The Decarbonized Electrification Pathway:
Taking Stock of Canada's Electricity Mix and Greenhouse Gas Emissions to 2030

Final Report (v7)

Research commissioned by CanSIA and CanWEA

EnviroEconomics

Dave Sawyer
dave@enviroeconomics.ca

navius research

Noel Melton
noel@naviusresearch.com

Wednesday, December 6, 2017

Executive Summary

The single constant in Canadian carbon policy has been the drive towards decarbonizing Canada's electricity system. Successive governments within the Federation have implemented real and binding clean energy and greenhouse gas (GHG) policy, systematically reducing the quantity of fossil fuel used in Canada's electricity mix. Results are evident, with GHG emissions from the electricity sector peaking at 128 Mt in 2001 and dropping to 79 Mt (38% decrease) by 2015. The *pan-Canadian Framework on Clean Growth and Climate Change* and Canada's *Mid-Century Long-Term Low-Greenhouse Gas Development Strategy* both point to a continued aspiration of the federal government to work with the provinces and territories to further decarbonize electricity. Looking forward, it is likely that provincial and federal policies will continue to increase the quantity of non-emitting generation in the supply mix leading to less electricity sector emissions. Given the policy that is being designed and implemented, now is a good time to pause and take stock of Canada's GHG aspirations for the electricity sector.

In this paper, we use modeling and analysis to take stock of the effectiveness of current and developing policy to further decarbonize Canada's electricity sector. We use a regionally explicit electricity dispatch model to assess the impact of provincial and federal policies on non-emitting generation to 2030. We use the federal government's stated objective of 90% non-emitting generation by 2030 as a benchmark to gauge success. Specifically, we ask:

Is Canada on a pathway to achieve 90% non-emitting electricity by 2030?

In assessing this question, we conclude the following:

- **Canada is not on target to achieve 90% non-emitting electricity generation by 2030.** Our analysis suggests Canada is significantly off a pathway to the 90% target, with 2030 non-emitting generation forecast at 80%, which is slightly better than the current level of 78%.
- **Natural gas generation is well above a level consistent with the 90% target.** Even with current clean energy and GHG policies, our simulations suggest about twice as much natural gas generation in 2030 relative to a pathway that achieves the 90% non-emitting target.

- **Generation from renewables is about 30% below a pathway to the 90% non-emitting target,** with annual growth needing to double above the current trajectory to be consistent with a pathway that achieves the 90% target.
- **Coal and oil are not shedding generation on a pathway consistent with the 90% target**. Current policies, while significantly reducing coal generation to 2030, are not enough to fully remove coal from Canada's electricity mix by 2030.
- **GHG emissions will continue to fall due to policy to shutter coal generation**. GHG emissions from fossil fuel sources are forecast at 48 Mt of $CO2_e$ in 2030, or 39% below current levels and 63% below the peak of 128 Mt in 2001.
- **Increased natural gas use will offset somewhat the emission reduction gains from reduced coal-fired generation.** Our analysis suggests natural gas GHGs will more than double current levels by 2030, accounting for three quarters of GHG emissions from the sector, up from 30% today. This is 19 Mt more GHGs and a grid GHG intensity that is 70% higher than a scenario that achieves the 90% non-emitting target.

Contents

1 Overview

A strong and sustained transition towards more decarbonized electricity is a key pathway for Canada to reach its longer-term greenhouse gas (GHG) emission reduction aspirations. The importance of the "decarbonized electrification" pathway is reflected in both the *pan-Canadian Framework on Clean Growth and Climate Change* and Canada's *Mid-Century Long-Term Low-Greenhouse Gas Development Strategy*. While these strategies signal intent to further drive down electricity sector GHGs, it is the roll out of clean energy and GHG policy across the Federation that is producing change. Indeed, the decarbonized electrification pathway is being operationalized now with provincial, territorial and federal governments implementing greenhouse gas emission and clean energy policies targeting the electricity sector. The electricity sector is now facing a spectrum of real, binding policy that seeks to squeeze GHG margins across the Federation while expanding non-emitting generation of all kinds.

It is therefore a good time to take stock of how Canada is progressing on decarbonizing its electricity system. With no explicit GHG emission target for the electricity sector's contribution to Canada's 2030 GHG emission target (its Nationally Determined Contribution), we frame the stock take against Canada's commitment to 90% non-emitting generation by 2030. This commitment, made by the Federal Government when announcing new regulations for coal-fired electricity generating stations, would see Canada move from an electricity grid that is 78% non-emitting today to one that is 90% non-emitting by 2030. Given this aspiration, we ask:

Is Canada on a pathway to achieve 90% non-emitting electricity by 2030?

