0.2) = 12%. We classified all storage units as “must run” for the purpose of this study, so they were expected to generate at these levels. We made this decision because we did not have the time to gather all the economic data and test Energy 2020 to assess how storage units competed with other unit types for the dispatch of electricity and for the model-driven construction of new “endogenous” units. For this study, the electricity generated by storage units was therefore free (see Discussion below).

The modelling setup for this project consisted of three runs: 1) a Control run without storage units in Canada; 2) a “PHS” run with PHS units only; and 3) a “BESS” run with BESS units only. Results shown below correspond to the difference between a run with storage units and the Control run. The Control run itself was similar to the 2018 “Reference Case” scenario used by Environment and Climate Change Canada in its 2018 Canada’s Greenhouse Gas and Air Pollutant Emissions Projections (see Section 3.a.v). In the other two hypothetical runs, we introduced storage units in 2030 at the levels provided in Table 5 and increased the installed capacities each year until 2050 by 15% of the 2030 values. This set of values was used for this study only and does not represent a forecast of expected deployment of storage units. While we introduced BESS units in each province and territory (PT), we included PHS units in eight of the thirteen PTs.

Table 5. Assumed capacity (MW) of storage units in 2030 and 2050 for provinces and territories

PT*	Capacity in 2030 (MW)	Capacity in 2050 (MW)	PHS	BESS
AB	470	1,880	Yes	Yes
BC	530	2,120	Yes	Yes
MB	240	960	Yes	Yes
NB	130	520	Yes	Yes
NL	88	352	Yes	Yes
NS	94	376	Yes	Yes
NT	4	16	No	Yes
NU	2	8	No	Yes
ON	1,150	4,600	Yes	Yes
PE	14	56	No	Yes
QC	1,800	7,200	Yes	Yes
SK	200	800	No	Yes
YT	6	24	No	Yes
Total BESS	***4,728***	***18,912***	*N/A*	*N/A*
Total PHS	***4,502***	***18,008***	*N/A*	*N/A*

* AB = Alberta; BC = British Columbia; MB = Manitoba; NB = New Brunswick; NL = Newfoundland and Labrador; NS = Nova Scotia; NT = Northwest Territories; NU = Nunavut; ON = Ontario; PE = Prince Edward Island; QC = Québec; SK = Saskatchewan; YT = Yukon

c. Results

Overview

The first objective of this project was to look into the ‘physical’ (as opposed to economical) impacts of adding Canadian storage units into Energy 2020. From this perspective, the results obtained were encouraging: for each year of each run, storage units usually generated the expected amounts of electricity, and the demand for electricity was balanced with supply in each area. The only exception was for the Newfoundland and Labrador storage units, which generated only about 80% of the expected amount of electricity each year.[3]

The second objective was to identify ways to improve Energy 2020 to better account for the impacts of storage units. Before looking into specific results, it is important to note that:

- In the model, dispatch from and construction of VRE units are independent of the level of storage from traditional hydroelectric reservoirs or new storage technologies; and

[3] At the time of writing this report, the cause of this exception has not been investigated yet.

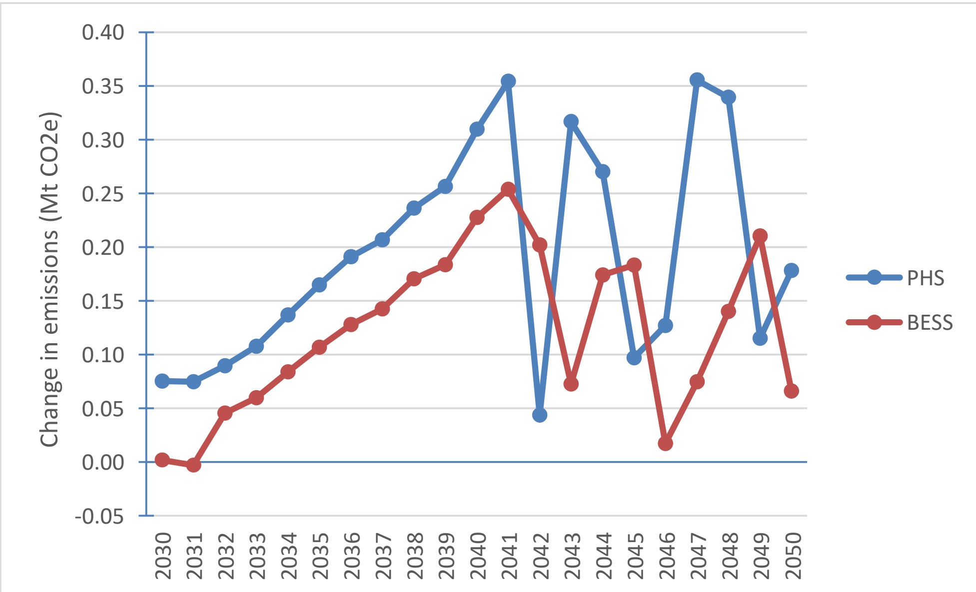
- Electricity prices in each area – and flows of electricity among PTs and with the U.S. – responded to the presence of storage units, but further work is needed to fully and accurately account for the impact of storage units on electricity prices.

