Accelerating the Coal Phase Out:
Nova Scotia and the Climate Emergency

A technical report and modelling analysis of a low-carbon transition for Nova Scotia's electricity and energy systems by 2030

Prepared by Ralph Torrie, Torrie Smith Associates
for the Ecology Action Centre

November 2019

Table of Contents

`

List of Figures

List of Tables

Acknowledgements

This report was prepared by Torrie Smith Associates on behalf of the Ecology Action Centre. This report would not have been possible without the in-kind support of Ralph Torrie.

Stephen Thomas, Energy Campaign Coordinator with the Ecology Action Centre worked to guide, edit and support the work of this report.

Data and technical support were generously offered by whatif? Technologies and Efficiency Nova Scotia.

This report was reviewed by Mitchell Beer, Susan Holtz, Steve Lapp, Patricia Lightburn, Jacob Thompson, Meghan McMorris, Moe Kabbara, and other anonymous reviewers. We are so grateful for their time, input and valuable feedback.

This report and modelling work were made possible by the generous financial support of the Ivey Foundation, the High Tide Foundation, and individual donors of the Ecology Action Centre's Energy Action Team.

While we are grateful for all the support that made this report possible, the opinions, low-carbon scenarios, policies and proposals presented in this report are those of the authors alone.

The work of moving forward with low-carbon solutions in Nova Scotia take place on unceded, unsurrendered Mi'kmaw territory that is governed by Treaties of Peace and Friendship. All work toward the transition to a low-carbon future on this land must take place in the spirit of these treaties and in collaboration with the Mi'kmaq of Nova Scotia, and with the free, prior and informed consent of Mi'kmaw communities.

Acronyms

BEV	Battery electric vehicle
CanESS	The Canadian Energy System Simulator, proprietary model maintained by whatif? Technologies Inc.
CEUD	Comprehensive Energy Use Database, maintained by Natural Resources Canada.
CT	Combustion turbine
CO_2e	Carbon dioxide equivalent
ENS	Efficiency Nova Scotia
EPRI	Electric Power Research Institute
EV	Electric vehicle
GHG	Greenhouse gases
GPP	Gross Provincial Product
ICE	Internal combustion engine
Mt	Megatonne, one million metric tonnes
NSPI	Nova Scotia Power Incorporated
PHEV	Plug-in hybrid electric vehicle
PKT	Person kilometres of travel
SFD	Single Family Detached
SUV	Sports utility vehicle
VKT	vehicle kilometres of travel
VRE	Variable renewable energy. This refers to resources such as solar and wind energy for which the supply fluctuates on multiple time scales, from seconds to hours to days.

Foreword

We are living in the era of the climate crisis. Business-as-usual planning for our energy systems is no longer an option. No matter what action we take, our future holds unprecedented change.

In this moment, we can set an ambitious course for the transition of our energy, economic and social systems that will meaningfully reduce emissions, create jobs and leave no one behind. The actions we take between now and 2030 will be critical in how the climate crisis takes shape over the many decades to come. Nova Scotia is well positioned to be a leader in this transition and take meaningful action on climate change. In order to rise to the challenge, however, we must do much more than is currently planned.

There is no longer time for half-measures and disjointed incremental actions. When it comes to climate change, there is a critical difference between doing *something* and doing *enough*. Moving forward, we must have the courage to look toward deep, system-level changes regarding the ways we produce, transport and use energy in order to set and meet climate targets that keep global temperature rise to below 1.5°C.

This report proposes transition pathways for the electricity sector that are compelling, bold and realistic. We do not seek to re-invent or compete with large-scope, million-dollar energy system modelling efforts, but we hope to propose low-carbon scenarios for the electricity sector that are technically, economically and socially achievable.

No matter which technologies or infrastructure we move forward with, when creating policies and frameworks for this transition we always must ask the central question, ‘who benefits?’. We must ensure that no one is left behind, and that the real benefits of this transition are seen by those already affected, and those affected worst, by existing environmental injustice, energy poverty and by the climate crisis.

Wherever possible, community-owned and Indigenous-owned distributed resources should be prioritized, energy affordability should be central, and community agency should always be upheld.

Although the use of existing hydroelectricity projects helps greatly toward the decarbonization of Nova Scotia’s electricity and energy mix, the construction of new large hydroelectricity projects should not be considered as a socially viable or cost-effective climate solution. The Gull Island project in Labrador, for example, should not be constructed in the name of decarbonization in Nova Scotia or elsewhere. This is in acknowledgement of the very real Indigenous land rights considerations and issues of human health, habitat loss and contamination, and environmental racism that are routinely associated with new large hydroelectricity projects.

Policy makers and institutions need to take leadership from those most affected and allow them to lead in creating and guiding the important work ahead - workers, Indigenous communities, African-Nova Scotian communities, migrant communities, low- and middle-income people, rural communities and young people.

We believe the analysis presented in this report is compelling, realistic and an example of the scale of thinking that is necessary when responding to the climate emergency. Yet, this analysis is only the beginning, and we welcome analysis from government and the private sector that builds upon the work of this analysis. We look forward to the necessary conversations that this report can begin, and we look forward to working together to ensure we rise to this challenge while leaving no one behind.

Together, we can get this done.

Stephen Thomas
Energy Campaign Coordinator, Ecology Action Centre
November 2019

Executive Summary

This report describes a scenario for an accelerated phase-out of coal and oil-fired electricity generation in Nova Scotia that results in a grid that is 91% supplied by renewable, zero carbon electricity, by the year 2030. The scenario also includes shifting to more electric vehicles and to electric heat pumps for space and water heating that reduce tailpipe emissions from personal vehicles by 50% and emissions from building heating systems by 67%. A snapshot of the changes to the electric grid and the emissions in the scope of this analysis can be found in figures ES-1 and ES-2, below.

The results of our analysis indicate that such a transition is both technologically feasible and fundamentally economic. This corroborates a growing number of studies that point to the same conclusion: we have the technologies we need to make this transition, and the economies we will create by implementing this transition are healthier, wealthier and more resilient than the economies we will fall into by continuing to burn fossil fuels. Where we need to do the most

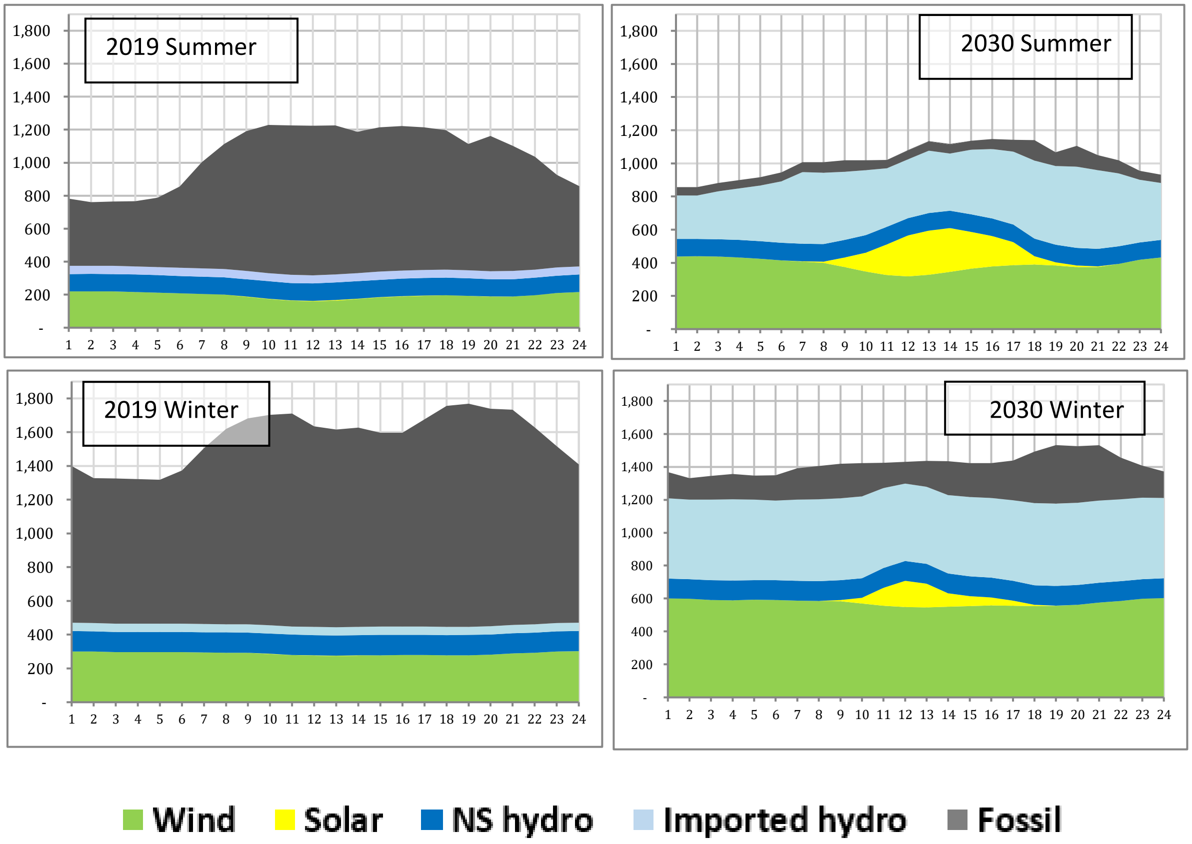

Figure ES- 1. Average electricity supply (MW), 2019 base year vs. 2030 low carbon scenario.

work is on the soft infrastructure -- on mobilizing the policies, institutional frameworks, and financing systems needed to take solutions to scale and do it quickly.

The technical and modelling work in this report is based on the three pillars of low carbon futures: efficiency, electrification, and decarbonization of the grid. It is only one illustrative scenario, but it reflects the rate and magnitude of change that is needed to mount an effective emergency response to reducing emissions throughout Nova Scotia's energy sector. With an initial focus on an accelerated schedule for shutting down the province's coal-fired power plants, the scope was expanded to include the fossil fuel consumption of buildings and personal vehicles. Key measures include a comprehensive, multi-billion dollar program of deep energy retrofits of residential and commercial buildings; converting half the oil-heated residential building stock to electric heat pumps; phasing out electric resistance heating in favour of heat pumps for both water and space heating; continuous improvement of the efficiency of lighting, appliances and other electrical equipment; and the growth of the electric vehicle stock to include 125,000 plug-in hybrids and 75,000 battery electric vehicles by 2030.

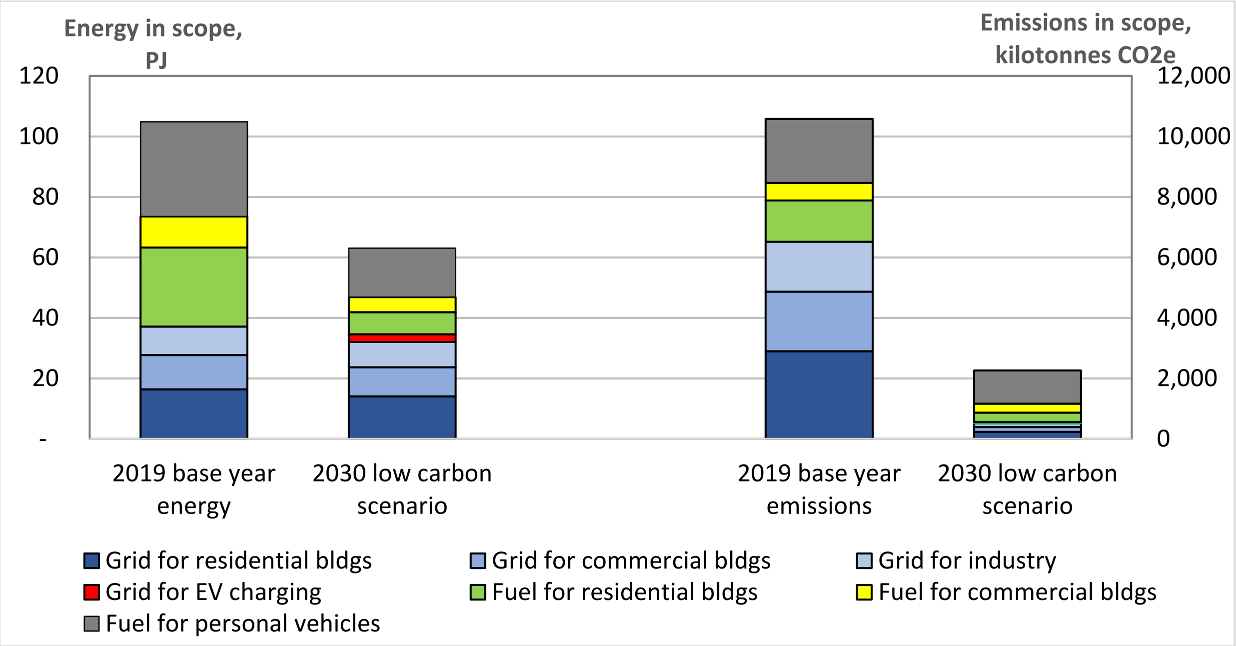

Figure ES- 2. Energy (bars on the left) and emissions (bars on the right) included in scenario, 2019 baseline vs. 2030 low carbon scenario.

Supply side measures include 800 MW of new wind generation, 430 MW of solar power, the construction of the second intertie with New Brunswick, and increased purchases of hydropower resources from Quebec and the Maritime Link market block.

As shown in figure ES-2, in the 2019 base year simulation, electricity provides 35% of the energy consumption included in the scenario analysis; by 2030, electricity's share has grown to 55% of the total. Yet with comprehensive energy efficiency measures, total electricity consumption in 2030 is 7% lower than in the 2019 base year simulation. With the total consumption of electricity held in check and even declining slightly, an expanded supply of wind, hydro and some solar electricity is enough to supply over 90% of total generation by 2030, and the carbon intensity electricity end use drops to 58 grams per kWh. The combined total of emissions from electricity generation and emissions from building and personal vehicle fuel use drops by 79% relative to the base year level.

This analysis developed primarily as an emergency response strategy for addressing the climate change crisis. However, as shown in Figure ES-3, a preliminary analysis indicates that financial savings from reduced fuel use in buildings and personal vehicles, and reduced fossil fuel purchases for power generation, could largely and possibly completely pay for the annualized investments in deep energy retrofits, electric vehicles, and renewable electricity generation required by the low carbon scenario put forward in this report.

The critical challenges facing the deployment of a transition to a low carbon energy system that is deep enough and quick enough to constitute an effective emergency response to climate change are not technological, and neither are they fundamentally economic. The climate emergency response scenario described here costs an estimated $1.6 billion in annual expenses and annualized investments in buildings and infrastructure. Offsetting those expenses are annual energy cost savings of $600 million in heating fuel, $529 million in gasoline savings, and $222 million in reduced coal and other fossil fuel costs for electric power generation. The transition will revitalize local economies, generate a small army of professional and skilled labour positions throughout the province, and largely or completely pay for itself while doubling energy self-reliance and enhancing economic independence.

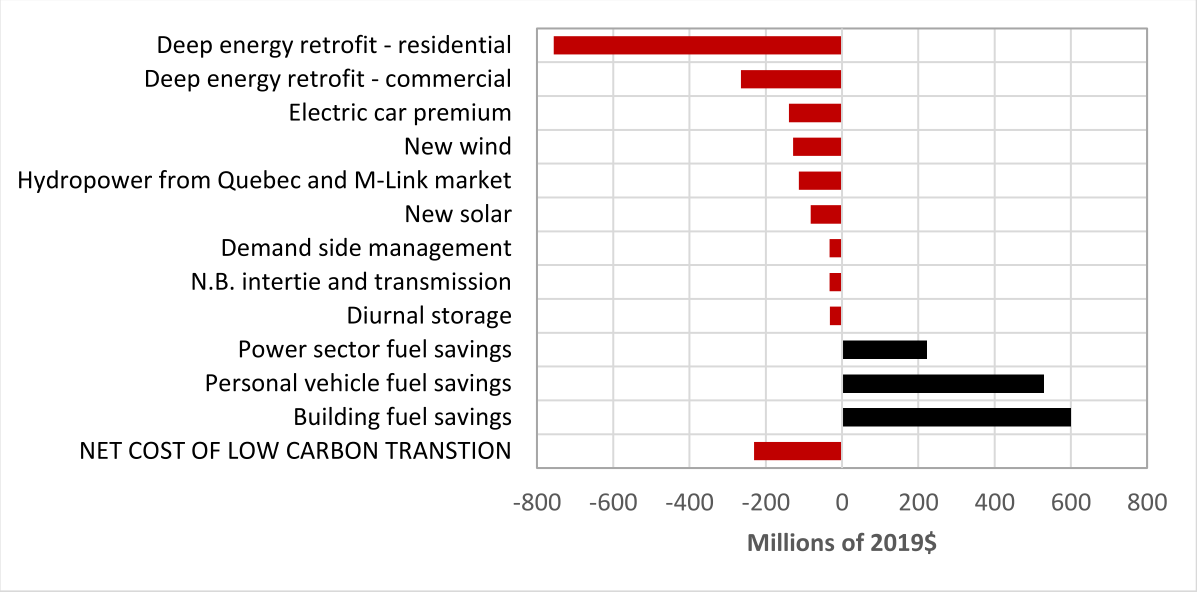

Figure ES- 3. Incremental costs, savings and annualized investments in 2030, low carbon scenario.

Introduction

This report describes a scenario for an accelerated phase out of coal and oil-fired electricity generation in Nova Scotia that results in a grid that is 91% supplied by renewable, zero carbon electricity by the year 2030. The scenario also includes shifting to more electric vehicles and to electric heat pumps for space and water heating. This would reduce tailpipe emissions from personal vehicles by 50% and emissions from building heating systems by 67%.

The results of our analysis indicate that such a transition is both technologically feasible and fundamentally economic. This corroborates a growing number of studies that point to the same conclusion: we have the technologies we need to make this transition, and the economies we will create by implementing this transition will be healthier, wealthier and more resilient than the economies we will fall into by continuing to rely on fossil fuels and suffering the climate change consequences [1][2][3][4][4][5][7]. Where we need to do the most work is on the soft infrastructure -- on mobilizing the policies, institutional frameworks, and financing systems needed to take solutions to scale and do it quickly.

Regarding the status quo planning of the electricity system in Nova Scotia, the transition to a low carbon future has not yet been a central driver. Both Nova Scotia Power Inc. (NSPI) and Efficiency Nova Scotia (ENS) are making investments and delivering programs that have the effect of reducing greenhouse gas emissions relative to what they would otherwise have been. Indeed, Efficiency Nova Scotia is widely regarded as among the most advanced institutional delivery agencies for efficiency programs in Canada. Wind energy's contribution to NSPI's supply mix is greater than all the other Atlantic provinces combined, and on a per capita basis is well ahead of all the other provinces in Canada except Prince Edward Island. Nevertheless, the achievement of Nova Scotia's climate change goals is not a central part of the mandate of these organizations, and so it is not surprising that their planning and investment strategies do not aspire to achieve deep greenhouse gas reductions. This is the point of departure for this scenario analysis; we are interested in the electricity system as an instrument for responding to the climate emergency.

The decarbonization of electricity in Nova Scotia must take place at the same time as electricity's share is increasing for space heating, water heating and transportation. Electric power generation contributes a larger share of greenhouse gas emissions in Nova Scotia than it does in any other province except Alberta and Saskatchewan, but it is still less than 50% of total provincial GHG emissions. The balance comes from other sources, primarily vehicle tailpipes and the furnace and boiler chimneys of residential and commercial buildings heated with oil or gas. Strategies for reducing greenhouse gas emissions from these sectors include a greater role for electric vehicles and heat pumps in the province. These emerging end uses for electricity must be considered in a holistic approach that includes the emission benefits of electrification at the end use level while at the same time ensuring decarbonization of the electricity supply so that the overarching goal of a climate friendly energy system can be achieved. Everything is connected and the simply stated goal of phasing out coal fired power in Nova Scotia can only be effectively considered in the wider context of the transition to a low carbon future.

There is a wide gap between what we must do and what we are currently doing to stave off the climate crisis. The climate emergency provides an opportunity to redirect our energy system toward renewable, low carbon and sustainable operation. To do so we must think about the problem in new ways, reframe and broaden the scope with which we are tackling climate change, and act with dispatch to implement the business and public policy strategies that can get us through the transition. These are the themes that we explore in this analysis.

Approach and Method

Approach and Context

The method and model developed for this analysis reflect both the objective of the exercise and the constraints of the limited resources available for deep system modelling. Our objective is to describe, in quantitative terms, a future electricity system in Nova Scotia that would be consistent with an effective emergency response to climate change. We interpret this to mean an electricity system that would be at least 90% carbon-free by 2030, no longer reliant on coal-fired power, and able to meet burgeoning growth of electric vehicles and buildings switching from oil to electricity for space heating and hot water. While limited resources necessitated a simplified modeling and analytical approach, it is also the case that a simplified approach is well suited to this type of long term, “big picture” scenario analysis.

While many of the components of our scenario are generically the same as one finds in conventional utility resource planning exercises – energy efficiency, renewable energy, legacy and conventional resources, demand response – there are significant differences in scale, scope, method, and assumptions that set this low carbon transition analysis apart from conventional utility planning exercises:

- We take a broad view of the scope of energy end uses and services that must be included in a scenario analysis of the electricity system’s role in responding to the climate emergency. Electrification of heat and mobility end uses is a necessary component of any transition to a low carbon future. It will not be enough to produce carbon-free electricity to supply the current consumption of electricity in Nova Scotia; provision must also be made for the electrification of the vehicle fleet, the switching of oil-heated residential and commercial buildings to heat pumps for electric heat, and the conversion of water heating to heat pump-based systems. This analysis considers the greenhouse gas emissions from all the current uses of electricity, plus all personal use vehicles, and all fossil fuel (mainly oil) space and water heating in residential and commercial buildings.
- In low carbon transition analysis, policy options and business opportunities are based on end users' demands for the goods and services that fuel and electricity help to provide. In this framing, the system includes the larger web of value creation to which electricity contributes. This approach is based on a well established maxim that there is no primary demand for any commodity, that the demand for a commodity like electricity is derived from more

fundamental demands for energy services (heat, mobility, information transfer, light) which are in turn derived from even more fundamental demands for amenity (e.g. health, comfort, convenience, access, knowledge, self-actualization). The price of a kilowatt-hour becomes relatively less important in both policy analysis and business models, in favour of a focus on service and amenity delivery.[1] This leads to a sharper understanding of the business landscape, a more strategic framing of opportunities and threats and, in the case of low carbon transition strategies, to a larger solution set and a wider net for engaging stakeholders.