To explore this question, we use modelling and analysis to assess two scenarios:

- **Progress to 90% under a "current policies" scenario**. To identify if there is a gap to the 2030 non-emitting target, we model and assess the impacts of provincial climate change and renewable electricity policies and the federal *pan-Canadian Framework on Clean Growth and Climate Change.*
- **A "90% benchmark" comparator scenario.** We simulate a least-cost policy pathway consistent with achieving 90% non-emitting generation across Canada by 2030. This

pathway is then compared with the *current policies* case to frame progress in terms of both the generation mix and greenhouse gas emissions (GHGs).

The modeling platform used is Navius Research's *Integrated Electricity Supply and Demand* model (IESD), which simulates the impact of government policies and economic conditions on electricity demand, supply, and prices. Model detail is provided in Annex A along with assumptions such as current policies modelled and market drivers.

The remainder of this report presents the results from the *current policies* case (Section 2) and then compares progress against the *90% benchmark* (Section 3). Scenario indicators focus on changes in the generation mix between 2017 and 2030, including the share of non-emitting generation and electricity sector GHGs. Section 4 summarizes our conclusions.

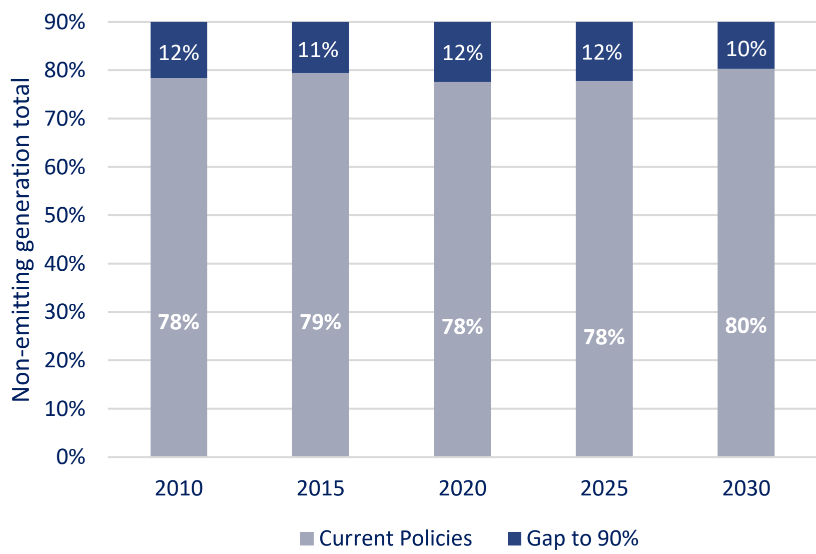
2 Is Canada on Track to Achieve 90% Non-emitting Electricity by 2030?

To assess if Canada is on track to achieve the 90% target by 2030, we simulate a **current policies scenario**. The *current policies scenario* includes existing and developing clean energy and GHG policies of the federal and provincial governments. Detail on the policies included in the *current policies* scenario is provided in Annex 2.

2.1 Canada Not on a Pathway Consistent with the 90% Non-emitting Target

Figure 1 shows the share of non-emitting generation[1] in the *current policies* case, with the total share of non-emitting generation falling short of the 90% target in all time periods simulated. The gap looks stable in time even with a considerable amount of clean energy and GHG policy driving out coal and increasing renewables penetration.

Figure 1: Current Policies Scenario: Non-Emitting Generation and the 90% Target



The big story is growth in electricity generation from natural gas and the associated emissions. The sustained growth in natural gas generation (both from new and existing units) in the simulation, averaging 5% per year between 2010 and 2030, is driven by low natural gas prices, accelerated coal retirement policies and a need to balance generation from variable renewable sources of electricity (for example, due to limited inter-provincial electricity transmission infrastructure in Alberta and Saskatchewan). The simulations suggest a rapid

[1] Non-emitting sources in the model include renewables other than large hydro (solar, wind, biomass, small scale hydro, tidal and geothermal), large hydro and nuclear.

ramping up of natural gas generation in 2020, with an average annual growth of 11% between 2016 and 2020.