We present below a summary of the main results for four different areas: Alberta, Saskatchewan, Ontario, and all of Canada. We focus on changes in the electricity sector alone, but also address changes in total GHG emissions for Canada. Emission projections are published by Environment and Climate Change Canada to 2030 only. For this exercise, results to 2050 are presented for illustrative purposes.

Alberta

The presence of storage units increased electricity GHG emissions in Alberta for all years under both scenario, except for a minor decrease in 2031 in the BESS case.

Figure 5. Changes in electricity emissions (Mt CO2e) in Alberta



As suggested by Table 6, the main cause for these higher emissions was the increase in Alberta electricity generation in order to recharge the storage units. Given that the non-emitting units in the province already generated at their maximum capacity in the Control run (we will address this point in the Discussion), the additional electricity came from natural gas units. Since the resulting additional emissions during the baseload period were higher than the emissions displaced by storage units during peak periods, the net impact of storage units was to increase total emissions from the electricity sector in Alberta.

Table 6. Change in generation (GWh) in Alberta for selected years

Scenario	Units	2030	2035	2040	2045	2050
PHS	Storage	556	973	1,390	1,806	2,223
	Oil and gas	189	387	723	193	398
	All others	0	-3	-10	-26	-83
	Total	744	1,357	2,102	1,973	2,538
BESS	Storage	494	865	1,235	1,606	1,976
	Oil and gas	38	254	535	417	117
	All others	0	-3	-12	-23	-41
	Total	532	1,115	1,758	1,999	2,052

The second factor that contributed the most to the change in generation in Alberta was modified exchanges of electricity with neighbouring provinces. The main difference was with Saskatchewan, to which Alberta generally sent more, and from which Alberta generally received less, electricity under both scenarios. This likely came from the decrease in Alberta electricity prices during peak periods due to storage units.[4] Changes in prices also affected electricity sales in Alberta, a response to interpret with caution given the additional work needed to improve the economic impacts of storage units in the model. The other components of the provincial electricity grid balance – i.e. line losses and electricity sold to the grid by industrial units – were also affected by storage units, but much less than utility generation and exchanges.

Figure 5 also shows that increases in electricity emissions were overall higher for PHS than for BESS, which might be the outcome of two elements. First, the storage efficiency is lower for the PHS technology (78% vs. 86% for BESS). Second, although the installed capacity of storage units was the same in both scenarios, storage units generated more electricity for the PHS technology due to a lower outage rate (10% vs. 20% for BESS). Together these two elements implied that more additional electricity was needed to recharge storage units in the PHS scenario; everything else being equal, this should lead to higher emissions in the PHS scenario.

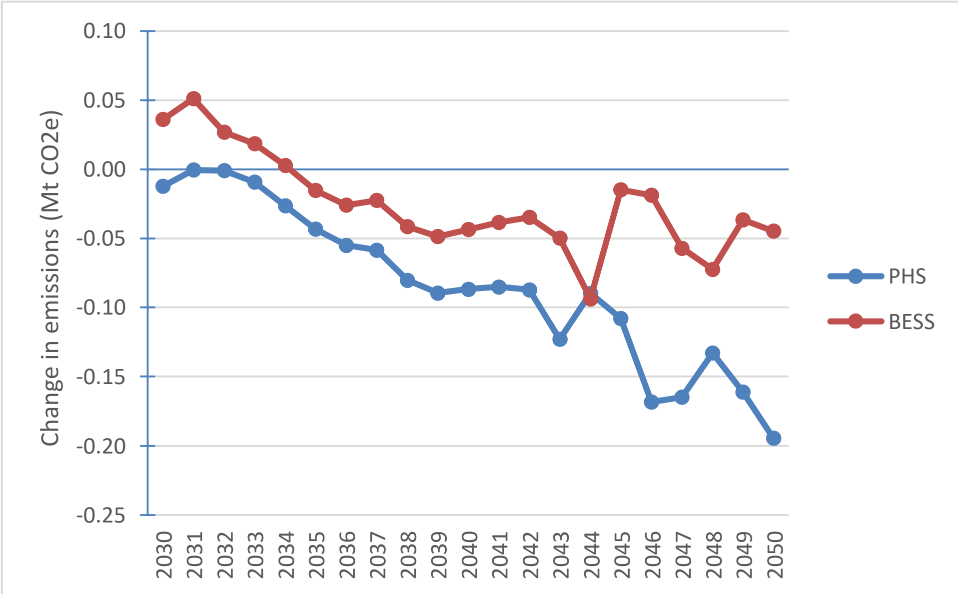
Saskatchewan

Figure 6 shows the change in electricity emissions in Saskatchewan. In the PHS scenario, emissions decreased each year even though there was no storage unit in the province. This happened due to the abovementioned modifications to exchanges with Alberta, which resulted in more electricity being available in Saskatchewan. Consequently, total electricity generation in Saskatchewan decreased with most of the reduction coming from two natural gas units. In the BESS scenario, conversely, storage units in Saskatchewan had to be recharged. The net effect resulting from these two opposing changes in the BESS scenario – i.e. decrease in generation due

[4] This effect was likely stronger in Alberta than in Saskatchewan for both scenarios: in PHS there were no storage units in Saskatchewan, whereas in BESS the assumed storage capacity was lower in Saskatchewan.

to exchanges with Alberta vs. increase in generation to recharge BESS units – changed through time, so that electricity emissions increased for a few years in Saskatchewan before decreasing.