- Greenhouse gas emissions are tied directly to the level of energy use, and only indirectly to the level of power consumption (the so-called "peak demand"). The amount of generating capacity required to reliably cover the maximum rate of electricity consumption when the system peaks is arguably *the* central focus of utility planning, but peak power planning is not the foundation for a low carbon transition. In a low carbon scenario analysis, it is the elimination or minimization of fossil fuel consumption that is the central focus, and in this frame the peak power levels are of lesser importance than total energy consumption. There are secondary considerations that bring peak issues into our analysis, but the minimization of peak consumption, the variability of some renewable resources, and the provision of reserve capacity are not primary concerns in this analysis.
- As is characteristic of emergency responses, we do not start with the question of what it would cost but with the question of what it would take to adequately respond to the emergency. We offer an analysis of the economic costs and benefits of the scenario outlined here, but the economic assessment comes after the scenario is developed. This is a different approach to that used in most integrated resource planning exercises, where a cost test of some sort is defined, and the plan is then devised by including only those measures that pass that test, sometimes with a carbon cost added as an embellishment.
- The costing of the low carbon transition with unit costs representative of historical technologies and practices will overestimate the cost of the

---

[1] There are many examples where the importance of the price of electricity, as opposed to the overall cost of the service and amenities being provided, is already of almost no concern to the consumer or the producer. An extreme but illustrative example is the common, one-dollar triple A battery, which delivers electricity at a cost of more than $250 per kWh but makes an insignificant contribution to the overall cost of the amenity being provided.

transition but we do not know by how much. Responding to the climate emergency requires reducing fossil fuel consumption to very low levels in a relatively short time and this in turn requires more aggressive mobilization of energy efficiency and renewable energy resources than is typical of "business-as-usual" integrated resource plans. These rates of mobilization are much higher than the incremental implementation rates considered in commodity price-based planning and they will trigger business and financing innovations that render obsolete current conventional wisdom on the costs of the measures themselves. For example, when deep energy retrofits of buildings are undertaken with the area-wide coverage envisaged in this scenario, rather than with the scattergun approach that has characterized the retrofit industry to date, pilot projects indicate that the unit cost of those retrofits will go down by 50% or more. In the low carbon future, building retrofits will be commodified, their management and financing will be systemized, economies of scale will come into play, and the level of activity will stimulate technological and business plan innovations.

Scope

As with other rich, post-industrial economies, greenhouse gas emissions in Nova Scotia are mainly the result of fossil fuel combustion. There are non-energy emissions from agricultural and industrial processes, and from landfills and other waste management facilities, but taken together these sources contribute less than 10% to total emissions in Nova Scotia. There are also significant amounts of greenhouse gas emissions generated in the production of goods that are imported to Nova Scotia that are outside the scope of this analysis. In terms of direct emissions in Nova Scotia, fossil fuel combustion generates over 90%, and there are three dominant source categories: power plant stacks, the tailpipes of cars and trucks, and the chimneys of residential and commercial buildings that use oil or gas for space heating.

This study has as its priority the decarbonization of the electric power sector but, as noted above, the transition to low carbon will include strong growth of both electric vehicles and the substitution of electric heat pumps for oil and gas heated buildings. In order to capture this dynamic in our scenario, we have expanded the scope of our analysis to include personal vehicle gasoline consumption, and all fuel use by residential and commercial buildings.

Nova Scotia's greenhouse gas emissions in 2016 are portrayed in Figure 1, in seven categories, with the coloured bars representing the emissions included in the scope of this analysis.

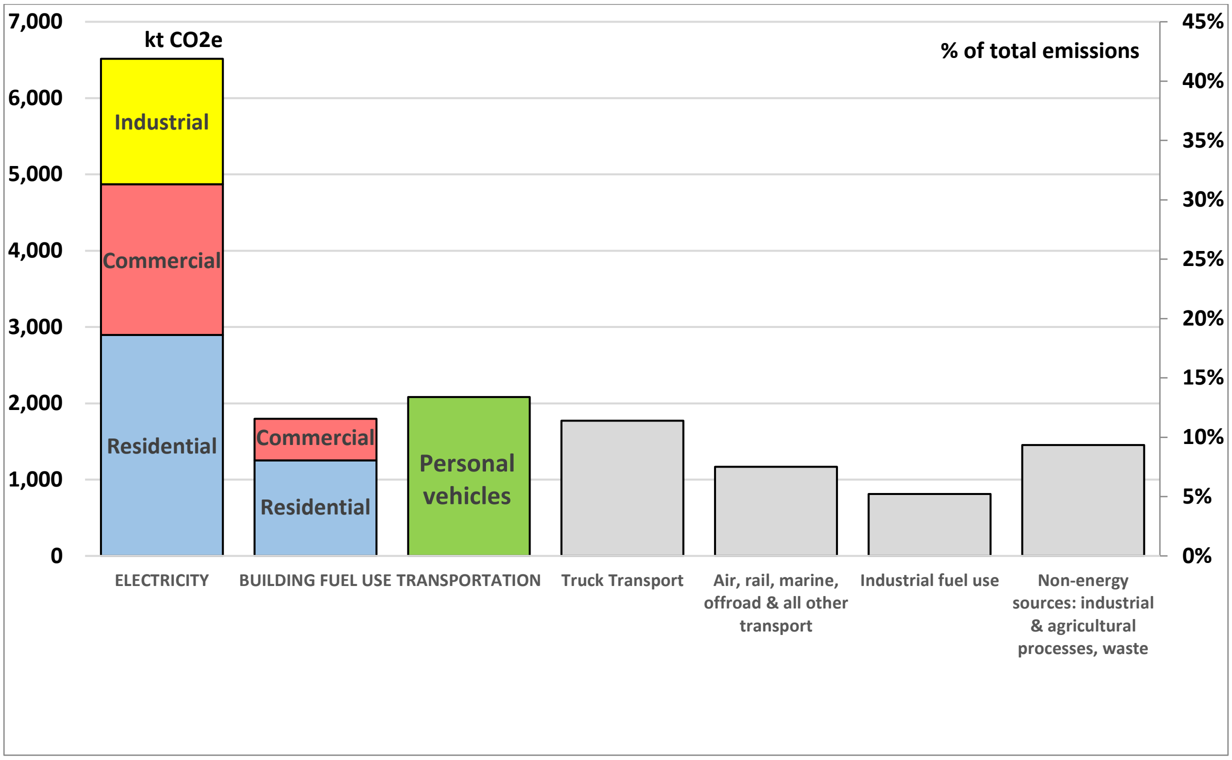

Figure 1. Greenhouse gas emissions in Nova Scotia, 2016

1. ***Emissions from electricity generation.*** These emissions are represented in the first bar and as a category represent 42% the province's total greenhouse gas emissions in 2016 and 46% of energy-related emissions. Although the emissions take place at Nova Scotia Power's combustion turbine and thermal plants, they are shown here prorated to the sectors in which the electricity is used.

2. ***Emissions from building fuel consumption***. These are the emissions from the use of fossil fuels – mostly light fuel oil, but also natural gas – for space and water heating in residential and commercial buildings.

3. ***Personal vehicles***. These are the tailpipe emissions from light duty vehicles – cars, SUV's, and pickup trucks. Light vehicles are defined as those with gross vehicle weights under 4,500 kg, almost all of which are powered by gasoline. There are about 620,000 light duty vehicles registered in Nova Scotia, split 60/40 between cars and light trucks. Almost all the cars and two-thirds of the light trucks are for personal use. For scenario modeling purposes, we have included in the study's base year (2019) scope a total of 500,000 personal light duty vehicles, and that the total grows at the same rate as population.

Not included in the analysis of this report are the following contributions of GHG emissions in Nova Scotia:

4. ***Trucks***. This category includes the non-personal use component of the light truck stock, plus all the medium and heavy trucks.
5. ***Other transportation***. These are the emissions from public transit, airplanes, boats, off road vehicles and equipment, construction and farm equipment.
6. ***Industrial fuel use.*** Industrial energy uses other than electricity uses are included in this category and are comprised of fuel consumption for the provision of medium and high temperature process heat and the space heating of industrial buildings.
7. ***All Other Emissions.*** These emissions come from a combination of non-energy sources, including waste and wastewater management, and industrial and agricultural processes.

The emissions covered by the scope of this analysis (represented by the coloured bars in Figure 1) totalled 10.5 Mt CO_2e in 2016, 67% of all energy and non-energy greenhouse gas emissions in Nova Scotia and 75% of all energy-related emissions. The power sector emissions account for the lion's share with 6.6 Mt CO_2e. The fuel consumption of residential and commercial buildings totals another 1.8 Mt CO_2e and finally the tailpipe emissions of personal vehicles are 2.1 Mt CO_2e.

While the transportation analysis in this report is restricted to personal use vehicles, the elimination of greenhouse gas from transportation is a much broader topic. Regarding supply chains, related commercial transportation, and personal access to goods and services, vehicle electrification takes place in the context of systemic transformations. This transformation includes greater use of public transportation, the emergence of mobility-as-a-service, improved infrastructure and land use planning for active transportation, and trends toward lower levels of mobility in the ways we access employment, education, goods and services.

The size of the fuel and electricity markets in the Nova Scotia economy must also be acknowledged. Nova Scotian households, firms and institutions spend over $90 million *per week* on fuel and electricity, equalling nearly $5 billion/year.[2] Added to this are all the costs

---

[2] Cost estimates are based on fuel and electricity prices as compiled by Natural Resources for Canada in the National Energy Use Data Handbook Tables and consumption data from Statistics Canada, Table 25-10-0029-01 Supply and demand of primary and secondary energy, annual.

and investments in the vehicles, buildings, and equipment and related infrastructure that give rise to the consumption of fuel and electricity.

Method

We use 2019 as the base year and 2030 as the scenario year. The modeling is carried out with a system of relational databases developed specifically for this type of long- term scenario analysis. We start with a representation of annual electricity use in Nova Scotia, disaggregated by sector, subsector and end use. We also track building fuel energy use and personal vehicle energy use (and related GHG emissions) as described in the previous section.

For the residential sector, the total number of dwellings is tied to population and household size, with dwelling types disaggregated by type, (single family detached, single family attached, apartments and mobile homes), by floor area and by vintage. The tertiary or output thermal energy per dwelling is represented by housing type and vintage, with heating system market shares and efficiencies determining secondary consumption of fuel and electricity for space heat. Coverage includes both single fuel and relevant dual and multi-fuel heating systems for oil, natural gas, electric resistance, electric heat pumps, wood and propane. Water heating fuel or electricity consumption per dwelling is based on per capita consumption of domestic hot water, market shares of the different available systems, and their corresponding system efficiencies. Electricity intensities are defined (per dwelling or household) for lighting, air conditioning, and several major appliance categories, as well as a miscellaneous category. The residential model was calibrated to total fuel and electricity use as projected for 2019.

For modeling commercial and institutional buildings, the unit of activity is the square metre of floor area, and the sector is represented with same building types employed in Natural Resource Canada's Comprehensive Energy Use Database (CEUD). For the commercial sector, the CEUD is only represented at the Atlantic Canada level, so we estimate floor areas by building type for Nova Scotia using previous research experience and data calibrations from the Canadian Energy System Simulator (CanESS), generously shared by whatif? Technologies. Energy intensities by building type and floor area, as well as electricity and fuel market shares for space and water heating, are based on previous modeling experience, the literature, the CanESS calibration, and the CEUD intensities for Atlantic Canada.

The industrial sector is represented in just two subsectors -- the Port Hawkesbury Paper Mill, and all other industry. In the case of the industrial sector, we are focused on electricity end uses, so the large differences in thermal intensities (process heat energy per dollar of value added (Gross Provincial Product)) that exist within the aggregate industrial sector are out of scope for this analysis.

Personal use light duty vehicles are categorized by fuel type (gas-powered internal combustion engine (ICE), plug-in hybrids and battery electric vehicles), annual vehicle-kilometres of travel per vehicle, fleet energy efficiency by vehicle type, and the percentage of plug-in hybrid vehicle travel powered by electricity.

A balanced scenario of fuel and electricity supply and consumption is developed covering all electricity-specific end uses in all sectors, plus space and water heat of all residential and commercial buildings, plus personal use light vehicles. Our analysis uses the following stepwise approach:

1. The end use model is populated with activity levels, energy intensities, and fuel and electricity market shares. This includes calibrated annual fuel and electricity totals that align with projected 2019 totals for the following categories: electricity consumption by sector, personal vehicle gasoline consumption, residential and commercial building consumption of oil, gas, wood, and propane for space and water heating.
2. An 8760 hourly load shape is applied to each end use to develop an end-use disaggregated hourly profile of electricity consumption for the base year. For residential and commercial end uses, similarities between Ontario and Nova Scotia in the temporal pattern of electricity consumption at the subsector and end use level facilitated the development of aggregate load shapes from a library of Ontario load shapes maintained by the Independent Electricity System Operator.
3. For general industrial electricity consumption, we use a standard EPRI load shape for general manufacturing. For the Port Hawkesbury Paper plant, we assume a constant, year-round, 24/7 average, while recognizing that it has significant demand response capacity. The demand response capacity of the plant is important in the context of short-term peak management, but not so much in the context of the long-term energy scenario developed here.
4. For electric vehicle charging, we base our assumed load shape on research by Electric Power Research Institute (EPRI)[8], but in the low carbon scenario for 2030 we move some of the evening charging to the after-midnight period, as explained more fully in the section on the low carbon scenario. We also assume

that EV energy use is 50% higher (per vehicle km travelled) from October through March than during the rest of the year.[3]

5. The previous step results in a load shape and peak consumption result close to the observed data in Nova Scotia; in this step minor adjustments are made to the assumptions regarding space heating intensities and market shares so that the simulated results align with the observed data, on an hourly time scale.
6. Calculate gross consumption of electricity by multiplying end use consumption by a factor to account for transmission and distribution losses; we assume such losses in 2030 are 6.9% of end use consumption.
7. A simple treatment of diurnal storage is included in the analysis, in which electricity is put into storage, up to a limit, during hours with end use consumption below the daily average, and withdrawn from storage, until it is used up, during hours with end use consumption above the daily average. The hourly generation requirement is equated with the gross consumption, plus or minus, any electricity put into or taken out of storage, using the following rules:
    a. Calculate the difference between actual gross consumption in each hour and the average hourly gross consumption for that day.
    b. If the hourly gross consumption (end use consumption plus losses) is less than the average for the day, then the hourly generation requirement will be equal to the hourly gross consumption plus the difference between the hourly gross consumption and the average daily gross consumption, subject to two constraints. The hourly amount put into storage is not allowed to exceed a specified maximum and there is a specified cap on total storage capacity.
    c. If the hourly gross consumption is more than the average for the day, then the hourly generation requirement will be equal to gross consumption minus any available storage up to an amount equal to the difference between the hourly gross consumption and the average hourly gross consumption for the day.
8. Project consumption to 2030 using assumed growth rates for population, floor area, and Gross Provincial Product (GPP), combined with assumptions regarding electricity market shares and efficiencies, as described in more detail in the

---

[3] This assumption may over-allocate EV consumption to the winter months (one reviewer suggested 30% would be a more appropriate difference) but total annual consumption is not affected.

section on the low carbon scenario. For 2030, add consumption from expanded electric vehicle population and from the switching of oil heated buildings to electric heat pumps.

9. Compile an hourly inventory of the generation that is available. Our focus is on the contribution that different generation sources could make to the energy supply, and the extent to which carbon-free, renewable resources could be supplying Nova Scotia's electricity by 2030. Each generation source can have physical and sometimes contractual constraints on the amount of energy it can supply at any given time, and these constraints are used to develop hourly profiles of the annual supply potential of each resource.
10. Our purpose in matching supply and consumption at an hourly level is to ensure that we are including seasonal and diurnal variations in our assessment of the potential for carbon-free resources. Our focus is on whether there is enough renewable energy supply, at the right time of year and the right time of day, to provide for the level and pattern of electricity consumption in Nova Scotia. As such the output of this exercise is not a dispatch analysis, or at least not a dispatch analysis on the time scale needed for daily operation and planning. While an hourly time step is used for the analysis, there is a range of granularity in the temporal scale of the different variables. For example, the minute-to-minute fluctuations in solar and wind supply are contained in hourly averages, and the hourly averages are in turn averaged to produce twelve 24-hour days, one representing the average 24-hour day for each month. Regarding the combustion turbine (CT) production, we have assumed it never drops below 50 MW, even though CT production will be highly variable. These are assumptions that suit our objective but would be out-of-place in a shorter-term dispatch or grid management analysis focused on peaks and transients in system operation over time scales that are many times smaller than the decade-long time horizon of this analysis.
11. With the above caveat in mind, for each hour of the year, available supplies of generation are matched to the generation requirements using the following rules to minimize GHG emissions:
    a. Apply all available wind supply.
    b. Apply all available solar supply.
    c. Apply Wreck Cove and Nova Scotia legacy hydro.

d. Apply the Nova Scotia and the Supplemental blocks from the Maritime Link, using the current rules about seasonal and diurnal availability. Add additional supply from the Maritime Link Market block, if needed.

e. Apply imports from Quebec, via New Brunswick, if needed. Our scenario includes the second tie line with New Brunswick and an upper limit of 200 MW to the rate of imports via N.B.

f. Calculate the surplus electricity (for 2030 only) as the difference between the "base supply" (defined as wind, solar, N.S. hydro, Nova Scotia block, supplemental block and in 2030 a 50 MW combustion turbine (CT) minimum) and the hourly requirement (consumption plus losses plus storage). Because flexible hydroelectric imports (NB imports, Maritime market block) are usually on the margin, surplus energy only occurs for hours in which generation requirements fall below what we have called the base supply. This is relatively rare in our simulations, and in the event would probably be avoided through adjustments to the hydro dispatch, storage, or price incentives for EV charging and other end uses capable of "supply following".

g. Close any remaining gap between consumption and supply with fossil fuel generation. For 2019, we use the forecast gas combustion turbine (CT) output for 2019 and thermal plants for the remainder. By 2030, all requirements for fossil power are met with gas combustion turbines.

h. Notwithstanding the large supply of variable hydro that is included in the low carbon scenario, we also assume that gas combustion turbines will contribute to peak shaving, transients and the provision of other grid management services. In the absence of a detailed analysis of the short-term variability of Nova Scotia grid supply in a low carbon future, we assume a minimum of 440 GWh from the combustion turbines in 2030. This capacity would be dispatched as needed but for purposes of including it in our supply-demand balance we assume it is delivered at a constant average rate of 50 MW.

Wind and Solar and the Future Grid

Wind and solar are variable renewable energy (VRE) resources and the available wind energy and solar insolation vary on multiple time scales. Utilities are accustomed to handling variations in the demand for electricity, which also occur on multiple time scales, but accommodating a large contribution to electricity supply from wind and solar energy requires new technologies and new approaches to grid management. In recent years, this has been an area of intense research and development around the world and rapid progress has been made in accommodating large amounts of VRE on electric grids. Several jurisdictions have achieved and maintained wind energy shares of 50% or more for extended periods. In 2018, the South Australia grid generated more than 50% of its electricity supply from wind and solar. The low carbon scenario in this study includes an electricity supply for Nova Scotia in 2030 that is 43% wind and 5% solar.

The key to achieving high percentage contributions from wind and solar is managing for the variability, and the nature of the problem is graphically illustrated in Figure 2. The supply of wind energy can and does fluctuate over the course of any given day, can change quickly, and periods of calm can last for hours or even for days. Figure 3 illustrates the hourly output of a typical kW of solar photovoltaic capacity for each day in January and in July, along with the hourly output of an average day for each month, and Figure 4 illustrates the variability of wind energy production in Nova Scotia over a month-long period in the summer of 2019.

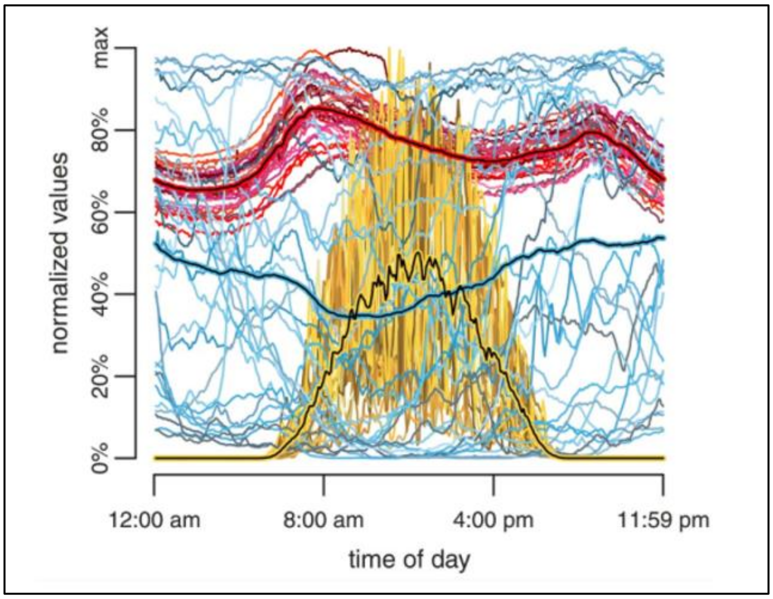

Figure 2. Wind generation (blue), solar (yellow) and demand (red) over a 30-day period, superimposed and normalized to their maximum values. The bold, colour-highlighted black lines represent the averages. Data from Bonneville Power for April 2010. Source: Barnhart [9].