To 2030, generation migrates to natural gas as:

- **Coal generation fades fast due to clean energy and GHG policy, but coal is still in the generation mix in 2030.** Coal generation falls significantly after 2026 as the provincial phase-outs bite, notably in Saskatchewan and Alberta, and the federal coal-fired electricity regulations backstop provincial action. Coal accounts for 2% of generation in 2030, down from 9% in 2017. GHG emissions from coal fall from 54 Mt in 2017 to 13 Mt in 2030. Agreements between the federal government and Saskatchewan and Nova Scotia enable coal generation to continue after 2030.
- **Nuclear fades**, as fewer units in Ontario service a decreasing share of flat demand. Refurbishments take some of this non-emitting nuclear generation off-line, especially after 2020. Nuclear capacity starts to come back online closer to 2030, as forecast in Ontario's 2017 Long-Term Energy Plan and the 2016 IESO Ontario Planning Outlook[2]. Natural gas fills much of the generation void in the simulations, hindering progress to the 90% non-emitting target.
- **Renewable penetration grows significantly.** Clean energy and GHG policy within the Federation is driving significant renewables penetration, with renewable generation other than large hydro expanding 250% from 2017 to 2030, or from 34 TWh to 88 TWh.
- **Still renewables penetration slows with decelerating policy signals.** Most current clean energy and GHG policies are expressed in nominal terms, for example the federal carbon price floor, which means their signal erodes with inflation. Some renewable policies have no announced continuation or increased policy stringency, which again erodes future signals. This weakening of policy signals then manifests as a slowing in both generation and capacity additions in the *current policies* scenario even as coal is shuttered, especially in the post-2020 period.

[2] The 2016 IESO Ontario Planning Outlook (OPO) informs Ontario's 2017 Long-Term Energy Outlook.

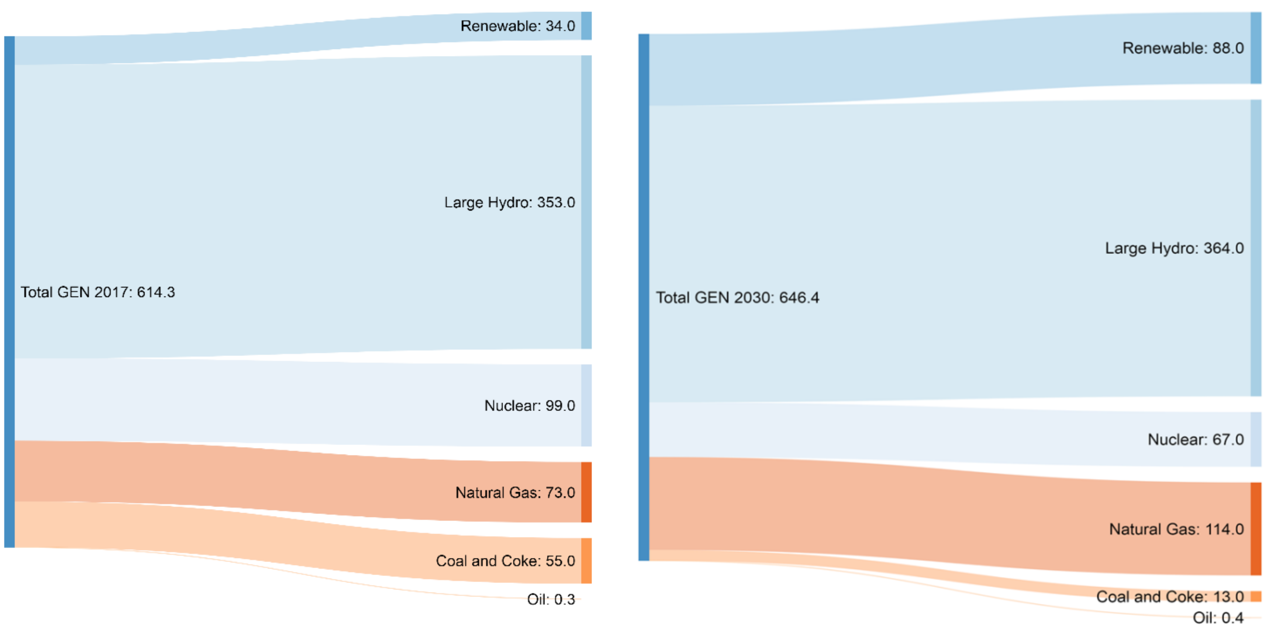
- **As coal backs away, GHGs from natural gas generation almost double accounting for 75% of electricity GHGs in 2030.** While GHGs fall rapidly in the simulation, from 77 Mt in 2017 to 48 Mt in 2030, natural gas GHGs grow significantly thereby partially offsetting the emission decline from coal generation**.**

The following section provides more detail supporting these conclusions.