Figure 6. Changes in electricity emissions (Mt CO2e) in Saskatchewan



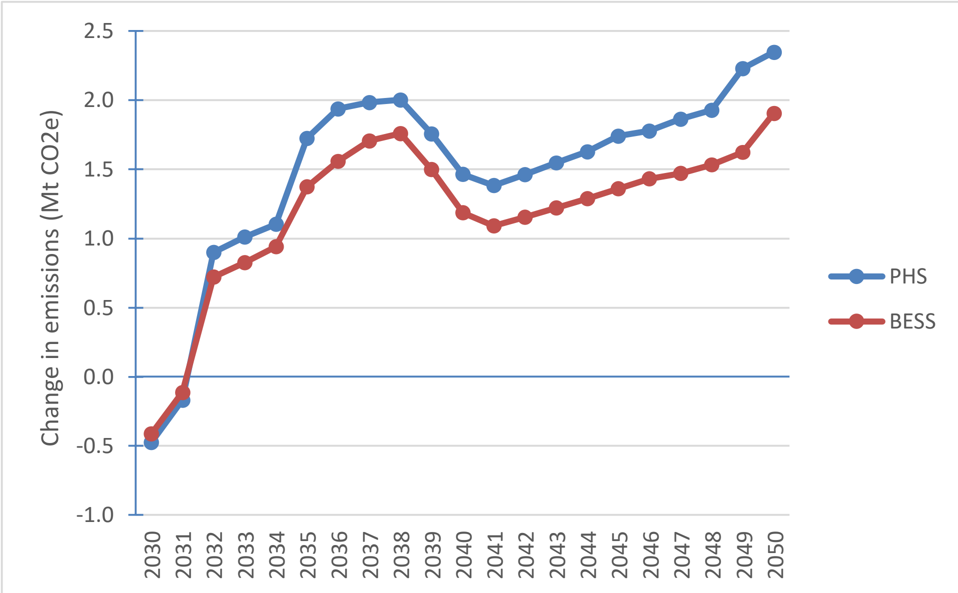
Ontario

Figure 7 shows that under both scenarios, storage units decreased electricity emissions in Ontario for 2030 and 2031, before leading to increased emissions from 2032 onwards. The main reasons behind these increases were similar to the ones explaining the Alberta results:

- More electricity was generated in the scenarios with storage units;
- Given that all non-emitting units were already generating at their full capacity, this additional electricity came from natural gas units; and
- The decrease in electricity prices led to higher net electricity flows out of the province.

However, there was one major difference from the Alberta results: for Ontario, the change in electricity flows – rather than the need to refill storage units – was by far the main factor responsible for the increases in emissions. Moreover, the most noticeable changes in electricity flows were not with neighbouring provinces, but with the U.S. Under both scenarios, electricity exports to the U.S. decreased in 2030 and 2031, but then increased markedly and explained most of the variation in emissions until 2050.

Figure 7. Changes in electricity emissions (Mt CO2e) in Ontario



These increases of exports towards the U.S. (see Table 7) came ultimately from the changes in electricity prices caused by storage units; given the aforementioned limitations in the economic outcomes from the current study, Ontario results must be considered with caution.

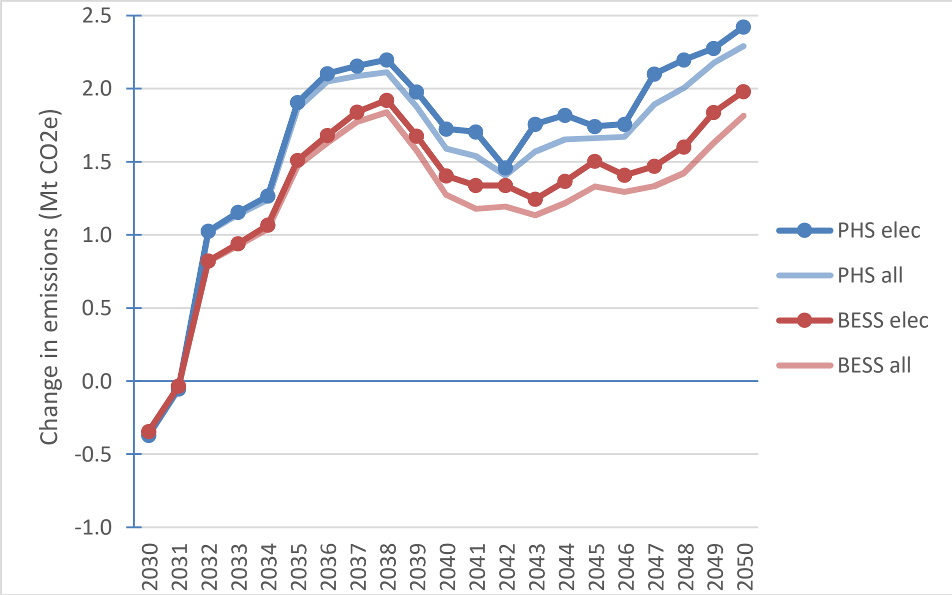
Table 7. Changes in net electricity exports (GWh) from Ontario to the U.S. for selected years