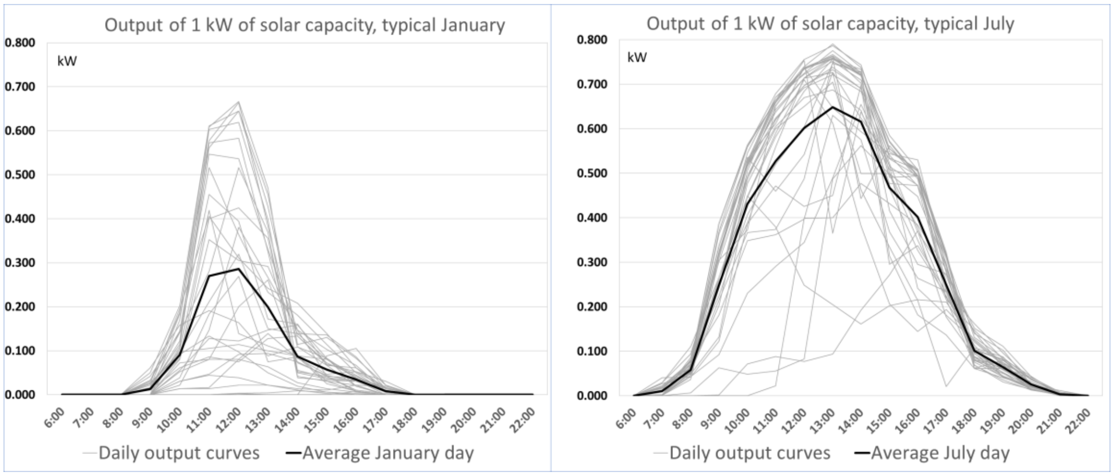

Figure 3. Hourly output of 1 kW of solar pv capacity in January and in July.

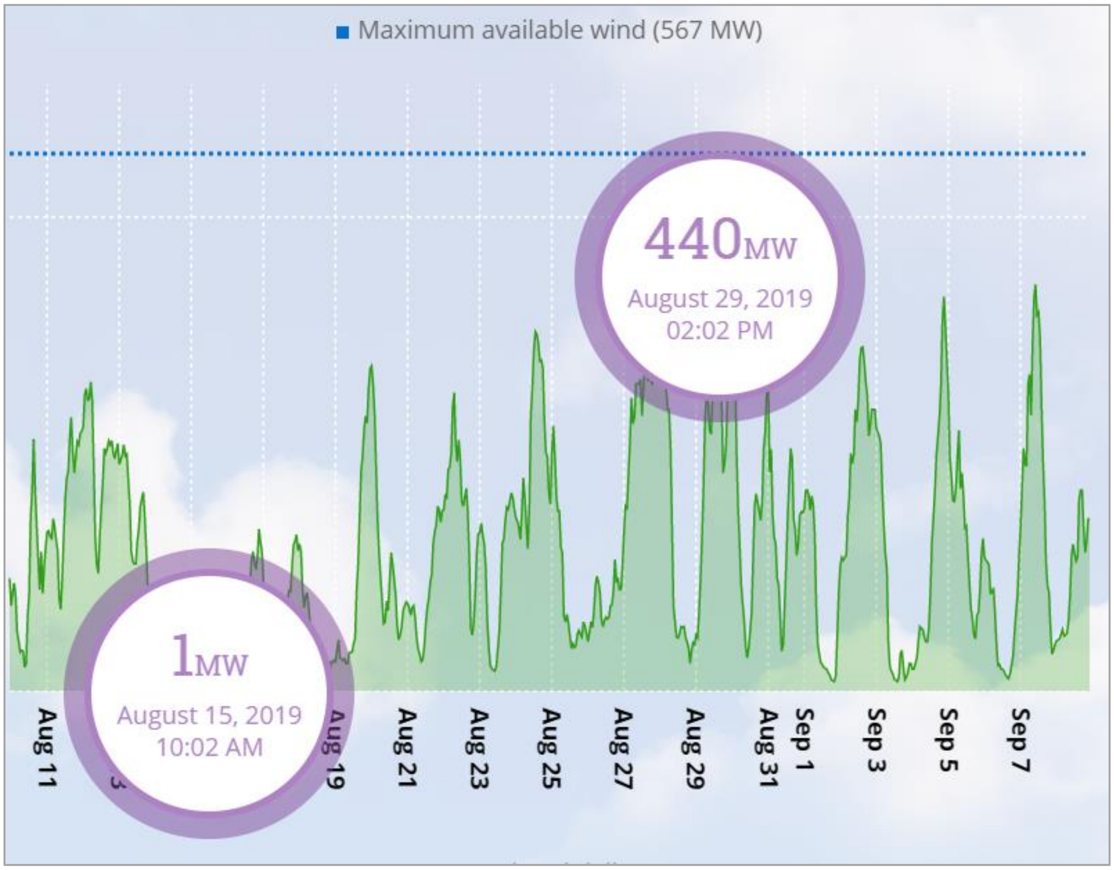

Figure 4. Variability of wind energy on the Nova Scotia grid, August/September 2019. From https://www.nspower.ca/en/home/about-us/todayspower

For the very short-term variations (on a time scale of seconds or minutes), short term reserve capacity or “spinning reserve” can be applied, and the challenge is not much different from the routine use of spinning reserve to match supply to short-term fluctuations in demand. Longer term variations on time scales of hours or days, present a greater challenge, and the appropriate strategy will vary with local circumstances. Having a large number of wind machines that are geographically dispersed will by itself smooth out the aggregate supply of wind power, but only to a degree, and periods of widespread and persistent calm must still be anticipated. The grid must have a combination of reserve capacity, storage and demand response options large enough to replace a drop in wind output, and that can be ramped up as quickly as the wind supply dies off and throttled back at the same rate as the wind returns. Hydroelectric resources with reservoir storage, natural gas combustion turbines, and battery storage are among the options that can be deployed in this role. Forecasting wind energy availability is another key element for ensuring a cost effective, reliable supply of power in a VRE-dominated grid.

Nova Scotia Power has published analysis of the issues associated with an expansion of VRE to the province’s electricity supply [10][11], but not on the scale envisaged in the scenario presented here, in which installed wind capacity grows to 1500 MW and VRE supplies 48% of Nova Scotia’s electricity by 2030. A technical analysis of how the Nova Scotia grid would be best managed with VRE in the 50% range is beyond the scope of this study but is a priority planning issue for the successful deployment of an effective low carbon transition in the province. We do include a number of elements that are likely to be components of such a strategy including the increased reliance on variable hydroelectricity from the Maritime Link and from Quebec (facilitated by the second intertie with New Brunswick); the inclusion of 120MW and 480 MWh of storage capacity; the provision of electric vehicle charging infrastructure with vehicle-to-grid capability; and maintaining at least 350 MW of gas combustion turbine capacity to be deployed as needed for transient response and grid management functions.

For the purposes of this scenario analysis, we assume annual capacity factors of wind and solar are maintained at or slightly below their current levels. We allocate the annual energy availability of wind using 24X12 sets of 288 hourly averages published by Energy and Environmental Economics[12]. These averages are portrayed in Table 1 as variations from the average annual hourly output. Table 2 is a similar table for the 288 hourly averages for the output of 1 kW of solar with an annual capacity factor of 12%. The temporal variations of these sources are smoothed over by this method, but it captures the diurnal and monthly variations that affect their potential for meeting end use energy consumption patterns over the long term.

It is important to note that the graphical portrayals of wind and solar electricity supply in this report (e.g. Figure 9 through Figure 12, Figure 18 through Figure 20) represent the average supply over entire seasons (three-month periods) and as such do not reflect the variation around the averages that occurs over the short and medium terms.

Table 1. Hourly wind power as a ratio of hourly output to annual average.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
January	1.22	1.20	1.18	1.17	1.18	1.18	1.18	1.18	1.19	1.16	1.13	1.12	1.11	1.12	1.12	1.13	1.12	1.11	1.11	1.13	1.18	1.19	1.21	1.21
February	1.15	1.15	1.16	1.17	1.17	1.16	1.15	1.14	1.11	1.08	1.05	1.01	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.02	1.05	1.08	1.11	1.13
March	1.18	1.18	1.17	1.15	1.16	1.15	1.15	1.15	1.14	1.12	1.11	1.12	1.13	1.16	1.18	1.20	1.21	1.21	1.20	1.17	1.15	1.16	1.19	1.21
April	1.03	1.04	1.05	1.06	1.07	1.07	1.07	1.07	1.05	1.01	0.99	1.00	1.02	1.04	1.07	1.09	1.11	1.13	1.08	1.05	1.02	1.00	1.02	1.04
May	0.97	0.97	0.97	0.98	0.96	0.96	0.94	0.93	0.90	0.86	0.84	0.85	0.88	0.92	0.96	0.99	1.02	1.03	1.00	0.98	0.95	0.94	0.96	0.99
June	0.93	0.93	0.93	0.92	0.89	0.88	0.87	0.84	0.78	0.74	0.71	0.71	0.73	0.78	0.82	0.87	0.91	0.92	0.92	0.89	0.86	0.87	0.89	0.92
July	0.83	0.84	0.84	0.84	0.82	0.81	0.79	0.76	0.69	0.63	0.58	0.57	0.60	0.63	0.67	0.70	0.72	0.73	0.73	0.71	0.70	0.72	0.78	0.82
August	0.79	0.78	0.77	0.76	0.75	0.73	0.71	0.70	0.66	0.60	0.56	0.54	0.57	0.60	0.64	0.67	0.68	0.69	0.68	0.66	0.67	0.70	0.76	0.79
September	1.00	1.01	1.01	0.99	0.96	0.94	0.94	0.94	0.93	0.88	0.83	0.80	0.81	0.83	0.86	0.88	0.88	0.87	0.84	0.82	0.86	0.92	0.95	0.97
October	1.17	1.17	1.17	1.15	1.13	1.13	1.13	1.13	1.13	1.11	1.07	1.04	1.04	1.05	1.06	1.06	1.06	1.06	1.04	1.05	1.09	1.15	1.17	1.19
November	1.21	1.21	1.19	1.19	1.20	1.20	1.20	1.20	1.20	1.18	1.16	1.14	1.13	1.13	1.13	1.13	1.10	1.10	1.12	1.15	1.18	1.22	1.22	1.23
December	1.20	1.19	1.17	1.15	1.16	1.17	1.16	1.15	1.15	1.13	1.11	1.09	1.08	1.08	1.08	1.07	1.07	1.07	1.10	1.16	1.21	1.25	1.26	1.25

Table 2. Average solar production in kWh for 1 kW with capacity factor of 12%.

	8	9	10	11	12	13	14	15	16	17	18	19	12 hr total
January	-	-	0.01	0.05	0.27	0.32	0.26	0.04	0.03	0.02	0.01	-	0.99
February	-	0.00	0.03	0.09	0.21	0.33	0.28	0.16	0.10	0.07	0.04	0.01	1.30
March	-	0.00	0.03	0.11	0.23	0.49	0.58	0.51	0.43	0.35	0.25	0.07	3.05
April	0.00	0.01	0.14	0.37	0.47	0.61	0.63	0.60	0.45	0.39	0.23	0.07	3.96
May	0.01	0.06	0.27	0.44	0.55	0.61	0.63	0.61	0.47	0.37	0.24	0.08	4.35
June	0.01	0.05	0.28	0.43	0.50	0.54	0.54	0.61	0.49	0.43	0.31	0.09	4.28
July	0.01	0.03	0.26	0.43	0.55	0.61	0.65	0.65	0.48	0.43	0.32	0.09	4.51
August	-	-	0.02	0.17	0.37	0.49	0.56	0.60	0.57	0.43	0.39	0.19	3.79
September	-	0.01	0.04	0.05	0.26	0.57	0.61	0.51	0.45	0.35	0.19	0.03	3.06
October	-	-	0.03	0.07	0.12	0.46	0.48	0.37	0.16	0.11	0.04	0.02	1.85
November	-	0.01	0.04	0.29	0.55	0.53	0.28	0.14	0.12	0.07	0.02	-	2.05
December	-	-	0.01	0.04	0.30	0.34	0.18	0.05	0.03	0.04	0.00	-	0.99

The Base Year (2019) Simulation

Electricity consumption in the base year

Table 3 summarizes base year (2019) electricity consumption by sector and by end use,[4] and Figure 5 provides a graphical portrayal of the same information. Figure 6 and Figure 7 illustrate the end use breakdown for the average electricity consumption in winter (Dec. 21 through March 20) and summer (June 21-Sept. 21), respectively.

As a starting point for the low carbon scenario analysis, there are a few observations about the way electricity is used in Nova Scotia that are of importance:

- For most end uses, the consumption of electricity is somewhat lower in the summer than the winter. Space heating and air conditioning loads define the seasonal difference in electricity consumption patterns in Nova Scotia. Average and peak consumption rates in winter are typically 50-60% higher than in summer.

Table 3. Electricity consumption by sector and end use, 2019 base year (GWh)

	Residential	Commercial	Industrial	Transportation	**Total**	**Percent of total end use**
Space heat	2,036	671			**2,707**	**26%**
Equip/appliances	1,420	1,045			**2,465**	**24%**
Other industry			1,545		**1,545**	**15%**
Port Hawkesbury Paper			1,078		**1,078**	**10%**
Lighting	376	605			**982**	**10%**
Water heat	673	34			**707**	**7%**
Air conditioning	57	344			**401**	**4%**
Motors		351			**351**	**3%**
Streetlighting		88			**88**	**1%**
EV charging				9	**9**	**0%**
Total	**4,563**	**3,138**	**2,624**	**9**	**10,333**	**100%**
Percent of total end use	**44%**	**30%**	**25%**	**0%**	**100%**	

---

[4] Reviewers have pointed out that the estimate of 9 GWh for EV charging in the base year is probably on the high side, but the absolute total is too small to make a significant difference to the overall portrayal of base year electricity consumption. The calculation of the EV charging total for the low carbon scenario in 2030 is independent of this base year estimate.

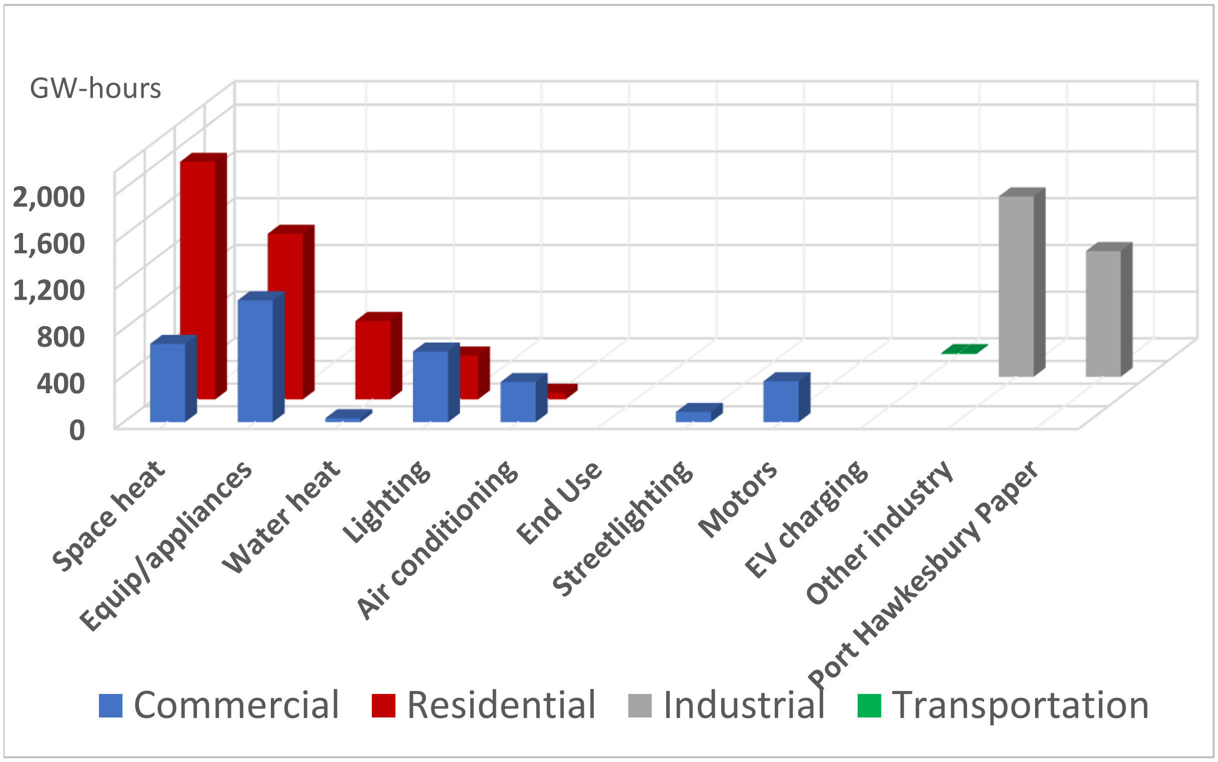

Figure 5. Electricity consumption by sector and end use, 2019 base year

- On a day-to-day basis, average summer consumption is "peakier" than in winter, again due to the differences in space heating and air conditioning consumption patterns. Air conditioning load in Nova Scotia is dominated by commercial buildings in the base year of this analysis, and the commercial air conditioning load drops off by as much as 80% at night before ramping up again in the morning. In the winter, the space heating load also drops off at night, but only by about 40%. As a result, the day-to-night swings in electricity consumption are both absolutely and relatively larger in the summer than they are in the winter.

- The use of electricity for space heating is the defining characteristic of electricity consumption in Nova Scotia and presents one of the central challenges to achieving a low carbon grid. On an annual basis space heating represents 26% of total electricity consumption in Nova Scotia but over the winter months it averages 47% of all electricity use and on the coldest days of winter space heating accounts for more than half of total consumption, as shown in Figure 8.

- The use of electricity for heating in Nova Scotia is complex and dynamic. Some buildings heat exclusively with resistance heating, some exclusively with heat pumps, and some use electric resistance heating or heat pumps in combination with one or more other energy sources (primarily oil and wood). Given this complexity, estimating the market shares for each source depends both on how many dwellings have which type of system (for which there are reasonably reliable statistics) but also on what share of total heat requirements are supplied by each source in the dwellings with two or more heating sources (for which there is less reliable data). Total consumption can be calibrated with total sales data, but statistics on total wood and fuel oil consumption in the residential sector are less reliable than statistics for electricity. In addition, the current strong growth in heat pump installations makes for a moving target when it comes to establishing a base year profile.

- For our base year simulation, we estimate that 50% of the residential floor area in Nova Scotia is heated with oil, 22% with electric resistance, 14% with heat pumps, and 10% with wood. These shares for thermal output energy are combined with system efficiencies to generate total fuel and electricity consumption for space heating, and the results track reported sales of fuel oil, wood, and electricity to the residential sector. With the prospect of much greater electrification of space heating in the transition to low carbon, even if that expansion were comprised solely of heat pumps, the thermal efficiency of the housing stock looms large as a determining factor in the prospects for a low carbon future.
- The Port Hawkesbury Paper plant accounts for about 10% of annual electricity use in Nova Scotia. Its use is dominated by the power requirements of the thermo-mechanical pulping machines. The PHP plant has, and regularly uses, its capability to scale back pulping operations during periods of peak electricity pricing, but for the purposes of our long-term scenario simulation, we assume a constant level of consumption throughout the year.