2.2 Generation Mix to 2030 in Current Policies

Total electricity demand is flat to 2030. Total generation from 2017 to 2030 in the *current policies scenario* rises about 5% to almost 650 TWh by 2030, averaging about 0.4% in average annual growth over the period (Figure 2). This forecast is based on a summing up of provincial electricity outlooks. Although uncertain, under a situation of relatively flat demand, all forms of new generation are competing in a flat market. The opportunity for new incremental generation comes as existing capacity retires, either due to policy or natural retirement.[3] With current policy driving out large amounts of coal in the *current policies scenario*, there is room for new generation of all kinds.

Figure 2: Current Policies: Type of Generation under Current Policies, 2017 & 2030 (TWh)



[3] Nuclear refurbishment in Ontario is scheduled fully completed by 2033, and therefore more non-emitting generation will come online after the time frame considered in our simulations. See Ontario's 2017 Long-Term Energy Plan, page 46.

New capacity additions and generation are dominated by renewables and natural gas. Figure 3 shows the average annual growth rate in generation between 2017 in 2030 by generation type. Dominating the additions in generation are renewables other than large hydro at an annual average rate between 2017 and 2030 of 9% per year. This result is not surprising given the considerable policy in place to drive more renewables into the system.

Natural gas grows year-over-year at a rate of 5% with the expansion driven both by policy to phase-out coal and price carbon but also a continued low natural gas price in the forecast. Coal generation falls 8.8% year-over-year during the simulation.

Figure 3: Current Policies: Average Annual Growth Rate in Generation
Percentage change in generation from 2017 to 2030

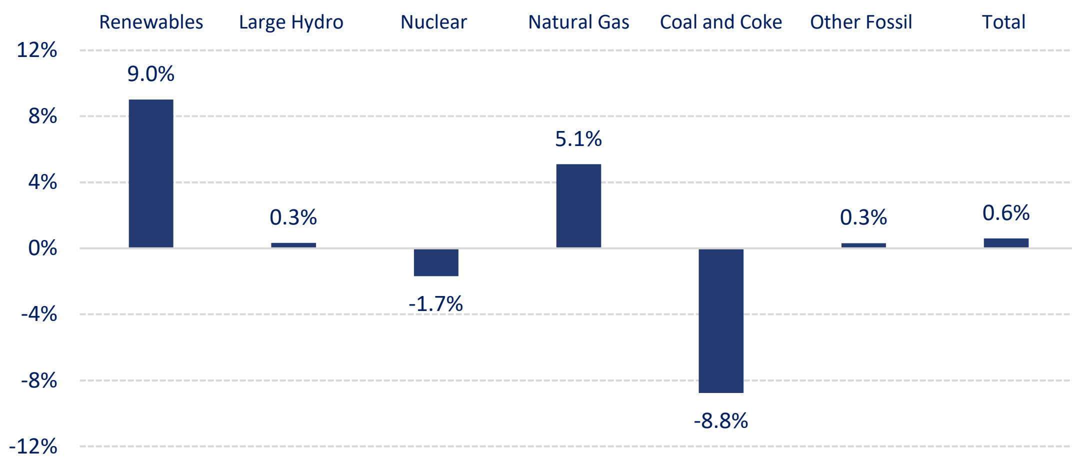
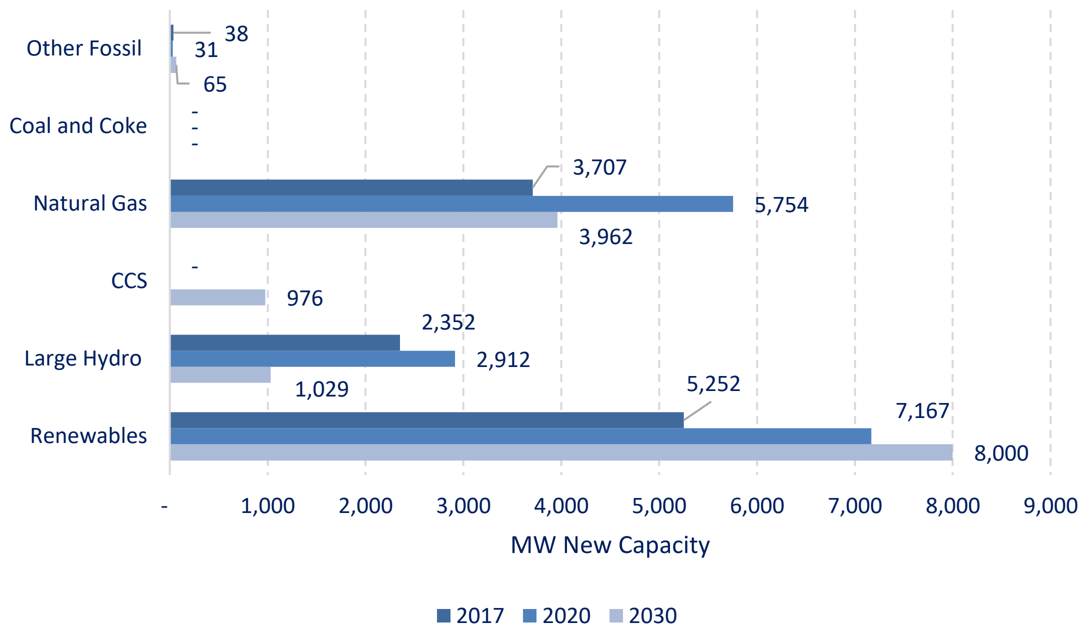