Scenario	2030	2035	2040	2045	2050
PHS	-1,863	4,407	3,187	3,419	4,142
BESS	-1,478	3,657	2,842	2,399	3,657

Canada

Figure 8 shows, for both scenarios, the change in Canadian GHG emissions for the electricity sector as well as for all sectors. We can draw two conclusions from this figure. First, by comparing it with Figure 7 for Ontario, we see that the net changes in Canadian electricity emissions were very similar to the changes in Ontario alone. Second, changes in electricity emissions were almost equal to changes in total emissions, so the impacts of storage units on emissions from non-electricity sectors were limited.

Figure 8. Changes in Canadian emissions (Mt CO2e); electricity alone and all sectors combined



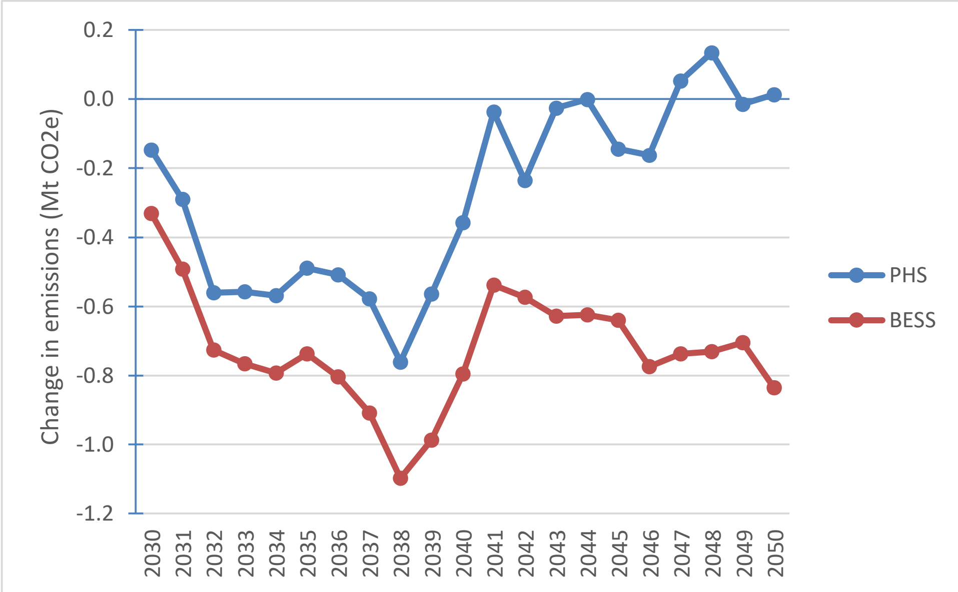
For analytical purposes, changes in electricity emissions (e.g. in tCO2e) can be assigned to two sources: changes in total generation (e.g. in GWh) and changes in grid-level emission intensity (e.g. in tCO2e/GWh). Comparing the results from Table 8 with Figure 8 suggests a succession of two responses. Initially (i.e. for about 2030-2040), changes in emission intensity seemed to have driven the changes in emissions. Then changes in emission intensity became noticeably lower – and even negative in BESS for 2041-2049 – yet changes in emissions slowly increased, suggesting a larger role from the higher generation in the scenarios with storage units. This increase in Canadian generation came primarily from the need to refill an ever-growing demand from storage units, but the higher net exports to the U.S. also contributed.

Table 8. Changes in Canadian electricity emission intensity (tCO2e/GWh) for selected years

Scenario	2030	2035	2040	2045	2050
PHS	-0.96	1.25	0.55	0.07	0.31
BESS	-0.89	0.88	0.30	-0.03	0.01

These higher net exports to the U.S. also displaced electricity emissions in that country. So although storage units generally increased GHG emissions in Canada, Figure 9 shows that their presence in the electricity grid decreased the sum of the total emissions from the two countries in all years for both scenarios, except for small increases in 2047, 2048, and 2050 for PHS. As previously noted for Alberta, the difference in technical specifications – i.e. storage efficiency and outage rate – may explain why the impact of storage units on total GHG emissions from Canada and the U.S. combined was always more beneficial for BESS than for PHS.

Figure 9. Changes in total emissions (Mt CO2e) for Canada and the U.S. combined



d. Discussion

Impact of storage units on electricity emissions

The results from this assessment of the impact of grid-level storage units in Energy 2020 generally showed an increase in Canadian electricity emissions for both the PHS and BESS scenarios. This was partly the outcome of some features from the current version of Energy 2020 – identified above (see Overview of Results) and discussed below – that may need improvement.