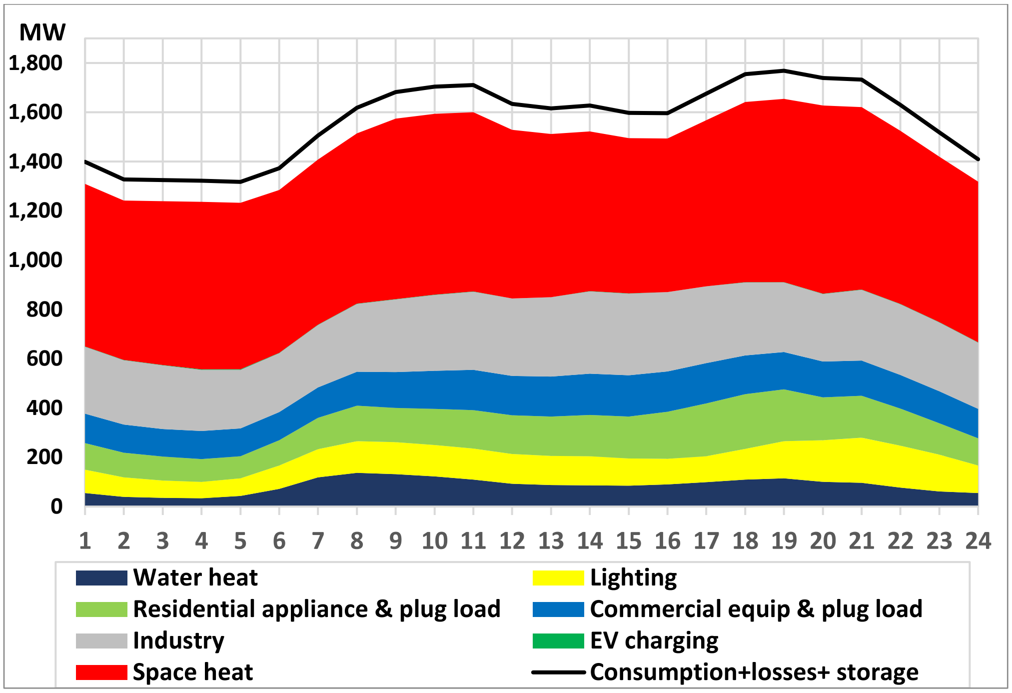

Figure 6. Average electricity consumption in winter, 2019 base year

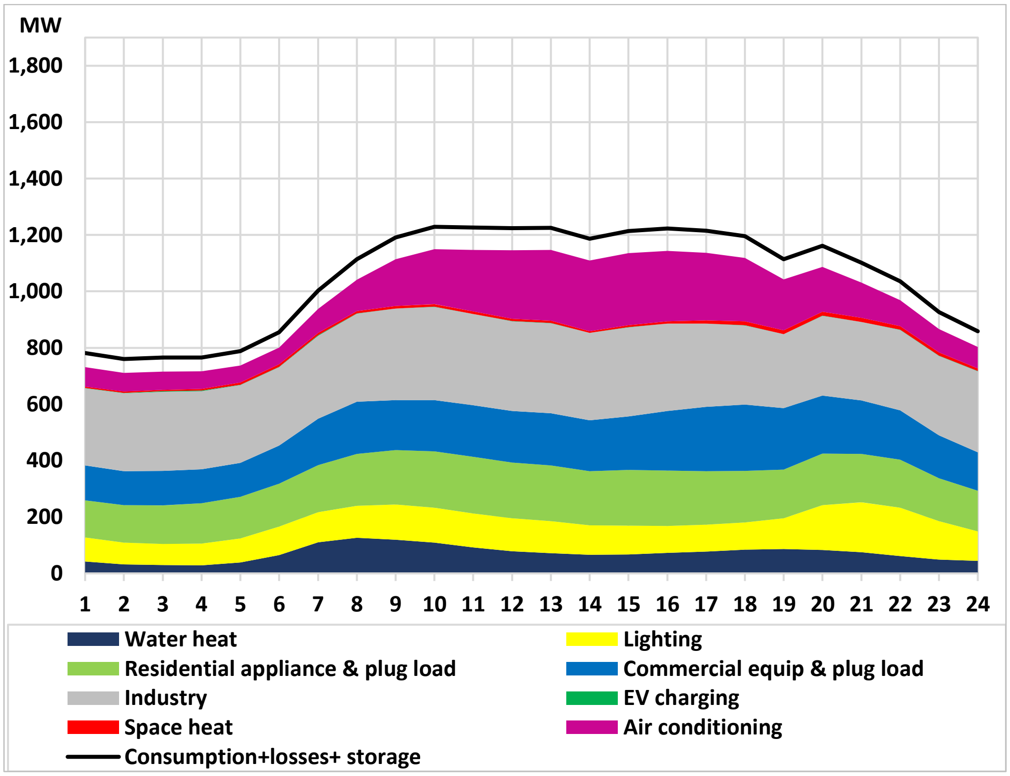

Figure 7. Average electricity consumption in summer, 2019 base year

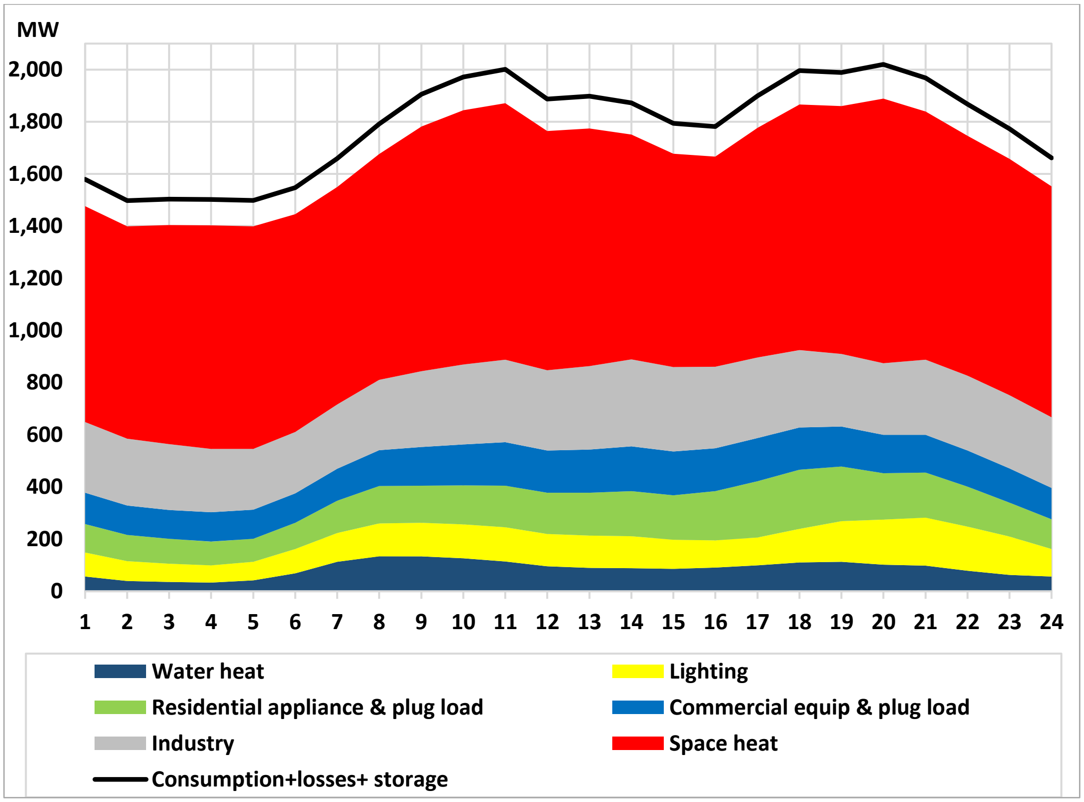

Figure 8. Average electricity consumption for the five coldest days of the year, 2019 base year

Base year (2019) electricity supply

The generating resources available in the base year (2019) of our scenario consist of the currently productive generation facilities, plus the Nova Scotia and Supplemental blocks from the Maritime Link, as described in recent Nova Scotia Power publications [13],[14]. The supply mix in our base year is summarized in Table 4, along with a modified supply mix that includes the Nova Scotia and Supplemental blocks from the Maritime Link. Although these flows of power from Muskrat Falls are not expected to begin until mid-2020, it is a *fait accompli* and for purposes of long-term scenario planning can be considered part of the existing supply mix.

Table 4. Base year (2019) electricity supply

	Actual		With Maritime Link NS block and supplemental block	
	GW-hours	Percent of total	GW-hours	Percent of total
Thermal plants (fossil)	7,126	64.5%	5,957	53.9%
Wind	2,225	20.1%	2,225	20.1%
NS legacy hydro	648	5.9%	648	5.9%
HQ hydro via NB	429	3.9%	429	3.9%
Wreck Cover	329	3.0%	329	3.0%
Gas CT	284	2.6%	284	2.6%
Solar	5	0.0%	5	0.0%
M-link: NS block			894	8.1%
M-link: supplemental block			275	2.5%
Total	**11,046**	**100%**	**11,046**	**100%**
Renewable share	3,636	33%	4,805	43%

Figure 9 and Figure 10 illustrate the average electricity supply in winter (December 21 though March 21) and summer (June 21 through Sept. 20), respectively. Figure 11 and Figure 12 show the same figures but with the addition of the Maritime Link supply (NS and supplemental blocks). As noted above on page 12, these figures are designed to illustrate seasonal and diurnal variations in energy production and are based on the output for each hour of the day, averaged over all the days in the specified season; as such they are much "smoother" than portrayals of real time supply. Even with the recent growth in wind power and after including hydropower from the Maritime Link, fossil fuel generation continues to supply over half the electricity in the province.

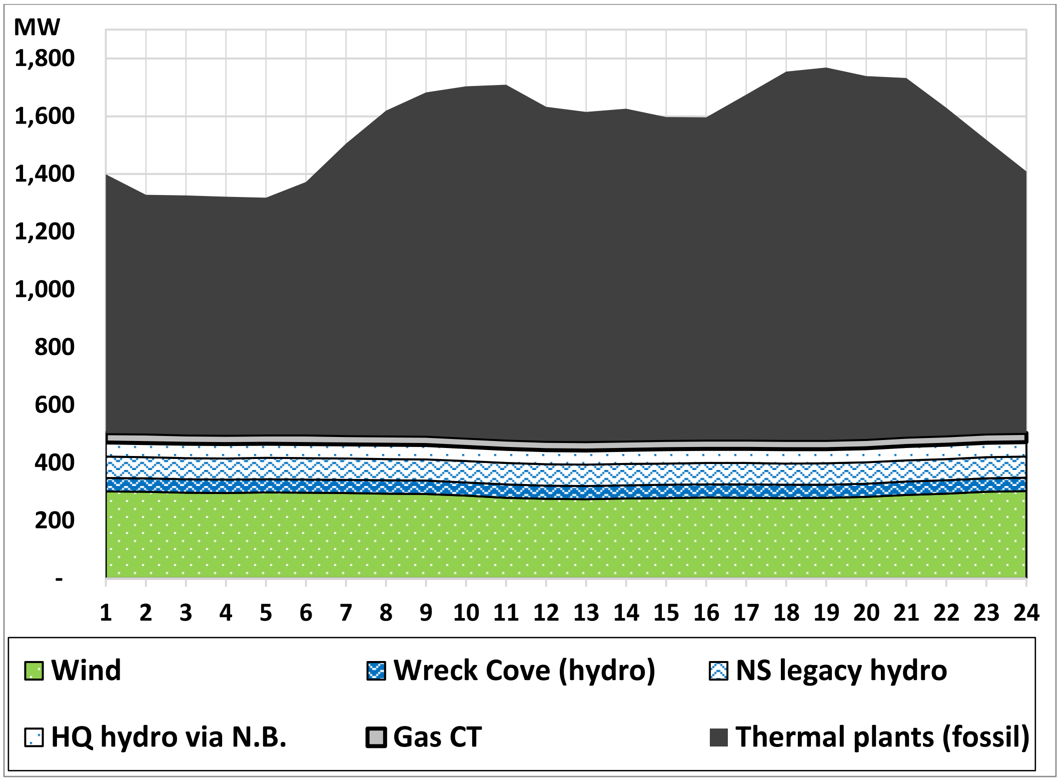

Figure 9. Average electricity supply in winter, 2019 (base year)

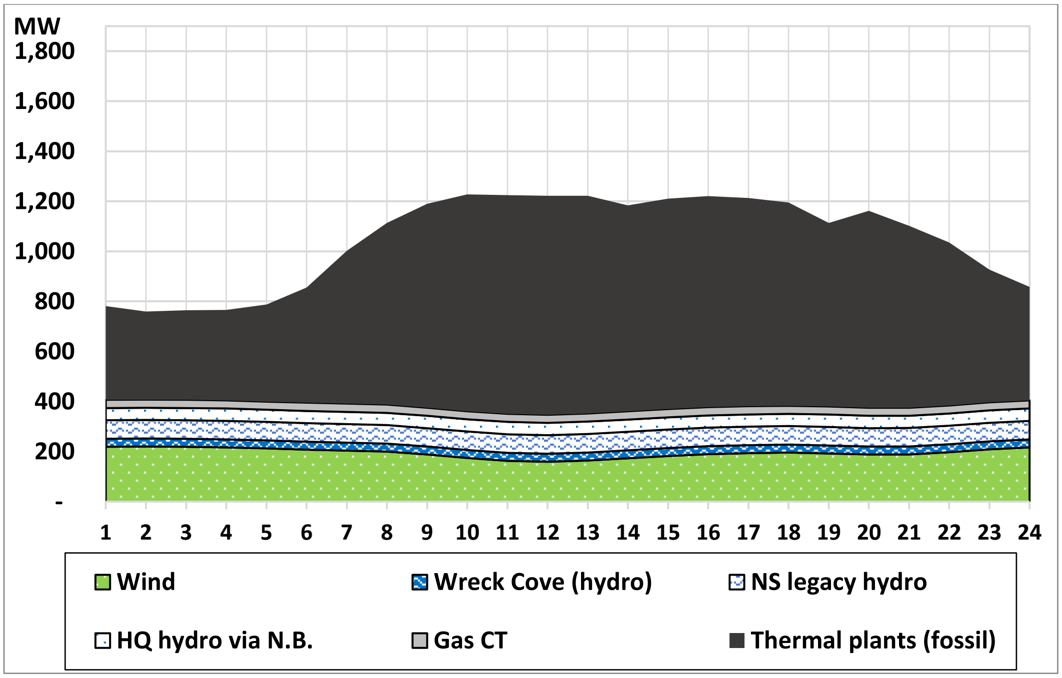

Figure 10. Average electricity supply in summer, 2019 (base year)

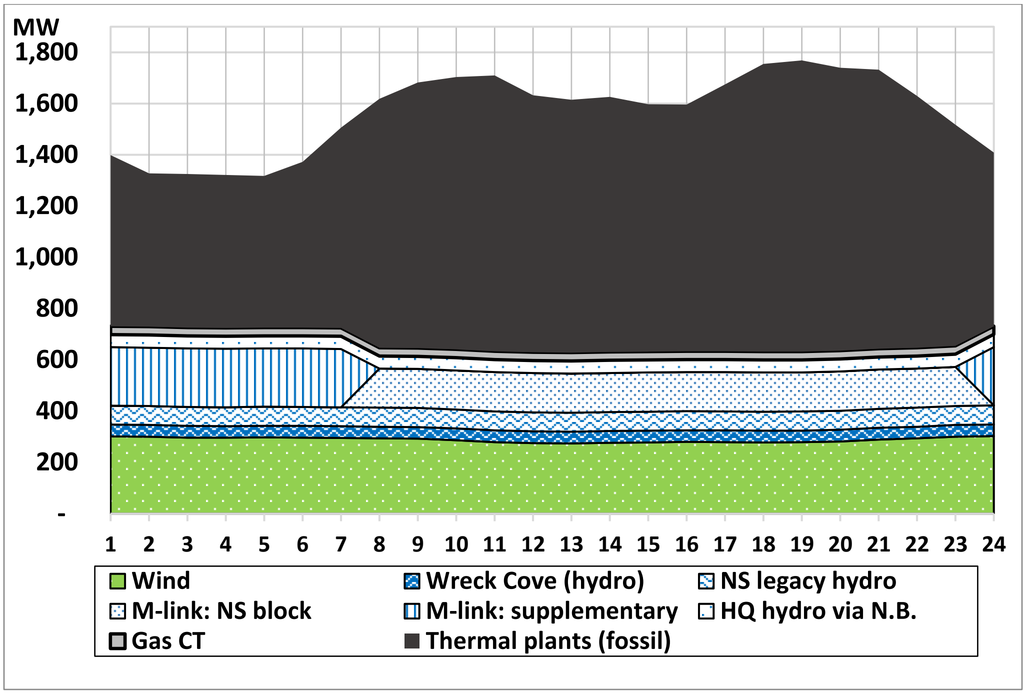

Figure 11. Average electricity supply in winter, 2019 (base year), including Maritime Link (Nova Scotia block and supplementary)

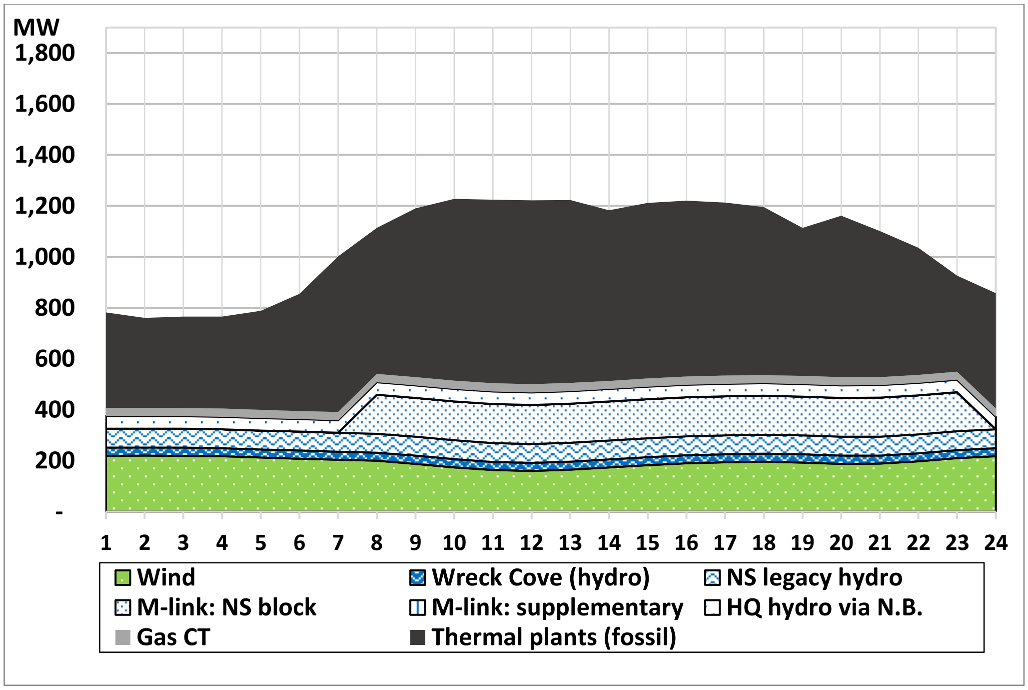

Figure 12. Average electricity supply in summer, 2019 (base year), including Maritime Link (Nova Scotia block and supplementary)

A Low Carbon Future for Nova Scotia

Low carbon futures: the essential elements

Over the past ten years there have been numerous scenario analyses of what low carbon futures might look like in advanced, post-Industrial economies like Canada[1][3]. While they differ in detail and emphasis, they share a set of common conclusions about several "must have" items that are necessary for the transformation of the energy system from fossil fuels to renewable, carbon free energy.

- First, the efficiency with which all fuels and electricity are used must more than double. The efficiency gains must be deep and widespread. This is not a conventional demand side management (DSM) program; it will be a deeply transformative transition in the energy system in which the emphasis shifts from the provision of energy commodities to the provision of energy services. The provision of human needs and amenities with less fuel and electricity and more design and innovation is a cornerstone of achieving the transition to a low carbon future. Without the efficiency gains, the carbon free energy supply will not be able to cover the projected level of consumption, at least not on the 2030-time scale that the climate emergency requires.

- Second, electricity takes on a much greater role in the provision of personal mobility, goods movement and heat -- markets that are currently dominated by fossil fuels. Electrification almost always comes with a large increase in energy efficiency. In addition to eliminating emissions at the point of end use, it also enables the efficiency gains that are another essential element of the low carbon transition. As illustrated by our analysis, two examples that will be central to the low carbon transition in Nova Scotia are the switch from gasoline powered vehicles to electric vehicles, and the switch to heat pumps for space and water heating in buildings.

- Third, the electricity supply must come from carbon-free sources. Without this component, the end use emission reductions brought about by efficiency gains and switching from fossil fuels to electricity will be clawed back at the power plants. The generation of electricity from fossil fuels is a fundamentally inefficient process. A radically new type of grid, powered by renewable and largely distributed sources, will characterize low carbon futures.

- Finally, even with efficiency gains and the shift to renewable electricity, innovation will be essential. There must be innovation in fuel and electricity using technologies. Most importantly in the long-term, there must be innovation that results in human needs and amenities being provided in ways that require less energy services and less consumption of fuel and electricity. After all, fuels and electricity have no intrinsic value; their value is derived from the contribution they make in larger systems for providing energy services such as heat, motive power, mobility, light, and information transfer. Even these energy services derive their value from their contribution to meeting fundamental human demands and needs for comfort, convenience, health, access, knowledge and self actualization. The efficient and electric vehicle innovations that are disrupting the personal mobility system provide a good example. In addition, telepresence technologies (e.g. telecommuting, teleshopping) are making it possible to reduce the amount of personal mobility that is required to access goods, services and employment. At the same time, car-sharing services, mobility-as-a-service business models, and advancing automation are transforming personal mobility and promise more equitable access to travel while at the same time reducing vehicle ownership rates.

The targeted emissions

As noted above, the greenhouse gas emissions within the scope of this scenario analysis include all the emissions from the power sector, plus the emissions from the fuel use of residential and commercial buildings for space and water heat, plus the emissions from 500,000 personal vehicles, as summarized by end use and source in Table 5. When the Maritime Link comes online in 2020, the incoming hydropower will boost the renewable share of the electricity supply to more than 40% and displace 1,000 kt CO2e per year. Even with this increase in renewable energy on the grid, however, electricity generation will remain the largest source of greenhouse gas emissions in Nova Scotia, and the carbon intensity of the grid will remain relatively high at 500 grams CO2e per kWh.

Table 5. Greenhouse gas emissions in study scope (kt CO_2e)

	2019 simulation	With M-link NS and supplementary blocks
Combustion turbines	170	170
Thermal plants	6,413	5,361
Subtotal for grid	6,584	5,531
Personal vehicles	2,115	2,115
Residential - space heat	1,125	1,125
Residential - water heat	246	246
Commercial buildings	579	579
Subtotal building fuel use	1,951	1,951
Total Emissions in Scope	**10,650**	**9,598**

The key components of decarbonization in Nova Scotia

Activity drivers

In line with the climate emergency, our decarbonization scenario focuses on the year 2030. The base year profile of energy and emissions is projected to the year 2030 by escalating the activity drivers of the end use model, as summarized in Table 6. We adopt conventional forecasts for population, household size, economic output, etc. – our purpose is to explore an alternative energy future, given standard outlooks for underlying activity drivers.

Table 6. Activity drivers for 2030 scenario analysis

	2019	**2030**	**AAGR**
Population	957,317	973,552	0.15%
GDP (billions of 2019$)	38	44	1.34%
Persons per household	2.32	2.15	-0.67%
Total housing requirement	412,636	451,918	0.83%
Number of residential dwellings			
Single family detached	278,632	303,992	0.80%
Single family attached	28,106	33,304	1.55%
Apartment	90,575	99,535	0.86%
Mobile	15,323	14,913	-0.25%
Total number of dwellings	**412,636**	**451,918**	**0.83%**
Light duty household based personal vehicles included in this analysis	500,000	508,480	0.15%
Fuel intensity of personal vehicles (ICE), L/100 km	8.0	6.8	-1.47%
Commercial and institutional floor area	**Millions sq. metres**		**AAGR**
Accommodate and food services	0.99	1.05	0.53%
Arts, entertainment & recreation	0.39	0.41	0.58%
Education	2.97	3.01	0.13%
Health care and social assistance	1.91	2.38	2.01%
Information & cultural industries	0.34	0.36	0.53%
Offices	7.62	8.12	0.59%
Other services	0.42	0.39	-0.85%
Retail trade	3.33	3.54	0.56%
Transportation & warehousing	1.07	1.09	0.13%
Wholesale trade	1.36	1.37	0.06%
Total floor area	**20.4**	**21.7**	**0.57%**

- Growth projections are modest for most categories that drive demand for energy services. The population projection is only 0.15% per year, but a continuing decline in the number of people per household results in projected growth in housing requirements of 0.83% per year. The population and household size projections are based on long term historical trends published by Statistics Canada [15] and trends in the housing mix are based on the Comprehensive Energy Use Database[16].

- Single family detached dwellings continue to dominate the housing stock, but there is a slight shift toward single family attached housing and apartments, and the average floor area of each increases. Trends are based on the Comprehensive Energy Use Database [16].

- Improvements in the fuel efficiency of personal vehicles continue, with the fleet average on-road fuel efficiency reaching 6.8 L/100 km, a 15% gain.

- Consistent with recent trends, commercial and institutional building floor area grow more slowly than economic output, except for the health care sector where an aging population drives growth in hospitals and other health care facilities. Commercial and institutional building floor area projections are based on projections of the Canadian Energy Systems Simulator [17].

Given recent trends and innovations, this “business-as-usual” approach to the levels of energy-using activities in the future represents a fundamental conservatism in this scenario analysis.