Yet one should not simply assume that grid-level storage units automatically decrease electricity emissions. In the case of no changes to the other components of the electricity balance (e.g. flows with neighbouring areas), the impact of such units in a given PT will be the difference between the emissions they displace vs. the emissions needed to recharge them. Expressed in terms of emission intensity (EI) and accounting for the fact that storage units consume more electricity than they generate due to their non-100% storage efficiency, the condition for grid-level storage units to decrease electricity emissions can be expressed as:

*EI_displaced * Storage_efficiency > EI_recharge ** [1]

This equation shows that, everything else being equal, the emission intensity of the electricity used to recharge grid-level storage units has to be *sufficiently* lower than the emission intensity of the electricity they displace in order for such units to decrease emissions. This equation also illustrates why different storage technologies can have different impacts on emissions, as we have seen for PHS vs. BESS. Of course, these two considerations become inconsequential for GHG emissions if the additional electricity generated to recharge storage units comes entirely from non-emitting sources (i.e. if *EI_recharge* is zero). However, this condition of 'carbon-free recharge electricity' should not be assumed to be met automatically, because it depends on the entire portfolio of generation units, their current levels of generation, and the conditions affecting their dispatch (e.g. prices and contracts) in the area(s) under consideration, as well as on the level of deployment of storage units. For example, from the late 2030s onwards in our scenarios, the electricity needed to recharge the grid-level storage units was higher than the total electricity that could potentially be generated by wind and solar units in Canada.

Changes in electricity prices

We saw that changes in prices strongly affected the results through their influence on electricity flows between neighbouring areas. As explained previously, the current version of Energy 2020 implicitly assumes that the electricity generated by storage units is free, which will be modified in the future (see Areas of improvements). Nevertheless, the economic rationale for storage units rests on the much lower prices during the baseload period compared with the peak periods. So although the current study overestimated this effect, storage units can be expected to decrease electricity prices during peak periods, thereby possibly affecting electricity flows and sales.

e. Areas of improvements

The current study allowed us to identify two areas of improvement for Energy 2020 to fully and accurately account for the range of impacts from grid-level storage units.

First, improving the impact of grid-level storage units on electricity prices should be relatively straightforward and involves two different tasks.

1. Gather appropriate data on the different economic parameters used by the model (e.g. operation and maintenance costs) for each storage technology. These parameters will affect the dispatch of storage units and the resulting effect on prices, as well as the amount of new storage units that the models builds endogenously to meet future electricity demands.[5]
2. To produce electricity, non-storage units use another energy source that is free (e.g. water) or has a price (e.g. natural gas) that does not depend on variations in electricity load demand. Grid-level storage units, by contrast, buy electricity as their energy source and do so at a specific time during the electricity load cycle. These units will therefore need to buy electricity at the price of the previous baseload period.

[5] In the current study, we prevented the competition of storage units with other unit types for both dispatch (by classifying them as "must run" units) and construction (by exogenously inputting their capacity for each year). Eventually, we may however want to let storage units compete with other unit types.

Second, a major reason why Canadian electricity emissions increased in the results presented above was that non-emitting units could not generate more because they already operated at full capacity in the Control case. This outcome should itself be analyzed along two different lines.

1. For unit types like traditional hydroelectric reservoirs, which are non-emitting but are not VRE units, this outcome is not necessarily wrong. It is possible that such unit types will be used at their maximum capacity regardless of the amount of additional electricity needed to recharge storage units, especially in PTs where the total capacity from such non-emitting non-VRE units is more limited, e.g. in Alberta and Ontario. In Québec, on the other hand, one would expect to see more generation from traditional hydroelectric reservoirs in the scenarios with storage units – which was the case, to some extent (results not shown). Additional analyses are warranted to assess the projected 'unused' amount of capacity from non-emitting non-VRE units in the 2031-2050 timeframe.
2. For VRE units like wind, solar, and run-of-the-river hydro, the lack of influence of grid-level storage capacity[6] on the dispatch and construction of VRE units appears to be a more immediate limitation. More research will be needed to identify how Energy 2020 could be adjusted to account for the impact of grid-level storage capacity on VRE deployment and collaboration with other modelling groups in Canada could be helpful. At this point, we have identified two possible approaches to do so: 1) use existing data and studies, ideally from Canada, to develop curves of VRE deployment potential vs. grid-level storage capacity, and apply them exogenously to the model; or 2) adapt the structure of the Energy 2020 so that the model uses its own results to estimate, on a year-by-year basis, the potential for VRE dispatch and deployment.

[6] Although the current study dealt with PHS and BESS technologies, other unit types – including traditional hydroelectric reservoirs – can provide grid-level storage capacity for VRE units.