- We commented above on the current disruption in the transportation sector, for example, where car-sharing, telepresence and value and behavioural shifts could accelerate recent trends toward lower rates of car ownership and personal mobility.

- Similarly, we have assumed business-as-usual trends for growth in size of dwellings, even while the number of people per household continues to decline.

- Demographic, economic and environmental factors could lead to a slowing of consumerism.

- Further declines in the consumption of newsprint, growing rates of materials reuse and recycling, and innovation in industrial production systems are all current trends with the potential to significantly reduce the level of energy-intensive primary materials production.

- The changing nature of work being brought about by shifts in global production systems and the advent of artificial intelligence could have far-reaching implications to the future consumption of fuel and electricity.

Factors like these – sometimes called structural factors in energy analysis – can act to increase or decrease fuel and electricity use, but in recent years they have been trending strongly in the direction of moderating fuel and electricity consumption and greenhouse gas emissions, and are likely to continue to do so [15],[16]. The low carbon scenario analysis developed here does not, however, rely on these "megatrends" for achieving the goal of a carbon-free electricity system in Nova Scotia, and instead relies primarily on fuel switching and technological efficiency improvements.

Residential and commercial buildings get deep energy retrofits

There is no pathway to a low carbon future for Nova Scotia that does not include both a major upgrade in the thermal efficiency of buildings and a phasing out of oil heating, mostly in favour of high efficiency electric heat pumps. The efficiency improvement itself will not get the job done, and the feasibility of heating buildings with carbon-free electricity (via heat pumps) hinges on reducing the thermal energy requirements of the buildings to low enough levels that there will be enough renewable electricity to go around.

Advances in technology and design are leading a trend toward high performance buildings with requirements for space heating in new buildings that are lower than conventional buildings by 90% and more, while at the same time providing a more comfortable and healthier indoor environment. Most of the buildings that will be occupied in Nova Scotia in 2030 are, however, already standing, and so the key to a low carbon transition in the buildings sector will require that these new technologies and techniques are widely applied to existing buildings. Although reductions in thermal energy requirements of 90% are not feasible on a wide scale for existing buildings, "deep energy retrofits" utilizing increased insulation, high performance windows and air sealing, combined with controlled ventilation with heat recovery and moisture management, can achieve reductions in thermal energy consumption in existing residential buildings by 50% or more [20].

Buildings with high thermal efficiencies, like those achieved after undergoing deep energy retrofits, have very stable indoor temperatures and are slower to respond to outdoor temperature drops. This reduces the urgency with which the energy supply system must be capable of responding to weather changes, and therefore is a significant systemic advantage in the highly electrified low carbon future.

In Nova Scotia, the thermal energy intensity of single family, detached (SFD) housing varies by age, reflecting the ongoing improvements in energy efficiency over the past several decades. Whereas the pre-War SFD's have annual thermal energy requirements in the range of 700 MJ/m^2, houses built in the last fifteen years have thermal requirements in the range of 300 MJ/m^2 and lower. Lower absolute intensities but similar trends exist for the attached housing stock and for apartment dwellings.

In our climate emergency response scenario, 80% of the housing stock undergoes deep energy retrofits by 2030, achieving average savings of 50% and bringing average thermal energy requirements down to 225 MJ/m^2 (121 kWh/m^2) for single family dwellings and to 125 MJ/m^2 (80 kWh/m^2) for apartments. These target thermal energy intensities are eight times higher than levels currently being achieved in new dwellings that meet Passive House design standards and are about double the potential for most existing dwellings. Table 7 summarizes the thermal performance of the residential housing stock, per household and in terms of the total thermal energy requirements.

Table 7. Thermal energy output of housing stock, base year and low carbon scenario (2030)

		No. of dwellings (thousands)		**Thermal output energy (GJ/HH)**		**Total thermal output energy required (TJ)**	
Housing Type	**Vintage**	**2019**	**2030**	**2019**	**2030**	**2019**	**2030**
Single Family Detached	Pre-1984	115	100	93	48	10.7	4.8
	1984-2005	107	98	57	34	6.1	3.4
	2006-2019	57	56	51	35	2.9	1.9
	2020-30	-	50		38		1.9
	Subtotal	**279**	**304**	**71**	**39**	**19.7**	**12.0**
Single Family Attached	Pre-1984	8	7	89	46	0.7	0.3
	1984-2005	12	11	50	34	0.6	0.4
	2006-2019	8	8	49	38	0.4	0.3
	2020-30	-	7		38		0.3
	Subtotal	**28**	**33**	**61**	**39**	**1.7**	**1.3**
Apartments and Other	Pre-1984	41	35	47	31	1.9	1.1
	1984-2005	38	35	31	24	1.2	0.8
	2006-2019	28	27	27	23	0.7	0.6
	2020-30	-	17		24		0.4
	Subtotal	**106**	**114**	**36**	**26**	**3.8**	**3.0**
Totals/Averages	Pre-1984	163	142	81	44	13.2	6.2
	1984-2005	156	144	50	32	7.9	4.6
	2006-2019	93	91	44	32	4.1	2.9
	2020-30	-	74		35	0.0	2.6
	TOTAL	**413**	**452**	**61**	**36**	**25.2**	**16.2**

At present, commercial buildings are less reliant than residential dwellings on electricity for space heating, but they will be increasingly electrified in a low carbon future and the improvement of their thermal performance is a necessary precondition for a low carbon transition. In the low carbon scenario, the space heating requirements of the base year stock of commercial buildings are 25% below base year levels and in the year 2030 range from 282 MJ/m^2 for offices, to 550 MJ/m^2 for hospitals and large hotels.

Electric resistance space and water heating are phased out

The efficiency of electric baseboard heating, conventional hot water tanks, electric furnaces and other forms of electric resistance heating is technically 100% in the sense that all the electricity is converted to heat, but electric heat pumps are much more efficient in using electricity to provide heat. As the name implies, heat pumps extract heat from the surrounding environment and can thereby “leverage” the electricity they consume by a factor of three or more. There is a wide variety of heat pumps for providing space heating and hot water [21], and recent technological advances have resulted in air source heat pumps that continue to operate efficiently at temperatures below minus 20 C. In Nova Scotia, heat pumps deliver more than three units of heat for every unit of electricity consumed, on a seasonal basis, making them three times more efficient than resistance heating. The transition to a low carbon future will require that the supply of carbon free electricity be stretched as far as possible, and the heat pump will play a central role in this regard.

As part of the transformation of the building stock that is central to an effective climate emergency response, electric resistance heating is phased out, for both water heating and electrically heated buildings, in favour of heat pumps. In the low carbon scenario, resistance heating for space and water is replaced with electric heat pumps with average coefficients of performance of 2.5 for the water heater systems. We conservatively assume an effective coefficient of performance for the space heating heat pumps in the low carbon scenario of 1.9, well below current best technology and taking no credit for any efficiency improvement in heat pump operation that will come with warmer average winter temperatures [22]. Using these factors, modern air source heat pumps operating in Nova Scotia will use only 50% of the annual electricity of 100% resistance electrical space heating.

Heat pumps are substituted for oil and gas heating in buildings

Achieving a low carbon transition in Nova Scotia requires that the use of oil and gas for space heating is phased out, or at least reduced to very low levels compared to present practice.

There are 61 million m^2 of residential dwelling space in our 2019 simulation, with half that space heated with oil, 22% with electric resistance, 14% with heat pumps, and 14% with wood and other fuels. As noted in the previous item, in the low carbon future electric resistance space heating is phased out in favour of heat pumps by 2030. In addition, oil's share of space heating drops from 50% to 21% of residential floor area. The result is an increase in the heat pump share of space heating from 14% in 2019 to 71% by 2030.[5]

The transition in the way residential dwellings are heated in the low carbon scenario, as compared to the base year, is summarized in Table 8.

Commercial and institutional building floor area totals 20 million m^2 in our base year simulation (see Table 6). The main sources of space heating are fuel oil (30%), natural gas (36%) and electricity (22%). As in the residential sector, in the low carbon future electric resistance heating is phased out in favour of heat pumps, and there is a shift from oil and gas heating to electricity, with electricity's share of total commercial and institutional space heating growing to 48% by 2030.

Table 8. Percent of residential space heating (tertiary) by source, 2019 base year and 2030 low carbon scenario

	Single Family Detached		**Single Family Attached**		**Apartment and mobile**		**Totals**	
	2019	**2030**	**2019**	**2030**	**2019**	**2030**	**2019**	**2030**
Electric resistance	15%	0%	2%	0%	5%	0%	**22%**	**0%**
Electric heat pump	14%	51%	0%	7%	0%	14%	**14%**	**71%**
Oil	35%	15%	4%	2%	11%	4%	**50%**	**21%**
Wood	7%	7%	1%	0%	2%	0%	**10%**	**7%**
Other	3%	1%	0%	0%	1%	0%	**4%**	**1%**
Totals	**74%**	**73%**	**8%**	**9%**	**18%**	**18%**	**100%**	**100%**

Even with the large shift from fossil fuel to electric heat pumps in residential and commercial buildings, the total amount of electricity consumption for space heating declines 18% by 2030 in the low carbon future. This is the combined result of the deep energy retrofits and the high efficiency of electric heat pumps.

Water heating goes all electric (heat pump)

In our base year simulation, the tertiary energy consumption of residential hot water heating (i.e. before considering the efficiency of the water heaters and the standing losses) averages 4.8 GJ per capita. In the low carbon scenario, we assume a moderate 20% decline to 3.84 GJ/capita, mostly as a result of water efficient appliances but partly due to conservation

---

[5] These are shares of floor area heated, not of the number of dwellings. Dwellings with one or more heating sources are expected to continue to be prevalent in Nova Scotia, so there is no one-to-one correspondence between a dwelling's principal heating system type and the share of the dwelling's space heat provided by that system.

behaviour. In our 2019 simulation, 50% of the residential domestic hot water consumption is provided by oil water heaters with 75% efficiency, 45% with electric water heaters (virtually all resistance heating) and most of the remaining 5% with wood at 50% efficiency (and 0.5% with propane at 65% efficiency). In the low carbon scenario, wood and propane retain their share of residential water heating but by 2030 95% of all residential hot water energy consumption is provided by heat pumps with an average coefficient of performance of 2.5. The efficiency of the heat pumps more than offsets the increase in electricity's share of residential water heating, so that total residential consumption for water heating declines by 40% to 401 GWh in 2030 from 673 GWh in 2019.[6]

In commercial buildings, hot water consumption is a minor energy end use (except for hospitals, hotels and restaurants) and electricity has a much smaller share. In the low carbon scenario, the tertiary consumption of hot water energy doesn't change, but by 2030 70% of energy consumption for hot water in the commercial and institutional sector is provided by heat pumps. This results in electricity consumption for water heating in commercial and institutional buildings increasing by six-fold to 180 GWh in 2030 from only 34 GWh in our base year simulation.

The gain in electricity consumption for water heating in the commercial and institutional sector is more than offset by the reduction in the residential sector, resulting in a net drop of 20% in electricity consumed for water heating in the low carbon scenario in 2030 as compared to the 2019 base year simulation.

Growth offsets efficiency gains for air conditioning energy consumption

In our base year (2019) simulation, electricity consumption for air conditioning in commercial and institutional buildings is six times greater compared to residential buildings (see Table 3 and Figure 5). Although the amount of residential floor area is three times greater than the amount of commercial and institutional building floor area, in 2019 most commercial and

---

[6] Heat pump water heating systems remove heat from the ambient air inside the house and during the heating season this adds to the load on the space heating system. Household water heating energy is much smaller than household space heating energy, even after implementation of the widespread deep energy retrofits included in the low carbon scenario. We estimate the ambient air heat pumps used for hot water systems in the low carbon scenario would increase the annual electricity consumption of the heat pumps used to provide space heating by 7-10%. This has not been explicitly included in the estimate of the electricity consumption of the space heating heat pumps included in the scenario. We do however use a very conservative assumption for the efficiency of those systems (COP of 1.9 as compared to observed COP's of 3.0 and higher), a conservatism 4-5 times larger than the impact of the water heating heat pump factor. In addition, the ambient air heat pump water heating systems will reduce the load on the building cooling system during the cooling season, but we have not subtracted those savings from the electricity consumption estimates for building air conditioning, another conservatism in the analysis presented here.

institutional buildings already have air conditioning systems and most residential dwellings do not. This balance is shifting, however, as global warming, rising incomes and the growth of heat pumps contribute to strong growth in the number of residential dwellings with air conditioning.

In the low carbon scenario, air-conditioned floor space in the residential sector increases by 7% per year, thereby more than doubling from 22% to 46% by 2030. The consumption per dwelling also goes up as global warming increases cooling degree days by 1% per year. These growth trends are partly offset by an increase in the average SEER to 15 by 2030 (from its base year value of 12), but the overall electricity consumption for air conditioning in the household sector more than doubles by 2030, from 57 to 125 GWh. In commercial and institutional buildings, where cooling systems are already widely used, efficiency gains more than offset the growth in consumption from hotter weather, and there is 19% decline in total consumption by 2030. Coincidentally, this 19% efficiency gain in the commercial and institutional buildings is about the same in absolute terms as the doubling of consumption in the residential sector, and so the total consumption of electricity for air conditioning in 2030 is about the same as in the base year simulation (see Table 10).

Efficiency continues to improve for lighting and other electrical equipment

While not as large as the contributions from phasing out electric resistance heating and implementing deep retrofits throughout the building stock, the continuing improvement in the efficiency of lighting and other electricity equipment and devices helps to achieve a key challenge of the low carbon future – stretching the carbon-free electricity budget as far as possible.

In the residential sector, per household ownership levels and electricity intensities are held constant for freezers, dishwashers, clothes washers and electric ranges. The average annual consumption of refrigerators declines by 4% by 2030 (to 550 kWh per year) and the average consumption of clothes dryers declines by 9% by 2030 (to 850 kWh per year).[7] For the miscellaneous category of household electricity consumption, which is comprised of a variety of small appliances and electronic devices, annual household consumption in 2030 in the low carbon scenario is 790 kWh, as compared with the base year level of 1,050 kwh. This represents a 25% gain due partly to efficiency gains and partly to smaller household sizes that reduce per household use of some of these devices. Finally, annual electricity consumption

---

[7] The potential for heat pump technology to reduce the electricity consumption of clothes dryers while at the same contributing to both summer cooling and winter heating could result in efficiency gains for this appliance far beyond what we have included in the low carbon scenario.

per household for lighting declines by 2% per year, reaching 730 kWh by 2030 as compared with 912 kWh in the base year. This relatively low 20% improvement results mainly from continued penetration of LED and other advanced lighting technologies, although some reduction in per household lighting comes with smaller household size.

For commercial and institutional buildings, and for general industry electricity consumption, end use intensities (per square metre for buildings, per dollar of GPP for industry) are 25% below base year levels in 2030, representing a rate of efficiency improvement of 2% per year between 2019 and 2030. This is higher than the rate of growth for building floor area or for industrial GPP, and so the result is an average 19% decline in electricity consumption for these end uses in 2030 as compared with 2019. Finally, for the Port Hawkesbury Paper Plant, annual electricity consumption in 2030 is held constant at the base year level of 1,038 GWh.

Plug-in hybrids and electric vehicles accelerate

The electrification of vehicles is another keystone element of low carbon futures. In Nova Scotia, emissions from road transportation (cars and trucks, for both and commercial transport) are second only to the power sector as a source of greenhouse gas emissions. As the grid decarbonizes, transportation becomes the largest source of emissions, as is already the case in most other Canadian provinces where electricity is less carbon-intensive than in Nova Scotia. Ongoing improvements in fuel efficiency of vehicles with internal combustion engines (ICE) have moderated greenhouse gas emissions from personal vehicles, but to date the trend toward pickup trucks and SUV’s has largely offset those gains [18],[19].

The greatest potential for reducing emissions from personal vehicles is by electrification. As with the conversion from oil heating to electric heat pumps, the conversion of vehicles from fossil fuel to electricity results in dramatic improvements in efficiency. A typical electric car uses 20 kWh per 100 km; a gasoline-powered car with that efficiency would have a fuel consumption rating of 1.9 L/100 km (or about 145 mpg (Imp)).

Our 2019 base year simulation includes 500,000 personal use light duty vehicles (cars, SUV’s, pickups), which grows with population to 508,500. In the low carbon scenario, by 2030 25% of these vehicles are plug-in hybrids that use electricity for 75% of the distance driven, and battery electric vehicles make up another 15% of personal vehicle use. Per capita vehicle ownership is constant over the scenario period, but we have assumed a 10% decline in per capita levels of automobile travel, reflecting a continuation of recent trends such as increased active transportation, more compact land use patterns, and substitution of telecommunication for mobility.

For both the BEV's and the electricity-powered portion of the plug-in hybrid mileage, average electricity intensity is 20 kWh/100 km. By 2030, the resulting consumption of 706 GWh for electric vehicle charging is offset by a 50%+ drop in the gasoline consumption of personal vehicles in Nova Scotia. The electric vehicle scenario is summarized in Table 9. Annual greenhouse gas emissions from combustion-powered personal vehicle use drop by a 1,000 kilotonnes CO_2e in this scenario. With the 91% carbon-free grid in the low carbon scenario, and assuming the electric vehicles are charged with average grid electricity, the associated power plant emissions would be about 35 kilotonnes CO_2e. Even if the cars were charged with electricity generated entirely with electricity from gas-fired combustion turbines or from coal-fired thermal plants, emissions would be less than the displaced tailpipe emissions from the vehicles the EV's replace.

Table 9. Personal vehicles in the low carbon scenario

	2019 base year	2030, low carbon scenario
Population of light duty vehicles	500,000	508,480
Billions of vehicle kilometres of travel (vkt)	11.5	10.5
Shares of vkt by vehicle type:		
Conventional internal combustion	99.5%	60.0%
Plug-in electric hybrid	0.5%	25.0%
Battery electric	0.0%	15.0%
Fuel intensity of combustion powered vehicle travel, L/100km	8.0	6.8
Electricity intensity of electric-powered vehicle travel, kWh/100km	20	20
Total gasoline consumption, millions of litres	920	476
Gasoline GHG emissions, kilotonnes CO2e	2,115	1,094
Electricity consumption, GW-hours	9	710

Diurnal storage helps smooth consumption patterns

As described in the section on Method, the low carbon future described here includes some capacity for short term, day-to-day battery storage of electricity. The batteries are charged during the overnight period when electricity end use consumption is at its daily minimum and discharged during heavy consumption periods the following day. This is an area of intensive research and development, and many believe that modular, utility-scale storage batteries will be widely deployed in the transition to a low carbon future [23]. With round trip efficiencies approaching 90% [24], the losses are much smaller than for pumped storage and compressed air storage systems. Storage will play a strategic role in integrating and maximizing the role of renewable electricity generation in the low carbon future [11].

In the low carbon scenario presented here, there is usually ample variable hydroelectricity available on the margin (see the following section on electricity supply in the low carbon scenario), and this limits the need for diurnal storage as a carbon reduction strategy. However, in scenarios where fossil-fired generation is more heavily relied upon during daytime peak periods, diurnal storage is a potentially critical component of an emission reduction strategy. It is also complementary to grid management requirements in a grid with a high percentage of its generation coming from wind.

In our low carbon scenario, the storage charging rate is somewhat arbitrarily limited to 50 MW, and the total storage capacity is capped at 480 MWh, a level that is infrequently reached given the 50 MW charging rule. The discharge timing is not optimized in this simulation -- discharging occurs when the hourly end use consumption exceeds the daily average, continues until the capacity is depleted, and the system clears daily. For purposes of the financial analysis of the scenario, we have assumed the 480 MWh storage capacity is provided by two 60 MW 4-hour utility scale storage batteries.

While we have assumed utility-scale batteries in the financial analysis, the electric vehicle batteries included in the EV scenario described above could also be used for diurnal storage. Just as the tanks in gasoline powered vehicles hold more fuel than is needed for the commuting and relatively short home-based trips that characterize a typical day's vehicle use, so too will EV batteries store more energy than is needed for a typical day's travel. With the appropriate infrastructure and pricing incentives, EV owners with vehicles that are fully charged overnight and are connected to the grid later in the day could make some portion of their battery storage available to be uploaded to the grid during periods of peak consumption.

Considering just the 75,000 BEV's in our scenario by 2030 (i.e. excluding the plug-in hybrids), if they each have a battery capacity of 50 kWh and a third of them are connected to the grid and authorized to make up to 50% of their battery storage available, it would provide 600 MWh of stored electricity during the day that was generated and stored in the vehicle batteries during the previous night. By comparison, the hourly consumption of electricity on winter days is around 1,600 MWh, suggesting there could be a very significant "peak smoothing" role for electric vehicles in the grid of the future. Also, even without contributing back to the grid, BEV's represent a significant, new "supply following" end use. In the future grid, with its high percentage of wind and solar generation, EV's will be able to "top up" their batteries when there is surplus non-dispatchable generation that might otherwise have to be curtailed.

Summary of electricity consumption in the low carbon scenario

The consumption of electricity in 2030 in the low carbon scenario is summarized by sector and by end use in Table 10 and Figure13 (which compare with Table 3 and Figure 5 for the base year). The change in electricity consumption between 2019 and 2030 is shown for each end use in Table11 and Figure13.