Section 3. Energy 2020 Uses and Potential Synergies

a. Usage

The uses of Energy 2020 have changed with time. In the 1980s, it was mostly used for load forecasting and energy resource planning, then in the 1990s, the model became a popular simulation tool for training concepts of and analyzing the potential impacts of deregulation. In the 1990s, the model use has shifted towards emissions-related analysis and planning, and whereas the model continues to be used for energy forecasting, its primary use throughout the 2000s has been focused on emissions policy analysis. Policy testing routinely include both demand-side, such as energy efficiency, and supply-side policies, such as renewable standards or capacity expansion.

i. Load Forecasting, Energy Resource Planning

The early uses of Energy 2020 in the 1980s were by U.S. electric and gas utilities and by U.S. states and Canada provinces energy planning departments. Utilities used Energy 2020 to develop load forecasts, perform least cost and integrated resource planning, supply planning and to conduct special studies, such as analyzing the impact of the potential development of a line from Hydro Quebec to Maine.[iv]

Some early utilities who used Energy 2020 include Kansas Gas and Electric Company, Wisconsin Power and Light, Minnesota Power, Southern California Edison, Southern Company, and Central Maine Power.

State and provincial energy planners used Energy 2020 to aid efforts in electric and gas utility planning and regulation, to analyze the impact of energy policies on the environment and the economy, and to develop their energy plans. Early states and provinces who used Energy 2020 include Wisconsin, Illinois, Michigan, Hawaii, Vermont, New Hampshire, Massachusetts, the Province of Ontario, and the Saskatchewan Energy and Mines. Other countries also used the model for energy planning, including: Natsionalna Elektricheska Kompania, Bulgaria, Latvenergo, Latvia, Eesti Energia, Estonia, Lithuanian State Power, ZE Turin, Poland, and Zaklad Energetyczny SA, Torun, Poland.

ii. Deregulation Analysis

By the 1990s, the ability of the model to simulate the market behaviors allowed Energy 2020 to be used as a tool to learn the dynamics of deregulation and analyze the impacts of deregulation on consumers, the energy system, greenhouse gases, and the economy, and identifying market strategies and opportunities. Deregulation analysis was in great demand, utilities and government agencies across the U.S., Canada, and other countries used the model for these purposes. Electric generating companies were simulated as competing companies to capture the impacts of energy company mergers, acquisitions, and bankruptcies.

Examples of utilities and government agencies who used Energy 2020 to perform deregulation studies include: the Bonneville Power Administration, Southern California Edison, Duke Energy, Massachusetts Executive Department of Energy Resources, Gornoslaski Zaklad Elektroenergetyczna (GZE), Gliwice, Poland, Ohio Edison, Western Interstate Energy Board, U.S. Department of Energy - Idaho National Engineering Laboratory, Minnesota Department of Public Service, Minnesota Power, Utilicorp United, Houston Lighting & Power Co., Utah Municipal Power Agency, Colorado Rural Electric Association, Northern California Power Agency, Pacific Enterprises, Enova, San Diego Gas and Electric, Pacific Gas & Electric, Enron Trading and Capital, SMG, Inc., Carolina Power and Light, Oklahoma Corporation Commission, New Century Energies, and Companhia Paranaese de Energia (COPEL) and ANEEL (Brazilian Federal Regulators), Duke Energy Brazil, U.S. DOE – Office of Power Technology/National Renewable Energy Laboratory.

iii. Emissions Forecasting and Emission Reduction Policy Analysis

In the 1990s, there also was a major shift to using the model for emissions forecasting and analysis of potential policies or regulations to reduce emissions, analyzing the energy impacts of climate change on the energy system, and emissions mitigation strategies such as carbon capture and sequestration.

The federal government of Canada started using Energy 2020 in 1991 for climate change and criteria-air-contaminant analyses.[v] Natural Resources Canada and Environment Canada used Energy 2020 to analyze policy portfolios that could ratify the Kyoto Accord.[vi]

Subsequently, Energy 2020 was used by the National Round Table on the Environment and the Economy (NRTEE) in its efforts to understand and anticipate the nature and scope of the impacts of climate change. An advisory report was published to address the issue of how to mitigate potential effects of climate change, through deep emission reductions.

Between 2000 and 2003, the Ontario Ministry of Energy, the Province of Alberta, and the Atlantic Provinces also used Energy 2020 to analyze the impact of potential policies related to meeting the Kyoto Protocol. The analysis examined the detailed impacts on emissions, energy usage, and the economy. The analysis considered all risks and uncertainties and included the differing dynamics associated with standards, Green taxes, and auctioned permits.

Other governments that used Energy 2020 for emission-reduction efforts include: the Ontario Ministry of the Environment, Ontario Ministry of Energy (2000-2001), Saskatchewan Energy and Mines (2004-2005), Atlantic Provinces (2003), and the Province of Alberta.

- **Natural Resources Canada, Energy Policy Branch (2010-2016):** NRCan used Energy 2020 to analyze various energy and emissions policies. They initiated development of an enhanced oil and gas production module, including oil refining, natural gas transmission. In January 2015, Natural Resources Canada (NRCan) commissioned a study using Energy

2020 to analyze the impact of a set of climate change scenarios on energy demand at the national level. Scenarios and analyses were performed for all of Canada's provinces/territories and ten U.S. census divisions.