Table 10. Electricity consumption in 2030 in Nova Scotia, low carbon scenario (GWh)

	Residential	Commercial	Industrial	Transportation	**Total**	**Percent of total end use**
Space heat	1,660	561			**2,221**	**23%**
Equip/appliances	1,391	848			**2,239**	**23%**
Other industry			1,238		**1,238**	**13%**
Port Hawkesbury Paper			1,078		**1,078**	**11%**
Lighting	330	488			**818**	**9%**
Water heat	401	180			**581**	**6%**
Air conditioning	125	279			**404**	**4%**
Motors		283			**283**	**3%**
Streetlighting		53			**53**	**1%**
EV charging				706	**706**	**7%**
Total	**3,907**	**2,691**	**2,316**	**706**	**9,621**	**100%**
Percent of total end use	**41%**	**28%**	**24%**	**7%**	**100%**	

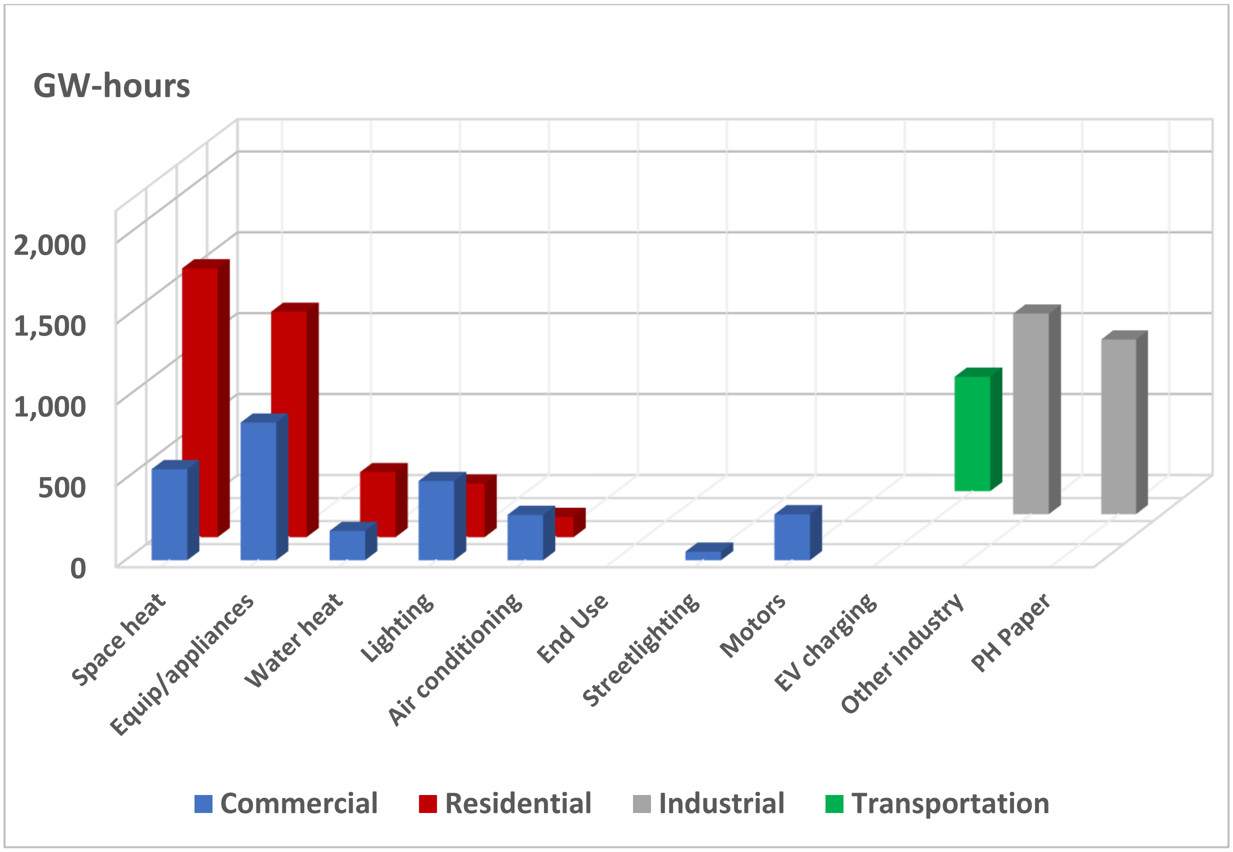

Figure13.Electricity consumption in2030 in Nova Scotia,low carbon scenario

Table11. Changes in electricity consumption, 2019 base year vs. 2030 low carbon scenario

	GW-hours consumption		**Change, 2019-2030**	
Aggregate end use category	**2019**	**2030**	**GW-hours**	**Percent**
Space heat	2,707	2,221	-486	-18%
Industry	2,624	2,316	-307	-12%
Home appliances	1,420	1,391	-29	-2%
Comm bldg equip & plug load	1,396	1,131	-265	-19%
Lighting	1,070	871	-199	-19%
Water heating	707	581	-126	-18%
Air conditioning	401	404	3	1%
Electric vehicles	9	706	697	Very large
Net decrease in consumption	**10,333**	**9,621**	**-712**	**-7%**

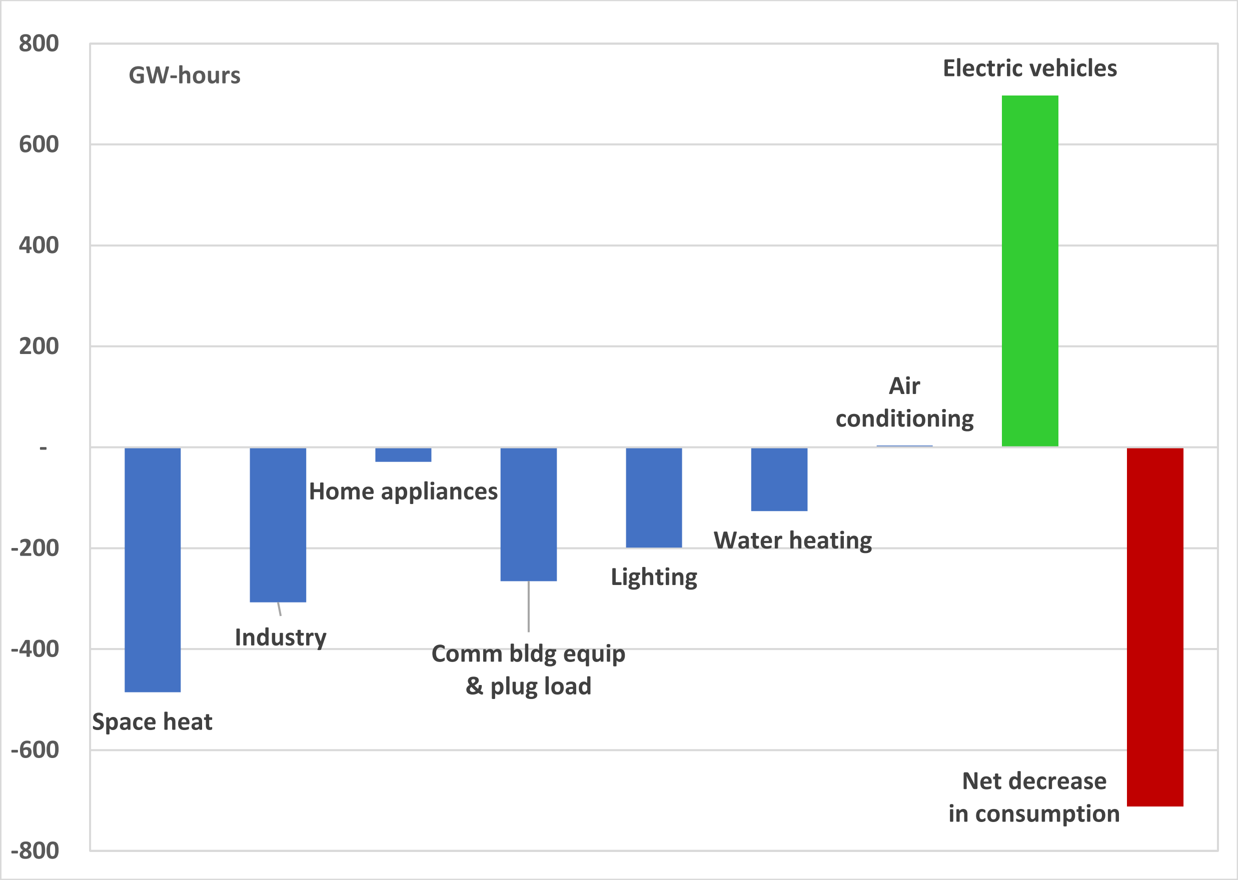

Figure 14. Change in annual electricity consumption, 2030 low carbon scenario vs. 2019

There are transformative changes beneath the surface of these numbers. Total electricity consumption in the low carbon scenario in 2030 is 700 GWh or 7% lower than in the 2019 base year, but this is the net result of a much larger 1,400 GWh drop in the aggregate consumption for all the established end uses, offset by 700 GWh of "new" consumption for electric vehicle charging. With 75,000 battery electric vehicles and 125,000 plug-in hybrids by 2030, vehicle charging grows from a negligible end use in 2019 to a 7% share of total electricity consumption by 2030. At the same time, the equivalent of more than 100,000 residential dwellings switch from oil to electric heat pumps as oil's share of residential heating drops by 50% between 2019 and 2030, with similar trends in commercial building heating and residential water heating.

The drop in the absolute amount of electricity consumption at the same time electricity's share is increasing for space heating, water heating and personal vehicle power is a "must have" in any low carbon future for Nova Scotia. This is made possible by the combined effects of the deep energy retrofits, which reduce thermal energy requirements per building by 50%, and the phasing out of electric resistance heating in favour of heat pumps, which will at least double the heat delivered per kWh consumed.

Figure 15 and Figure 16 illustrate the average winter and summer consumption patterns, by end use, for the low carbon scenario. The line at the top of the chart represents the generation requirement and is the sum of the end use consumption, the net storage, and system losses. Average hourly consumption in the winter is particularly sensitive to cold weather, as illustrated in Figure 17.

In the low carbon future, the system is less “peaky” both seasonally and diurnally. Space heating consumption occurs disproportionately in the peak, and the deep energy retrofits therefore have the effect of reducing the difference between the winter and summer consumption levels. Electric vehicle charging occurs disproportionately during off-peak periods (middle of the night) and this, along with the diurnal storage system, also contribute to the flatter load characteristic of the low carbon future.

In the 2019 base year simulation, end use consumption peaks at 2,040 MW, plus system losses of 141 MW for a total peak generation requirement of 2,181 MW. In 2030 in the low carbon scenario consumption peaks at 1,766 MW, plus system losses of 122 MW for a total peak generation requirement of 1,888 MW. In the base year, winter consumption averages 50% more than in the summer, and this gap is reduced to 40% by 2030 in the low carbon scenario. In the 2019 base year simulation, average end use consumption is 72% of peak consumption in the winter and 75% of peak consumption in the summer; these figures increase to 75% and 77%, respectively, in 2030 in the low carbon scenario.

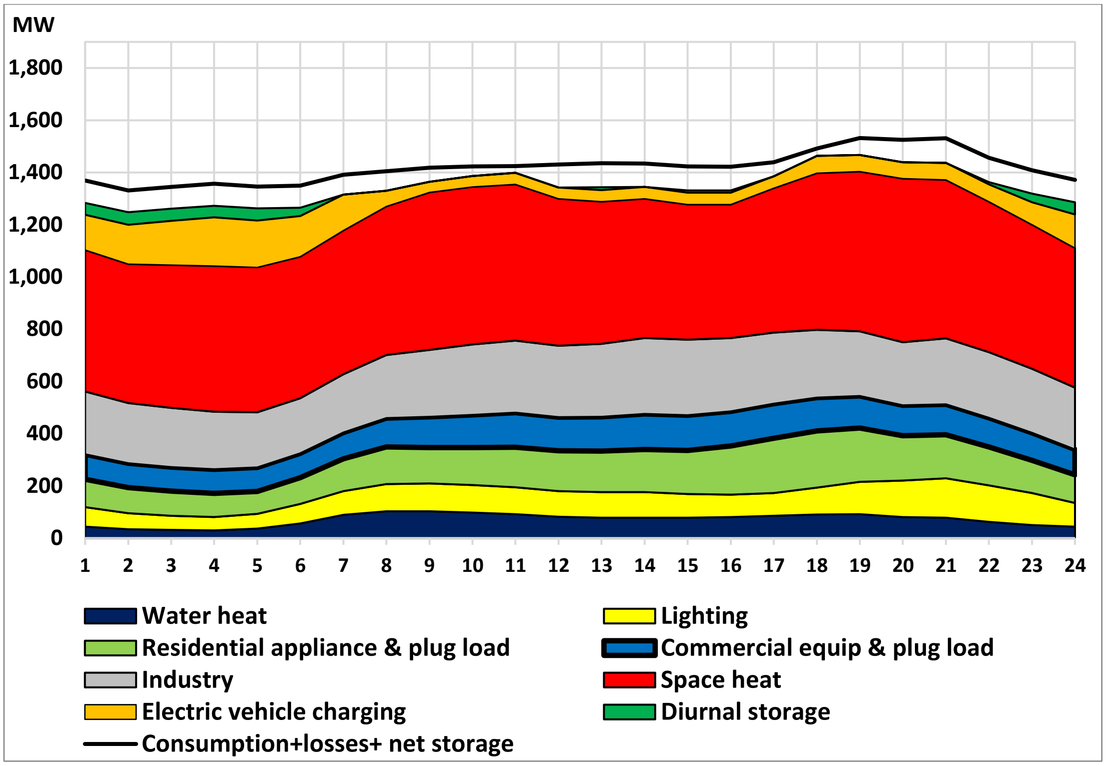

Figure 15. Average electricity consumption in winter, 2030, low carbon scenario

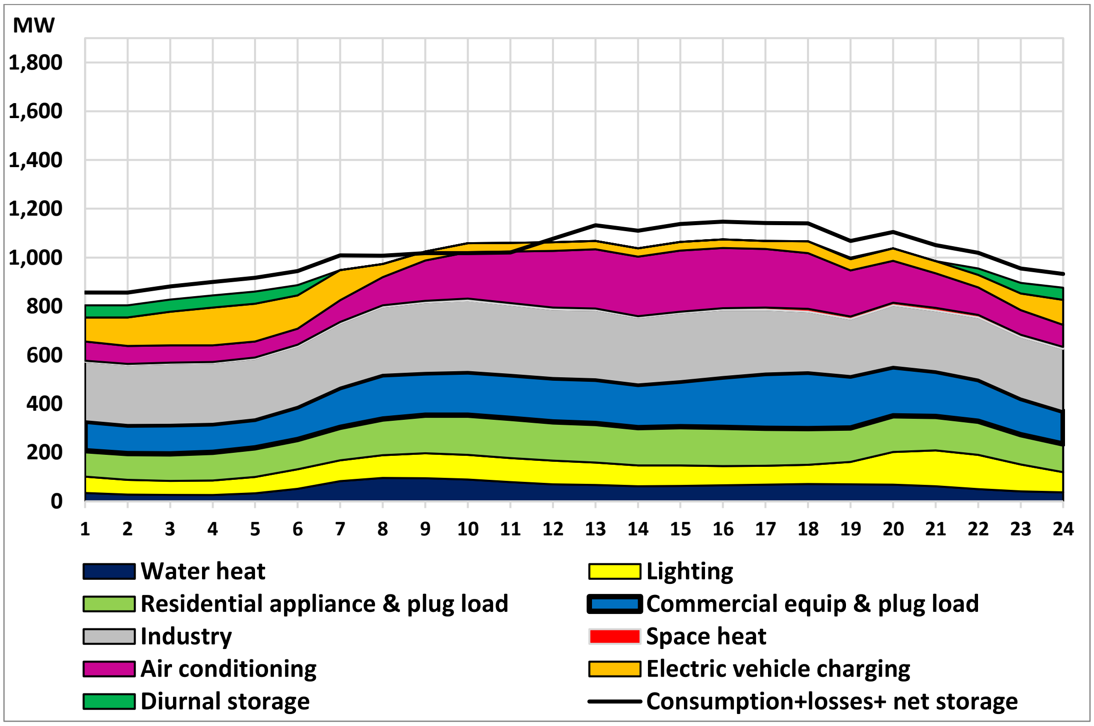

Figure 16. Average electricity consumption in summer, 2030, low carbon scenario

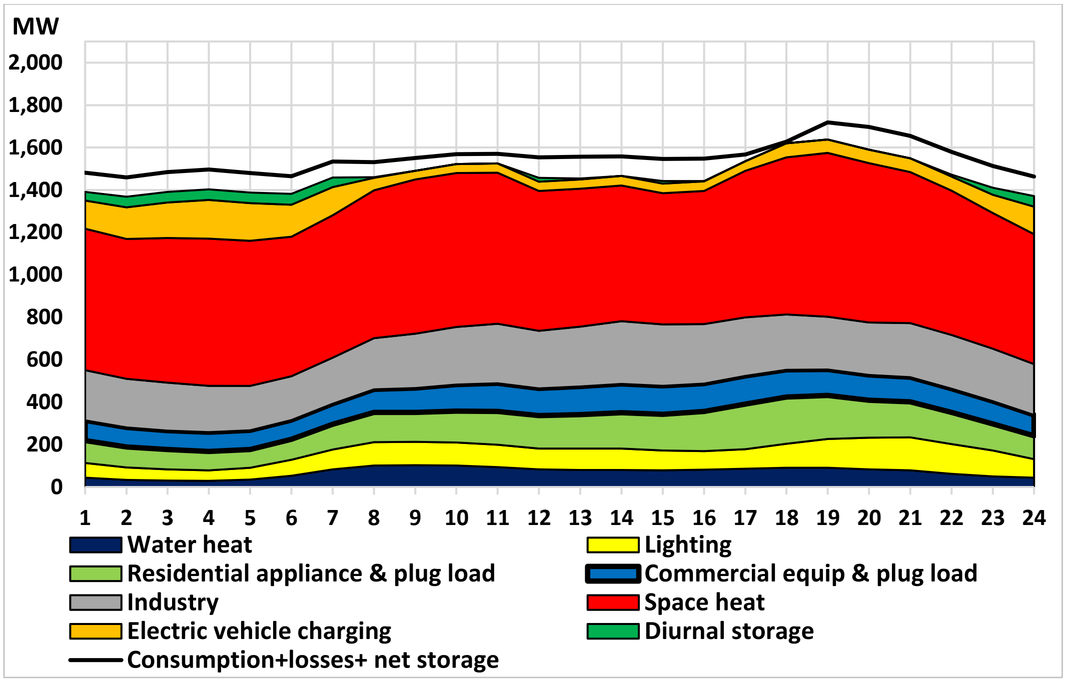

Figure 17. Average electricity consumption for five coldest days of the year, 2030, low carbon scenario

The program of efficiency and fuel switching measures described above, or one with equivalent impact on electricity consumption, is the key enabler of the transition to both a renewable electricity grid and a low carbon future for Nova Scotia. Even without any new renewable electricity resources beyond those already committed (i.e. including the Nova Scotia and Supplemental blocks from the Maritime link), the lower level and flatter pattern of electricity consumption would increase the percentage renewables share on the Nova Scotia grid to 47% by 2030. Beyond that, and more importantly, it holds consumption to levels that facilitate the development of a renewable grid by 2030 through additional hydro imports and domestic wind and solar resources.

Electricity supply in Nova Scotia's low carbon future

In the low carbon scenario, annual electricity consumption in 2030 totals 9.6 TWh, and generation requirements total 10.3 TWh. The renewable electricity supply already committed (including the Nova Scotia and Supplemental blocks of hydropower via the Maritime Link) totals 4.8 TWh. To achieve the objective of a fully renewable grid requires an additional 5.5 TWh of renewable electricity supply.

Increase hydro power imports via the Maritime Link

The low carbon scenario includes an additional 1.3 TWh of hydropower via the Maritime Link, over and above the 1.2 TWh from the Nova Scotia and supplementary blocks. Power in this discretionary or "market" block is taken as needed, provided it does not cause the total rate of import over the Link to exceed a limit of 300 MW.

Double down on wind power

Nova Scotia, and more specifically Nova Scotia Power, is an established leader in the deployment of wind power in Canada; only Prince Edward Island has a greater share of its electricity supply generated by wind. Even without including offshore potential, the wind energy resource is many times larger than existing generation; the expansion of wind electricity in Nova Scotia is not constrained by a shortage of wind [25].

Our 2019 base year simulation includes 2.2 TWh of wind from over 350 turbines, almost all of them brought online over a period of less than ten years. In the low carbon scenario, wind energy production doubles over the next ten years, reaching 4.4 TWh by 2030. This is well below the 5.8-6.0 TWh included for Nova Scotia in GE Consulting's Pan-Canadian Wind Integration Study (PCWIS)[26] but is delivered in the context of the overall lower level of electricity consumption in our scenario and brings wind power's share of total grid generation to 43% by 2030. Depending on the capacity factors achieved by these new wind turbines, they will add 600-800 MW of additional wind capacity to the Nova Scotia grid.

Build the second tie link with New Brunswick and increase hydro power imports from Quebec

In the low carbon scenario, there is 200 MW of capacity available via interconnections to New Brunswick, based on the presumption that the second intertie will be built, a project of both direct and indirect value in the decarbonization of the Nova Scotia grid [11]. As noted in the Method section, imports via New Brunswick are applied as needed in our analysis, after Nova Scotia's domestic renewable resources and power available through the Maritime Link have been fully utilized. The flow of electricity via New Brunswick therefore varies in the low carbon scenario, from zero to 200 MW, but averages 115 MW. In terms of energy, imports of power via the New Brunswick intertie increase by 0.6 TWh, bringing the total to 1.0 TWh in 2030, all of which is assumed to be a combination of renewable hydropower and wind power from Hydro-Quebec's existing system. The 1 TWh of electricity from Hydro-Quebec is well within Hydro-Quebec's existing generating and export capacity. It represents 2.7% of Hydro-

Quebec's total 2018 export sales of 36.1 TWh, and less than half of one percent of Hydro-Quebec's annual generation of more than 210 TWh.

Develop Nova Scotia's solar power resource

Solar power generation increases to 0.47 TWh in 2030. Using a conservative estimate of 12% for the capacity factor, this represents 430 MW of solar photovoltaic generation capacity. Like wind power, the solar energy generation is distributed and individual installations vary from residential rooftop systems that are generally under 10 kW, to larger installations on commercial and institutional buildings that can be hundreds of kW (the largest such system in Canada is over 1,000 kW), to 1-100 MW utility-scale solar farms.

Our scenario does not specify the mix of system types. The potential for residential solar in Nova Scotia in 2030 was recently estimated to be 96-187 MW, generating 104-212 GWh [27], suggesting that this type of system could supply up to 45% of the 0.47 TWh in the low carbon scenario. This would correspond to about 20,000 home installations, implying a solar electricity generator on less than 5% of Nova Scotia houses.

Solar installations on the flat rooftops of warehouses, box stores, and other large commercial and institutional buildings offer a potential equal or greater than that in the residential sector. With a conservatively estimated 12% capacity factor, and given the range of solar insolation in Nova Scotia, solar panels on these rooftops produce about 150 $kWh/m^2/year$[28]. There are at least 2 million m^2 of large, flat rooftops in Nova Scotia; if a third of these buildings installed solar systems, it would supply 100 GWh per year of solar power.