- **Western Climate Initiative (2008-2011)**: Energy 2020 was used for the modeling and economic analysis of the Western Climate Initiative (WCI) greenhouse gases (GHG) cap-and-trade program from 2008 to 2011. The WCI is a group of U.S. states and Canada provinces which developed a GHG Cap and Trade program to reduce GHG. Energy 2020 was used to simulate the regional cap-and-trade system generating forecasts of energy demands, emissions, and GHG allowance prices.
- **California Air Resources Board (2007-2009):** Energy 2020 was used for the modeling and analysis of the California law AB 32, designed to reduce GHG to 1990 levels, and the development of the AB 32 Scoping Plan. With the California Air Resources Board staff support, the model generated a forecast and analyzed the economic impacts of market-based measures to reduce greenhouse gases.

iv. Current uses of Energy 2020

Currently governmental bodies and utilities use Energy 2020 to address climate change policy options, including cap-and-trade, carbon taxes, conservation/efficiency programs, and renewable energy. Using the model as a lingua franca, the Bonneville Power Administration and the Northwest Planning Council both use Energy 2020 to evaluate climate policy and energy/environmental planning issues. The Governor's Offices of Illinois[vii] and Wisconsin[7], Ontario Ministry of Energy,[viii] California Air Resources Board[ix], and the Michigan Department of Environment Quality[x] have recently used Energy 2020 for assessing climate policies. The largest current effort is associated with Western Climate initiative[xi] composed of U.S. western states and Canadian Provinces.

- The **Canada Energy Regulator (CER),** previously called the National Energy Board, uses Energy 2020 to forecast energy demand and supply, analyze the impact of various energy and/or emission-reduction policies (such as energy efficiency programs or carbon pricing), and test scenarios using alternative assumptions (such as price and economic growth). The CER has been using Energy 2020 to develop its annual forecasts published in its Energy Futures reports since 2005.

- **Northwest Power and Conservation Council (NWPCC)** – located in Portland, Oregon, NWPCC has used Energy 2020 since 2006 to develop its electricity and natural gas load forecast, published in its Power Plan reports. NWPCC uses the forecast to help the region's electricity resource strategy. In addition to producing an annual load forecast, NWPCC uses Energy 2020 to test alternative scenarios and analyze impacts of potential electricity

[7] http://dnr.wi.gov/environmentprotect/gtfgw/AG_t.html

and natural gas-related policies. Examples of those scenarios and policies include: high and low price or economic growth scenarios; decarbonization policies; climate change scenarios; energy efficiency and building standards; and policies which encourage fuel switching, such as electrification or direct use of natural gas in water heating.

- **Collaborative Effort with Stanford University's Energy Modeling Forum (EMF).** Energy 2020 is one of the contributing models of studies conducted by Stanford University's Energy Modeling Forum (EMF)[8]. The Forum's goal is to improve the use of energy and environmental policy models to support corporate and government decisions. For each study, the Forum organizes a working group to develop the study design, analyze and compare each model's results and discuss key conclusions. Stanford University provides a non-partisan platform for objective discussion of energy and environmental issues. EMF participants offer alternative views based upon their varied models and experience.
- **Environment and Climate Change Canada (ECCC) -** ECCC uses Energy 2020 to develop its integrated energy and emissions forecast as well as to analyze energy regulatory policies. ECCC has used Energy 2020 dating back to 1999/2000.

v. Use of the Model by Environment and Climate Change Canada

The E3MC modelling framework is used by Environment and Climate Change Canada (ECCC) to develop GHG and air pollutant projections for Canada's 13 provinces and territories, which are published on an annual basis[9]:

- Canada's GHG and Air Pollutant Emissions Projections: 2018[10]
- Pan-Canadian Framework[11]
- Canada's 2016 GHG Reference case[12]
- Canada's Emissions Trends (2011, 2012, 2013 and 2014)
- Canada's National Communications 5, 6, 7 and Biennial Reports 1, 2, 3 to UNFCCC[13]

The model is used to analyse various energy and environmental policies, regulations, programs. It has been used on numerous occasions in developing cost benefit analysis for the regulatory

[8] https://emf.stanford.edu/projects/emf-31-north-american-natural-gas-markets-transition

[9] https://www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/projections.html

[10] http://publications.gc.ca/collections/collection_2018/eccc/En1-78-2018-eng.pdf

[11] https://www.canada.ca/en/services/environment/weather/climatechange/pan-canadian-framework.html

[12] https://www.canada.ca/en/environment-climate-change/services/climate-change/publications/2016-greenhouse-gas-emissions-case.html

[13] http ://unfccc.int/national_reports/

impact assessment statements. In particular it has proven its capacity in modeling electricity related regulations, such as coal-fired electricity phase-out regulations.