Utility scale solar farms offer a third mode of solar production. Although these installations can locate 100 MW of solar capacity on one site, they are more typically in the 10 MW range and generate around 10 GWh of solar electricity per year. At that scale, 10-20 such solar farms could provide 100-200 GWh per year, up to 40% of the 470 GWh of the solar electricity in the low carbon scenario for 2030.

The renewable grid in 2030

With the addition of the supply blocks described above, the level and pattern of electricity consumption in the low carbon future is met with a grid that is 91% renewable, with the aggregate breakdown by source as shown Table 12. The total of 10.3 TWh includes transmission and distribution losses of 6.9% of end use consumption, and all the end use consumption summarized in Table 10. This includes the charging needs of a fleet of 75,000 battery electric and 125,000 plug-in hybrid electric vehicles and a move away from fossil fuel and electric resistance heating in favour of heat pumps for space and water heating in buildings.

Table 12. Electricity supply in 2030, low carbon scenario

	GW-hours	Percent of total
Wind	**4,438**	**43%**
Wreck Cove (hydro)	329	3%
NS legacy hydro	648	6%
M-link: NS block	899	9%
M-link: supplementary	263	3%
M-link: market	1,308	13%
HQ hydro via N.B.	1,013	10%
Subtotal - hydro	**4,460**	**43%**
Solar	**467**	**5%**
Gas CT	**932**	**9%**
TOTAL GENERATION	**10,297**	**100%**
Renewable share	**91%**	

Wind and hydropower each provide 43% of annual electricity, and solar contributes an additional 5%. The residual use of fossil fuel is restricted to gas-fired combustion turbines which were deliberately left in the mix for their grid management benefits.

Figure 18, Figure 19 and Figure 20 show the average electricity supply in the low carbon scenario in 2030 for winter, summer, and the five coldest days of the year, respectively. The dotted lines in these figures represent the level of generation that would be required in absence of diurnal storage, thus illustrating its load smoothing impact. When the line is below the level of generation, it indicates that the storage system is being charged (as shown by the green areas in Figure 15, Figure 16 and Figure 17, above) and when the line is above the level of generation it indicates the storage system is discharging.

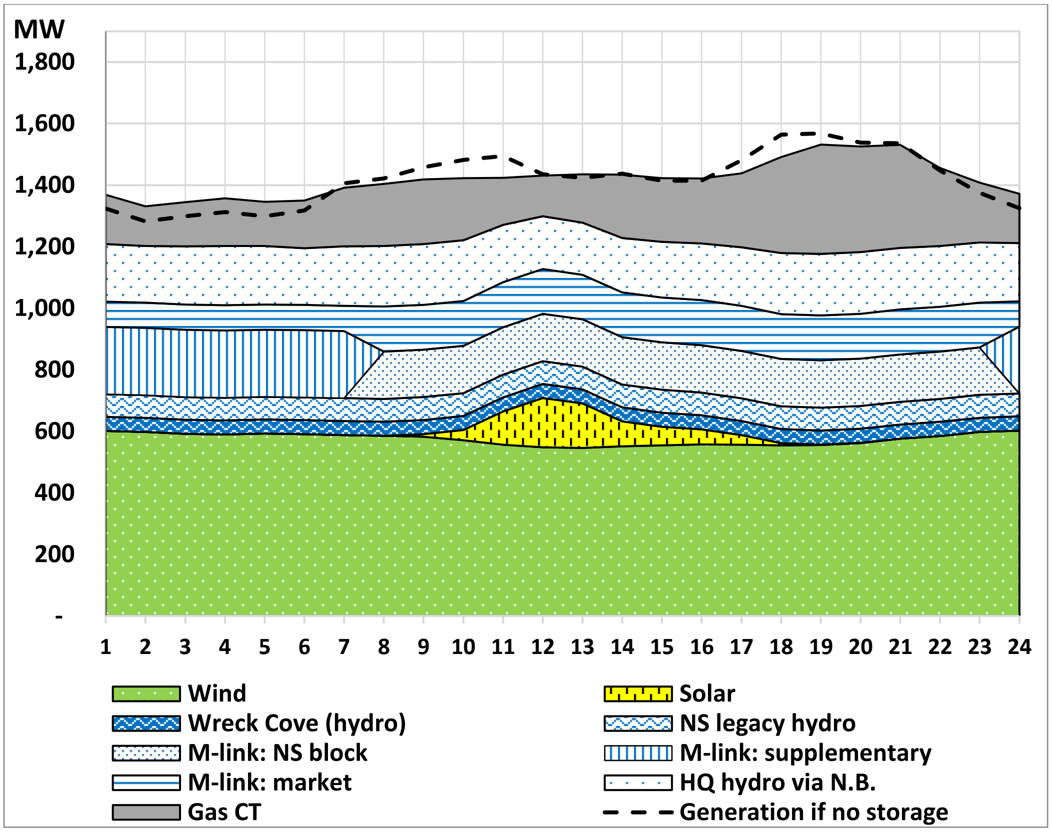

Figure 18. Average electricity supply in winter 2030, low carbon scenario

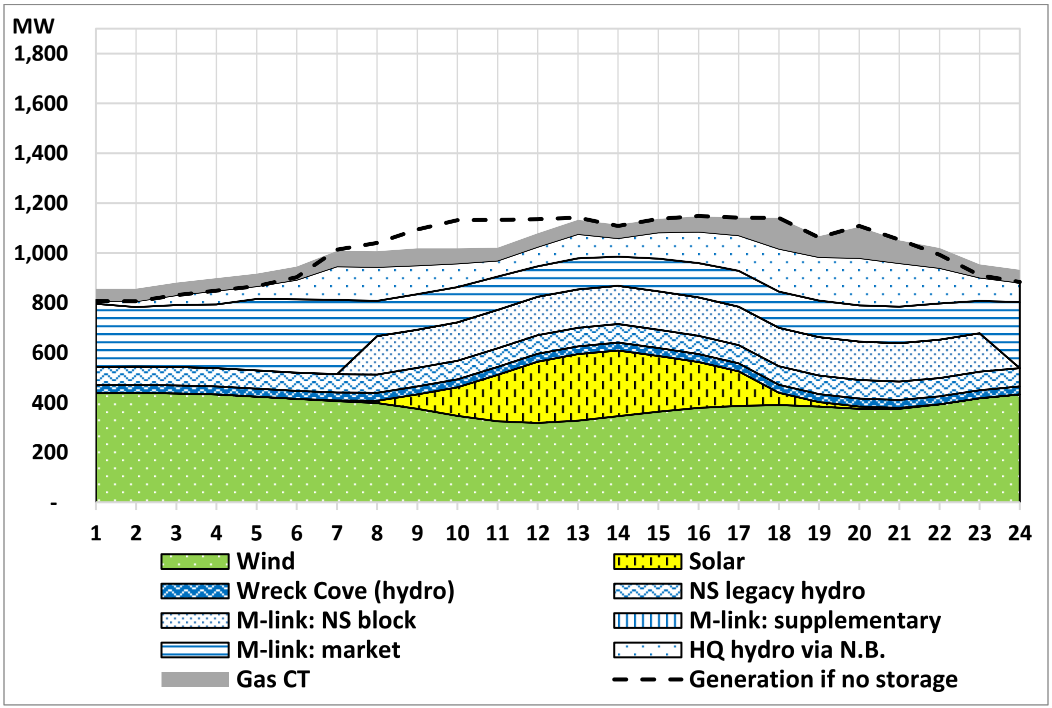

Figure 19. Average electricity supply in summer 2030, low carbon scenario

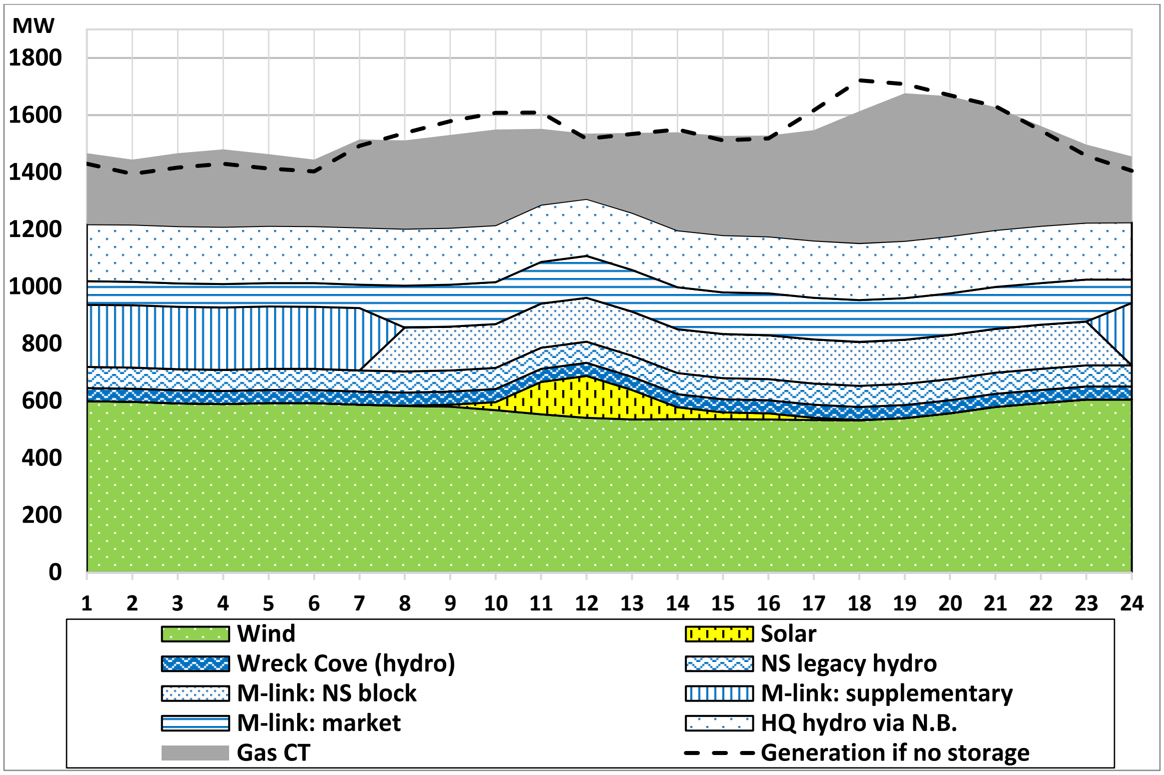

Figure 20. Average electricity supply on five coldest days in 2030, low carbon scenario

Integrated results – Toward a Carbon Free Nova Scotia

The scenario described above takes Nova Scotia a long way toward a carbon-free energy system based on the three pillars of low carbon futures: efficiency, electrification, and decarbonization of the grid. It is only one illustrative scenario, but it reflects the rate and magnitude of change that is needed to mount an effective emergency response to the climate crisis.

By 2030, half the buildings currently heated with oil switch to electric heat pumps, all the water heaters in the province are converted to electric heat pumps, and a third of all personal vehicle travel is powered by electricity. In the 2019 base year simulation, electricity provides 35% of the energy consumption included in the scenario analysis; by 2030 electricity's share has grown to 55% of the total. Notwithstanding this rapid rate of electrification, and "business as usual" population and economic growth, the efficiency gains from the deep retrofit of the building stock, the efficiency gains of heat pumps, the inherent efficiency of electric vehicles, and ongoing improvements in the efficiency of lighting and other electricity using devices, total electricity consumption in 2030 is 7% lower in 2030 than in the 2019 base year simulation. In addition, fossil fuel consumption for personal vehicles drops by 50%, mostly due to the switch to electric drive, and fuel consumption for building space and water heating drops by 67% from the combined effects of deep retrofits and the switch to heat pumps.

With the total demand for electricity held in check and even declining slightly, an expanded supply of wind, hydro and some solar electricity is enough to supply over 90% of total generation by 2030. Emissions from the electric power system in 2030 in the low carbon scenario are 91% lower than their base year (2019) level, and the carbon intensity of electricity end use drops to 58 grams per kWh. In addition, the electrification of buildings and the growth of electric vehicles cause emissions from fuel consumption in buildings to drop by 69% and from personal vehicles by 48%. Overall, the GHG emissions in the scope of this analysis drop by 79% relative to their base year levels. Even without additional renewable electricity supply beyond that included in the low carbon scenario, total emissions would drop further with a more aggressive transition to electric vehicles or a more rapid transition to heat pumps for space and water heating. The reductions in greenhouse gas emissions due to the efficiency of heat pumps and electric vehicles are greater than the emissions from the increase in electricity generation required to operate them.

The greenhouse gas emissions in the base year and in the low carbon scenario in 2030 are summarized in Table 13. It includes a modified version of the base year emissions that reflects the already-committed hydro resources from the Maritime Link that will come online in 2020. The “before” and “after” consumption of fuel and electricity, and the related greenhouse gas emissions, are illustrated in Figure 21 for the energy and emissions included in the scope of the scenario.

Notwithstanding the transformative nature of this emergency response scenario for decarbonizing Nova Scotia’s energy system, there are numerous conservatisms in the assumptions used throughout the analysis. For example, in no particular order:

- the post-retrofit thermal losses from the residential building stock are still more than double the current passive house retrofit standard;
- the thermal losses assumed for new housing are far short of current best practice;
- the growth in commercial and institutional floor area is likely overestimated;
- the Port Hawkesbury paper mill is assumed to still be operating in 2030 without having achieved any efficiency gains in its electricity consumption;
- the rate of lighting efficiency improvement underestimates the potential impact of the market transformation to LED technology;

- there is no assumed improvement in electric vehicle efficiency beyond the performance of currently available vehicles;
- there is no explicit allowance for reduced space heating requirements due to global warming itself;
- continued, unmoderated growth in electricity for air conditioning is assumed with no allowance for the lower cooling requirements of the thermally efficienct post-retrofit housing stock;
- the assumed coefficients of performance of the heat pumps are well below current best technology;
- the efficiency of major household appliances remains unchanged;
- a medium rate of improvement has been assumed for efficiency in electricity use in the commercial and industrial sectors;
- the structure of the Nova Scotia economy is held constant even though it has been trending in the direction of lower fuel and electricity consumption per dollar of economic output;
- the assumed capacity factors for wind and solar are relatively low and are held constant over the scenario period;
- solar generation is all fixed panel, with no tracking; and
- no credit is taken for a possible shift toward a culture of "sufficiency" in which people consciously change their decisions and behaviours at home and at work in order to reduce ecological stress and restore ecosystem health in their communities [29][30][31][32].

Table 13. Greenhouse gas emissions in study scope (kt CO2e)

	2019 simulation	With M-link NS and supplementary blocks	2030, Low Carbon Scenario	Percent change from 2019
Combustion turbines	170	170	559	
Thermal plants	6,413	5,361	-	
Subtotal for grid	**6,584**	**5,531**	**559**	**-92%**
Personal vehicles	2,115	2,115	1,094	-48%
Residential - space heat	1,125	1,125	302	-73%
Residential - water heat	246	246	1	-99%
Commercial buildings	579	579	302	-48%
Subtotal building fuel use	**1,951**	**1,951**	**605**	**-69%**
Total Emissions in Scope	**10,650**	**9,598**	**2,259**	**-79%**

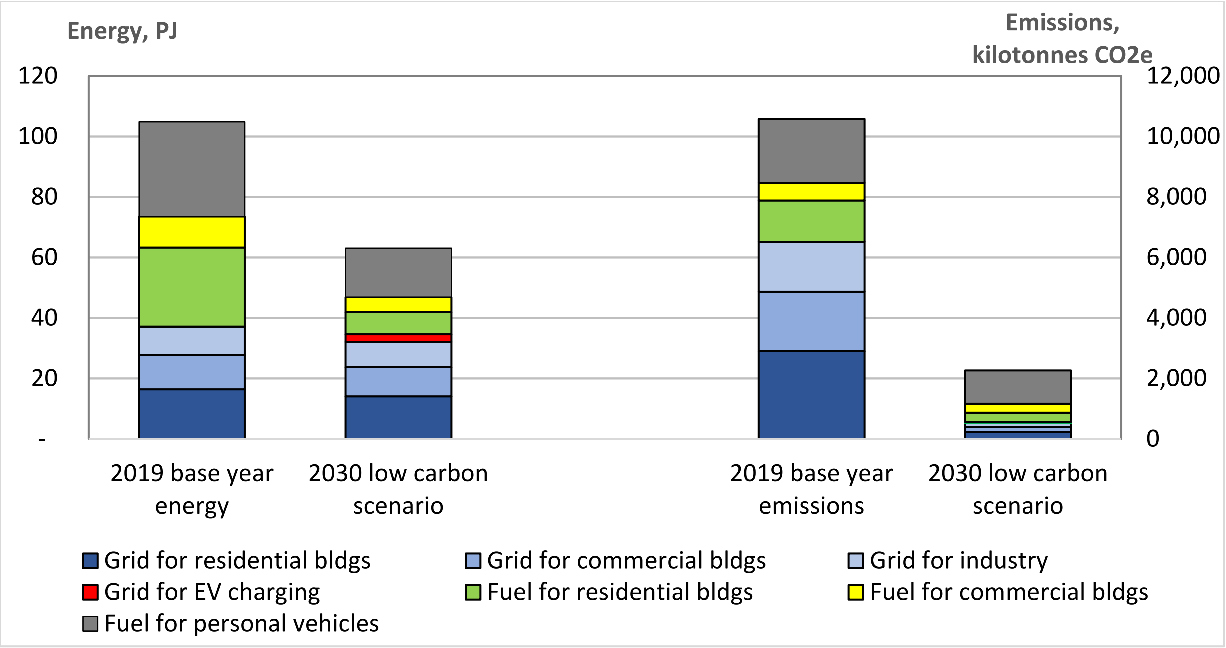

Figure 21. Energy (bars on the left) and emissions (bars on the right) included in scenario, 2019 baseline vs. 2030 low carbon scenario

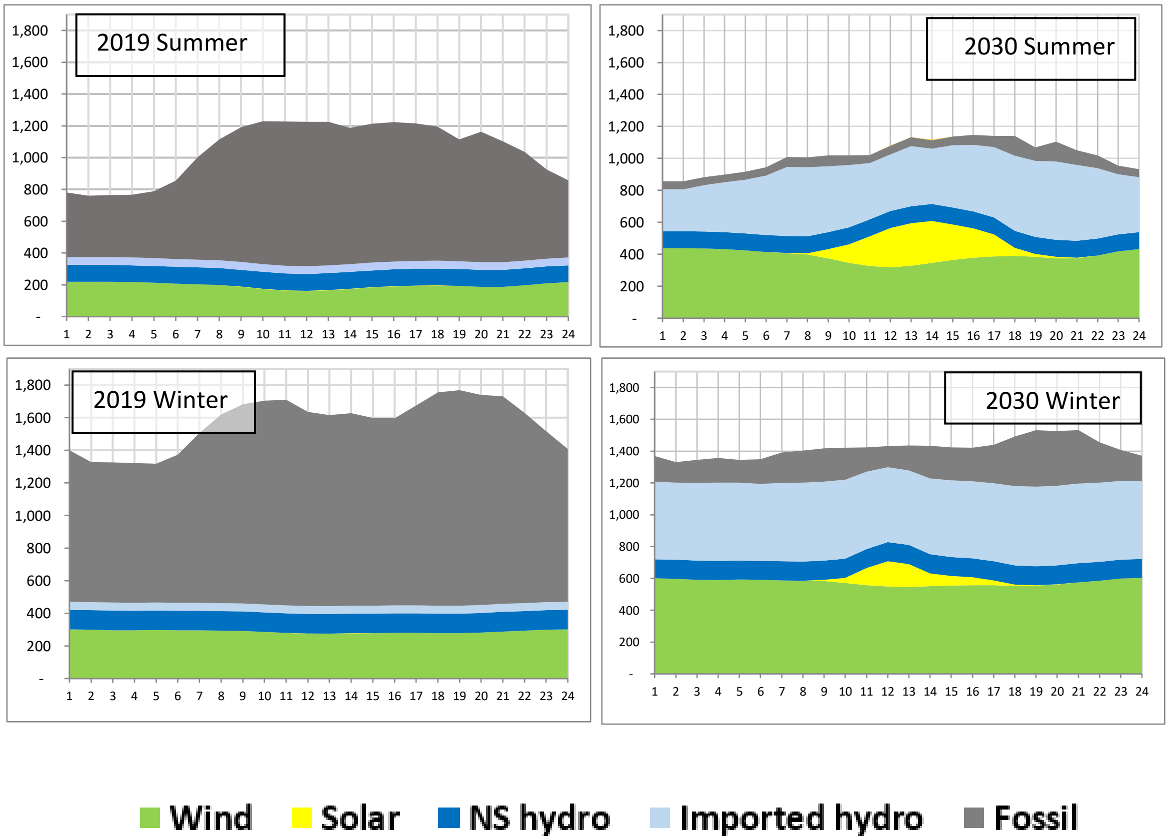

Figure 22. Electricity supply mix (MW), 2019 vs 2030 low carbon scenario

Table 14. The low carbon transition -- by the numbers

Indicator	2019 base year	2030 low carbon	Percent Change
Average dwelling size (including apartments), m^2	148	155	5%
Thermal energy loss of residential housing (kwh/m^2)	115	65	-43%
Average residential fuel and electricity consumption (kWh/m^2)	194	85	-56%
Residential floor area heated with electricity (thousands of m^2)	22,202	49,537	123%
Percent of water heat provided by electricity	45%	95%	111%
Average energy intensity of commercial floor area (MJ/m^2)	1,040	665	-36%
Commercial floor area heated with electricity (thousands of m^2)	4,518	10,507	133%
Personal vehicle kilometres powered by electricity, millions	43	3,552	8160%
Percent of grid electricity provided by renewables	33%	91%	176%
Percent of grid electricity from in-province resources	29%	57%	97%
GHG intensity of electricity (g CO2e/kWh)	596	54	-91%
Grid emissions (kilotonnes CO2e)	6,514	559	-91%
Emissions from building fuel use, res and comm (kt CO2e)	1,951	606	-69%
Emissions from personal vehicle fuel use (kt CO2e)	2,115	1,094	-48%
Emissions from electricity to charge electric vehicles (kt CO2e)	~0	39	Very large

Financial Costs and Benefits

The low carbon scenario described here comes with a complex mix of costs and savings. Capital investments are required to carry out the deep energy retrofits and to build additional renewable electricity generation capacity and the second tie line to New Brunswick. Increased power from the Maritime Link (above the Nova Scotia and supplemental blocks) and from Hydro Quebec (via New Brunswick) will increase the annual expenditures on hydropower from these other provinces. On the other side of the ledger, fuel consumption for personal vehicles and for building space and water heat declines, and Nova Scotia Power's spending on imported fossil fuels will drop to a fraction of current levels.