- Multi-Sector Air Pollutants Regulations
    - http://www.gazette.gc.ca/rp-pr/p2/2016/2016-06-29/html/sor-dors151-eng.php
- Reduction of Carbon Dioxide Emissions from Coal-fired Generation of Electricity Regulations
    - http://gazette.gc.ca/rp-pr/p2/2018/2018-12-12/html/sor-dors263-eng.html
- Regulations Amending the Reduction of Carbon Dioxide Emissions from Coal-fired Generation of Electricity Regulations
    - http://www.gazette.gc.ca/rp-pr/p1/2018/2018-02-17/html/reg3-eng.html
- Regulations Amending the Renewable Fuels Regulations, 2013
    - http://www.gazette.gc.ca/rp-pr/p1/2013/2013-05-18/html/reg3-eng.html
- Regulations Amending the Passenger Automobile and Light Truck Greenhouse Gas Emission Regulations
    - http://www.gazette.gc.ca/rp-pr/p2/2014/2014-10-08/html/sor-dors207-eng.php
- Heavy-duty Vehicle and Engine Greenhouse Gas Emission Regulations
    - http://canadagazette.gc.ca/rp-pr/p2/2013/2013-03-13/html/sor-dors24-eng.html
- Proposed Regulations Amending the Heavy-duty Vehicle and Engine Greenhouse Gas Emission Regulations and Other Regulations Made Under the Canadian Environmental Protection Act, 1999
    - http://www.gazette.gc.ca/rp-pr/p1/2017/2017-03-04/html/reg1-eng.php
- Proposed Regulations Amending the Ozone-depleting Substances and Halocarbon Alternatives Regulations
    - http://www.gazette.gc.ca/rp-pr/p1/2016/2016-11-26/html/reg1-eng.php

vi. Collaborative Projects

ECCC has also participated in a couple of collaborative modelling projects:

- EMF25 [14] on Energy Efficiency and Climate Change Mitigation, where results from a 10 different energy-economy models for seven modeling scenarios were compared and analyzed. ECCC's participation in this study culminated with a publication of an article in The Energy Journal[xii].

- Another project on the impacts of the deployment of data centres led by Thomas Dandres from Polytechnique Montreal in collaboration with ECCC and other organizations, was done using the Energy 2020 in combination with life cycle assessment methodology[xiii].

[14] https://web.stanford.edu/group/emf-research/docs/emf25/summary25.pdf

b. Possible synergy with other models

i. How to go beyond current results?

As mentioned in the Discussion of our Results (see Section 2.d), results from other models could help us improve Energy 2020 by simulating the influence of grid-level storage capacity on the dispatch and construction of VRE units. For example, models that simulate the hourly cycle of electricity demand and generation, and that use a more detailed representation of intra-provincial transmission and distribution networks, could be used to develop, ideally for each PT, realistic curves of VRE actual maximum generation (i.e. accounting for curtailment of generation when demand is too low) versus the amount of storage capacity. These curves could then be used in Energy 2020 to modulate the annual dispatch from existing VRE units and the annual construction of new VRE units based on the grid-level storage capacity available that year.

ii. Is it a standalone tool only? If not, has it soft or hard coupling?

As described in Section 1.a. ECCC is using Energy 2020 in combination with the macroeconomic model (The Informetrica Model). The two models are linked through a VB interface (hard coupling). In 2016 ECCCC has contracted Oxford Economics to develop a new macroeconomic model, which will be linked to Energy 2020 in a similar fashion.

iii. Does it feed on other models output?

For the development of energy projections, ECCC is exogenously populates the model with oil and gas price and production forecast from the CER, as published in the CER's Energy Future Reports. A recently developed oil and gas production module of Energy 2020, however, allows ECCC to model shocks to the oil/gas prices or supply costs and impact the oil and gas production levels.

For the projections for agriculture sector ECCC is using exogenously the forecast from Agriculture and Agri-Food Canada, developed using the Canadian Economic and Emissions Model for Agriculture (CEEMA) model.

iv. Does it make use of common data sets? Can it produce inputs for others?

ECCC has a well-established relationship and the information sharing with the CER. In most of the situations the data we receive from CER is not yet published.

We also annually align the Energy 2020 model to the most recently available data from Statistics Canada's Report on Energy Supply and Demand (RESD) and other data, as well as the National Inventory Report, that is produced by ECCC using the RESD. However, ECCC does not make use of the published data sets, but rather the full data that arrives under the confidentiality provisions of Statistics Act.

On the other hand, ECCC publishes its data sets underlying the projections report on the Open Data Portal. This includes annual emissions to 2030 by province, by sector and by scenario. With the 2018 projections report we have also published underlying energy demand and supply balances at national level on the Open Data Portal[15].

The outputs (e.g. energy and emissions projections) from E3MC model are used by other models within ECCC, such as EC-Pro, EC-MSMR, and GCAM for Canada, since all of them are calibrated to the projections developed in E3MC. Special routines have been designed to automate the alignment process to the extent possible.

[15] https://open.canada.ca/data/en/dataset/7ba5acf6-ebae-45b6-bb14-84ab56ad2055

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[xiii] Dandres, T., Vandromme, N., Obrekht, G., Wong, A., Nguyen, K.K., Lemieux, Y., Cheriet, M., Samson R. Journal of Industrial Ecology. Volume 21, Issue 5. October 2017. Consequences of Future Data Center Deployment in Canada on Electricity Generation and Environmental Impacts: A 2015–2030 Prospective Study. http://onlinelibrary.wiley.com/doi/10.1111/jiec.12515/full