We have taken a high-level look at the major incremental costs and savings of the pathway described in this report, and the results suggest that as transformative and disruptive as the transition may be, it appears to be relatively inexpensive on a net basis. It is largely a matter of capital expenditures for efficiency and renewable energy, offset by savings in annual expenditures on fossil fuels. It will cost about $1.6 billion per year and it will save about $1.4 billion per year, with a net annual cost of about $200 million. To put this in context, $200 million is about half of one percent of Nova Scotia's economic output, or about 10% of the revenue the government collects every year in sales tax. The measures in the plan eliminate more than 7,000 kilotonnes of CO_2e per year by 2030.

The value of the benefits in our cost analysis are restricted to the direct energy cost savings from the efficiency and fuel switching measures scenarios. It does not include any financial credit for any collateral social, economic and environmental benefits that go along with a low carbon economy, and which are increasingly being recognized as equally or more valuable than the carbon reductions themselves. We have used conservative assumptions to compensate for the lack of detail in this necessarily broad-brush assessment, and the results are sufficiently robust and compelling to establish the urgent need for a comprehensive financial analysis and investment strategy for Nova Scotia's low carbon transition.

Our estimates of costs and savings are incremental to the status quo, including the already committed blocks of power from the Maritime Link. Capital costs are annualized using a discount rate of five percent over the life of the investment, unless otherwise noted.

The investments

Annualized investments and annual expenditures total $1.57 billion by 2030. Over the ten-year implementation period, capital investment totals $19.9 billion, annualized to $1.4 billion. Annual expenditures in 2030 on Quebec and M-Link hydropower and DSM total an additional $147 million.

Residential retrofits -- $11.6 billion, or $756 million annualized. At a scale of investment that is usually associated with supply side megaprojects, the deep energy retrofit of 80% of the existing residential dwellings by 2030 is by far the largest cost of the low carbon transition. The retrofits constitute a critical component of the low carbon transition, both for the direct energy and emissions savings, and for their role in keeping electricity consumption to a level that can be met with renewable generation.

In addition to $7500-$10,000 labour costs, the key material costs for deep energy retrofits in the residential sector include insulation and air sealing ($1,000), high performance windows and/or wall re-insulation ($18,000), heat recovery ventilators ($3,000), water heating heat pumps ($2,000), and for some dwellings, conversion to heat pumps for space heating ($10,000). Of the 120,000 oil heated dwellings that are retrofit, 50% are converted to electric heat pumps by 2030, as are another 55,000 buildings currently heated with electricity. A total of 250,000 single family dwellings are retrofit by 2030 at an average cost of $40,000 and a total cost, over ten years, of $10.1 billion. In addition, 80% of apartment buildings undergo deep retrofits at a cost of $150-$250 per square metre, for a total ten-year investment of $1.5 billion. The residential retrofits are amortized over 30 years, yielding an annualized cost by 2030 of $756 million.

Some reviewers commented that these estimates are on the high end of the range of what it will cost to achieve the thermal intensities and energy efficiency gains included in the low carbon scenario; the techniques for deep energy retrofits are developing rapidly and costs are coming down. Also, as noted above, a project of this magnitude (millions of windows, hundreds of thousands of heat pumps) carried out over a ten-year period will result in economies of scale, reduced labour time per dwelling, and other efficiencies that will translate into cost savings of 50% or more, but we have not assumed such savings in this estimate.

Commercial and institutional building retrofits -- $4.1 billion, $265 million annualized. Average savings of 25% are achieved in the 20.4 million m^2 square metres of commercial and institutional floor area, at a cost of $\$200/m^2$. This cost is high for the relatively modest level of savings assumed, and sums to $4.1 billion over ten years, with annualized costs reaching $265 million by 2030.

Electric car premiums -- $750 million, $139 million annualized. We have assumed a $10,000 premium for each of the 75,000 battery electric vehicles in the low carbon scenario, even though electric cars are expected to continue to come down in price and should eventually be less expensive than gasoline-powered vehicles. The premium assumed here totals $750 million over ten years. For this item, annualization is at 7% over 7 years.

General efficiency of electricity use -- $33 million per year. This represents an annual expenditure in demand side management to support the achievement of the two percent per year annual efficiency improvement in electricity use in the low carbon scenario. Note that this spending, like other estimates in this financial analysis, is incremental to current funding support for DSM.

New wind generation capacity, $1.6 billion, $128 million annualized. The low carbon scenario includes 800 MW of new wind generation, with an assumed capital cost of $2,000 per KW, annualized over 20 years.

New solar generation capacity, $1.027 billion, $82 million annualized. This includes 467 MW of solar photovoltaic generation at an average capital cost of $2,200 per kW.

New Brunswick intertie and other transmission. $500 million, $33 million annualized. This includes assumed cost sharing with New Brunswick of the $400 million second intertie, plus an allowance for additional transmission investments required by the shift to a hydro/wind-based grid.

Market-based hydropower purchases, $114 million per year. This includes additional annual power purchases by 2030 of 1,300 GWh from the Maritime Link, (over and above the Nova Scotia and supplemental blocks that are part of the baseline for this financial analysis) and 580 GWh of hydropower from Quebec, via New Brunswick. A price of $60/MWh is assumed, reflecting the rate of the recently negotiated long term power supply contract between Massachusetts and Quebec.

Utility scale battery storage, $210 million, $27 million annualized. The storage in the low carbon scenario could be provided with two, 60 MW utility scale batteries. Capital costs are currently $2,300/kW (with four hours of storage) and are expected to drop as much as 50% by 2030, to less than $1,200/kW; we have assumed a capital cost of $1,750/kW for the 120 MW of diurnal storage in the low carbon scenario, annualized over ten years.

The savings

Deep energy retrofits and electrification, $600 million per year by 2030. The reduction in fuel oil consumption accounts for 80% of this total. Eighty percent of oil heated buildings undergo retrofits, achieving a reduction of about 50% of thermal losses in the residential sector and 25% reduction in secondary energy intensity in the commercial/institutional sector. Half the oil-heated buildings that are retrofit are also switched to electric heat pumps, and electric heat pumps displace 95% of water heating systems by 2030. The remaining savings are about evenly distributed between gas, wood and other fuels (mostly propane). Savings are calculated at assumed prices in 2030 of $1/litre for oil, $0.40/m^3 for gas, and $330/cord for wood.

Reduced gasoline consumption for personal vehicles, $529 million per year by 2030. Gasoline consumption drops by half as a result of both efficiency improvements and electrification. Savings are estimated using an assumed price for gasoline in 2030 of $1.15/litre. Total gasoline savings consumption for personal vehicles declines from 920 million litres in 2019, to 476 million litres in 2030, by which time 25% of vehicles (125,000) are plug-in hybrids using electric drive for 75% of vehicle-kilometres travelled, and 15% of vehicles (75,000) are battery electric.

Reduced coal and other fossil fuel costs for power generation, $222 million/year by 2030. This figure represents the net change in Nova Scotia Power's annual fossil fuel related costs.

The total is dominated by an estimated $200 million per year in savings in fuel purchases. The low carbon scenario will also reduce the annual maintenance investments in the fossil fleet (currently in the $50 million range) while at the same triggering a smaller but offsetting cost increase for the acceleration of thermal plant decommissioning. We have not analyzed the amount of reserve capacity required in the wind/hydro grid that is the core of our low carbon scenario, or what role the legacy thermal plants might play in providing that reserve, so we cannot specify the maintenance cost savings and accelerated decommissioning costs. For purposes of the scenario cost estimate, we have used a placeholder value of $22 million per year in net savings, based roughly on the assumption that maintenance investments will be reduced by 50%, and that the incremental costs of accelerated decommissioning will be in the range of $3 million (annualized).[8] In general, both the maintenance investment savings and the decommissioning costs will increase as the decommissioning schedule is accelerated.

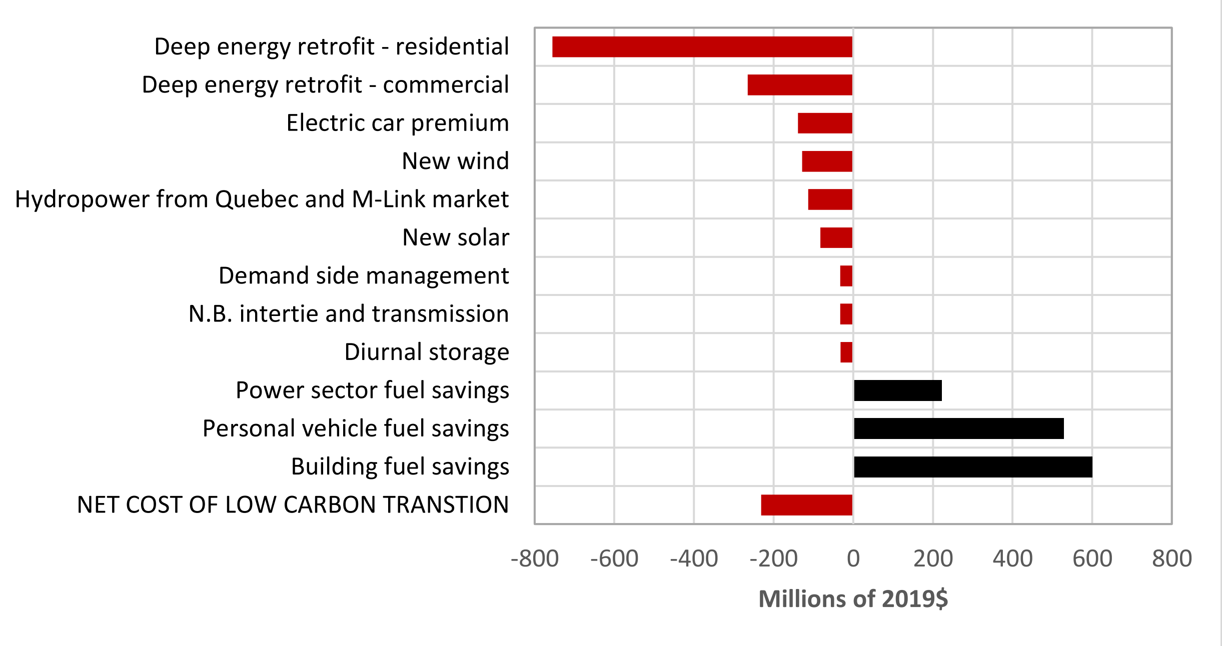

Figure 23. Incremental costs, savings and annualized investments in 2030, low carbon scenario. (Note that the estimate of the net cost of the transition includes no financial credit for socio-economic and public health benefits, reduced air pollution, or greenhouse gas emission reductions.)

---

[8] As a point of reference, the analysis supporting the federal regulations for the reduction of GHG emissions from coal-fired power puts the incremental cost for the early decommissioning all seven of the coal units that would otherwise continue operating beyond 2030 at $29 million ($3.75 million annualized at 5% over ten years) [33]. This figure does not include the Tufts Cove units (oil/gas) or the Point Tupper biomass plant, none of which are relied upon for annual energy in the low carbon scenario presented here.

The above summary of costs and annualized investments is depicted in Figure 23. This analysis is indicative; our objective was only to test the financial feasibility of the low carbon scenario to get an approximate understanding of its costs and benefits. We have included 350 MW of combustion turbine capacity and added 120MW/480 MWh of short-term storage, but we have not estimated the costs of managing the short-term fluctuations in power production from wind and solar.

There is often little or no up-side to emergency response, only cost, but the climate emergency is not like that. While the low carbon transition is expensive, it can nearly and perhaps completely pay for itself through the savings and avoided costs incurred when fossil fuel consumption is curtailed.

Conclusion

Emissions from Nova Scotia power plants, buildings and personal vehicles total 10.7 million tonnes of CO_2e in the 2019 baseline of this analysis, making up 75% of all the energy-related greenhouse gas emissions in Nova Scotia. This total will be reduced to 9.6 Mt CO_2e after Muskrat Falls hydropower starts flowing through the Maritime Link in 2020. Nova Scotia Power's fossil fuel generators account for 56% (5.5 Mt), personal vehicles for 22% (2.1 Mt) and fuel use in buildings for 20% (2.0 Mt) of these emissions. In the low carbon scenario presented here, these emissions can be reduced to 2.6 Mt CO_2e by 2030, through a set of efficiency, electrification and decarbonization measures. Emissions from the electric power sector are reduced by more than 90% of their base year levels, even while tens of thousands of oil heated buildings switch to electric heat and the electric car fleet grows to 125,000 plug-in hybrids and 75,000 battery electric vehicles.

Developed primarily as an emergency response strategy for addressing the climate change crisis, a preliminary analysis indicates that financial savings from reduced fuel use in buildings and personal vehicles, and reduced fossil fuel purchases for power generation could largely pay for the annualized investments in deep energy retrofits, electric vehicles, and renewable electricity generation that make up the core of the low carbon scenario put forward here.

The critical path for the low carbon transition is the need for financing, logistical and business model innovations for accelerating the deployment of the technologies at many times the scale, and at many times the speed, at which they are currently moving forward. This problem is epitomized by the deep energy retrofit of buildings. The low carbon scenario in this report includes the deep retrofit of 250,000 single family dwellings and 80,000 apartment dwellings in a ten-year period at a cost exceeding $11 billion. This will require a small army of highly skilled professionals and tradespeople, with retrofit crews systematically evaluating, planning and executing the retrofit of entire neighbourhoods. This implies the commodification of retrofits and their financing, the rapid training of thousands of building technologists and skilled trades, and the removal of virtually all risk and capital investment requirements from home and building owners -- not unlike the manner in which power plants are planned, financed, and built.

The critical challenges facing the deployment of a transition to a low carbon energy system that is deep enough and quick enough to constitute an effective emergency response to climate change are not technological, and neither are they fundamentally economic. The climate emergency response scenario described here costs an estimated $1.6 billion in annual expenses and annualized investments in buildings and infrastructure. Offsetting those expenses are annual energy cost savings of $600 million in heating fuel, $529 million in gasoline savings, and $222 million in reduced coal and other fossil fuel costs for electric power generation. The transition will revitalize local economies, generate many thousands of professional and skilled labour positions throughout the province, and largely or completely pay for itself while doubling energy self-reliance and enhancing economic independence.

References

[1] T. L. Green, “Zeroing in on Emissions Canada’s clean power pathways -A review,” 2019 [Online]. Available: http://rgdoi.net/10.13140/RG.2.2.28135.29600. [Accessed: 09-Sep-2019]

[2] A. B. Lovins and Rocky Mountain Institute, *Reinventing Fire: Bold Business Solutions for the New Energy Era*. Chelsea Green Publishing, 2011.

[3] R. D. Torrie, David Suzuki Foundation, and Canadian Electronic Library (Firm), *Low-carbon energy futures: a review of national scenarios*. Vancouver, B.C: David Suzuki Foundation, 2013 [Online]. Available: https://www.researchgate.net/publication/303633499_Low_Carbon_Energy_Futures_A_Review_of_National_Scenarios

[4] C. Bataille, D. Sawyer, and N. Melton, “Pathways to deep decarbonization in Canada,” Deep Decarbonization Pathways Project, Sep. 2015 [Online]. Available: deepdecarbonization.org

[5] Duane, T, Koomey, J., Belu, K., and Hausker, K., “From risk to return: Investing in a clean energy economy,” 2017 [Online]. Available: http://riskybusiness.org/site/assets/uploads/sites/5/2016/10/RBP-FromRiskToReturn-WEB.pdf. [Accessed: 23-Jan-2017]

[6] A. Gouldson, A. Sudmant, H. Khreis, and E. Papargyropoulou, “The Economic and Social Benefits of Low-Carbon Cities: A Systematic Review of the Evidence,” Coalition for Urban Transitions, London and Washington, 2018 [Online]. Available: http://newclimateeconomy.net/content/cities-working-papers

[7] S. Law, M. Weiss, E. Farnworth, S. Bristow, and R. Harding, “We Mean Business: Economic opportunity through bold climate action,” Carbon Disclosure Project, Business for Social Responsibility, The Carbon Group, The Prince of Wales’s Corporate Leaders Group, B-Team, CERES, World Business Council for Sustainable Development, 2014.

[8] J. Dunckley, “Electric Vehicle Driving, Charging, and Load Shape Analysis,” EPRI, Palo Alto, CA, USA, Jul. 2018.

[9] C. J. Barnhart, M. Dale, A. R. Brandt, and S. M. Benson, “The energetic implications of curtailing versus storing solar- and wind-generated electricity,” *Energy Environ. Sci.*, vol. 6, no. 10, p. 2804, 2013 [Online]. Available: http://xlink.rsc.org/?DOI=c3ee41973h. [Accessed: 03-Nov-2019]

[10] M. Sampson, “Challenges of Large Scale Wind Integration in Nova Scotia,” Nova Scotia Power, Inc., White Paper, Jan. 2013.

[11] K. Kabiri, PSC North America, “Nova Scotia Power Stability Study for Renewable Integration Report,” Nova Scotia Power, Inc., Jul. 2019.

[12] Energy and Environmental Economics (E3), “Planning Reserve Margin and Capacity Value Study,” Nova Scotia Power, Inc., Jul. 2019.

[13] Nova Scotia Power Inc., "Nova Scotia Power 10-Year System Outlook: 2018 Report REVISED," report to Nova Scotia Utility and Review Board, Jul. 2018.

[14] Nova Scotia Power Inc., "2020-2022 Rate Stability Plan Application REDACTED," Application before the Nova Scotia Utility and Review Board, Jun. 2019.

[15] Statistics Canada, "Population Estimates Quarterly." [Online]. Available: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1710000901

[16] Natural Resources Canada, "National Energy Use Database (NEUD)," *Government of Canada*, 2019. [Online]. Available: http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/data_e/databases.cfm

[17] whatif? Technologies Inc., "Canadian Energy Systems Simulator (CanESS)," 2017. [Online]. Available: http://www.whatiftechnologies.com/caness

[18] R. D. Torrie, C. Stone, and D. B. Layzell, "Understanding energy systems change in Canada: 1. Decomposition of total energy intensity," *Energy Economics*, vol. 56, pp. 101–106, May 2016 [Online]. Available: http://linkinghub.elsevier.com/retrieve/pii/S0140988316300500. [Accessed: 21-Apr-2017]

[19] R. D. Torrie, C. Stone, and D. B. Layzell, "Reconciling energy efficiency and energy intensity metrics: an integrated decomposition analysis," *Energy Efficiency*, May 2018 [Online]. Available: http://link.springer.com/10.1007/s12053-018-9667-z. [Accessed: 14-May-2018]

[20] R. Osser, K. Neuhauser, K. Ueno, and B. S. Corporation, "Proven Performance of Seven Cold Climate Deep Retrofit Homes," p. 97.

[21] M. Patel, J. Tran, A. McKenzie, and T. Sferrazza, "Global Heat Pump Performance Review," E2S Environmental Consulting, for Toronto Atmospheric Fund, Apr. 2015.

[22] P. W. Francisco, L. Palmiter, and D. Baylon, "Understanding Heating Seasonal Performance Factors for Heat Pumps," *ACEEE Proceedings*, p. 13, 2004 [Online]. Available: https://aceee.org/files/proceedings/2004/data/papers/SS04_Panel1_Paper08.pdf

[23] R. Fu, T. Remo, and R. Margolis, "2018 U.S. Utility-Scale Photovoltaics-Plus-Energy Storage System Costs Benchmark," *Renewable Energy*, p. 32, 2018.

[24] M. Wilson, "Lazard's Levelized Cost of Storage Analysis—Version 4.0," Nov. 2018.

[25] Government of Canada, "Canadian Wind Atlas." [Online]. Available: http://www.windatlas.ca/index-en.php

[26] GE Energy Consulting, "Pan-Canadian Wind Integration Study (PCWIS)," Canadian Wind Energy Association, Oct. 2016 [Online]. Available: https://canwea.ca/wp-content/uploads/2016/07/pcwis-fullreport.pdf

[27] Dunsky Consulting, "Nova Scotia Residential Solar: Market Outlook and Labour Force Study, Final Report," Canadian Solar Industries Association (CanSIA), Apr. 2019.

[28] W. Groszko and M. Butler, "Solar Photovoltaics in Nova Scotia: Report on Costs and Measured Electrical Productivity," Ecology Action Centre for Nova Scotia Department of Energy, Halifax, N.S., Version 1.9, Feb. 2013 [Online]. Available:

https://energy.novascotia.ca/sites/default/files/files/Solar_PV_Report_NS_Feb25_2013_1_9c.pdf

[29] A. Hayden, *When Green Growth is Not Enough*. McGill-Queen's University Press, 2014.

[30] S. Samadi, M.-C. Gröne, U. Schneidewind, H.-J. Luhmann, J. Venjakob, and B. Best, "Sufficiency in energy scenario studies: Taking the potential benefits of lifestyle changes into account," *Technological Forecasting and Social Change*, vol. 124, pp. 126–134, Nov. 2017 [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S0040162516303006. [Accessed: 07-Nov-2019]

[31] S. Darby and T. Fawcett, "Energy sufficiency: an introduction," European Council for an Energy Efficiency Economy, 2018.

[32] A. Grubler *et al.*, "A low energy demand scenario for meeting the 1.5 °C target and sustainable development goals without negative emission technologies," *Nat Energy*, vol. 3, no. 6, pp. 515–527, Jun. 2018 [Online]. Available: http://www.nature.com/articles/s41560-018-0172-6. [Accessed: 07-Nov-2019]

[33] Government of Canada, "Regulations Amending the Reduction of Carbon Dioxide Emissions from Coal-fired Generation of Electricity Regulations: SOR/2018-263," *Canada Gazette, Part 2*, vol. 152, no. 25, p. 44, Nov. 2018 [Online]. Available: http://www.gazette.gc.ca/rp-pr/p2/2018/2018-12-12/html/sor-dors263-eng.html