Figure 4 indicates capacity additions by type to 2030. As can be seen, there is significant growth in renewables to 2030 but also in natural gas generation. While the total capacity (i.e. MW) of natural gas and renewables other than large hydro are about the same in 2030, there is about 30% more natural gas generation in 2030 given its higher capacity factor.

Figure 4: Current Policies: Capacity Additions (MW)[4]



There is excess capacity in fossil generation to 2030, and a policy gap to control oil generation. In the simulation, renewables capacity and generation move in lock step to 2030, implying that what is deployed is utilized in the simulation (Figure 5). This is not the case with natural gas, where the change in capacity is greater than the change in generation, implying there is room for natural gas to ramp and further erode progress to the 90% non-emitting target. Also of interest is the expansion in oil capacity and generation, at least in the simulation, with oil generation not seeing strong policy signals to constrain growth as in the case of coal. While oil is a very small share of total generation and is mainly limited to Atlantic Canada, its growth in the *current policies* case suggests there is a hole in current policy that is not constraining new oil generation.

[4] Note the 2015 values are drawn from Statistics Canada, CANSIM Table 127-0009 "Installed generating capacity". At the end of 2015, CanSIA estimates installed solar PV to be 2,500 MW while CanWEA estimates installed wind to be 11,205 MW.

Figure 5: Current Policies: Change in Capacity and Generation
Percentage growth from 2017 to 2030

	Change in Capacity	Change in Generation
Renewable	154%	149%
Large Hydro	5%	-2%
Nuclear	-34%	-35%
Natural Gas	65%	47%
Coal and Coke	-54%	-77%
Oil	8%	10%

Natural gas expansion in the early parts of the simulation locks-in high emitting capital. Figure 6 presents the average annual growth rates for all generation types broken down by five-year period from 2010 to 2030. The results are presented in red light, green light format showing when growth (green) and decline (red) occur in the simulation. As can be seen, renewables ramp fast but then generation tapers off somewhat closer to 2030. Natural gas generation expands quickly in the short-term as new capacity is added and excess capacity is utilized but then generation tapers off later in the simulation. Coal falls consistently while nuclear follows the refurbishment schedule in Ontario's Long-Term Energy Plan. Oil shows a steady increase whereas large hydro is constrained by our baseline assumption of no new large hydro-power facilities beyond what is already committed[5].

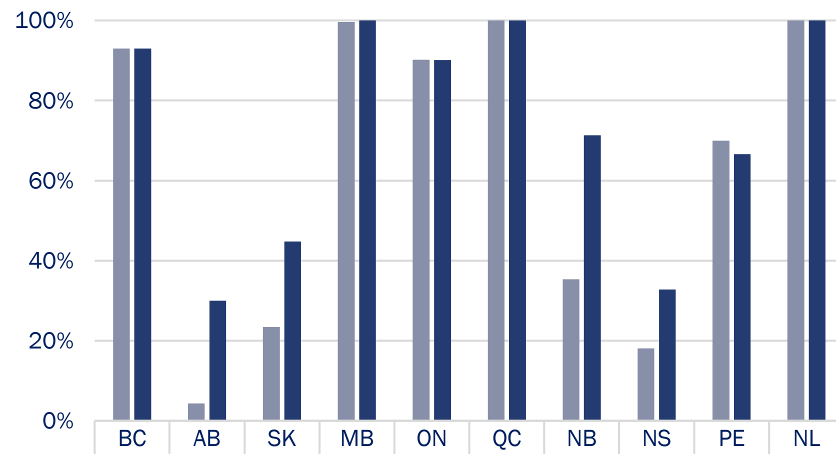
Figure 6: Current Policies, Generation and Capacity
Average Annual Growth Rate by five-year period

	2016-20		2021-25		2026-30	
	Generation	Capacity	Generation	Capacity	Generation	Capacity
Renewables	8.2%	4.9%	8.1%	7.5%	7.1%	6.8%
Large Hydro	0.5%	0.3%	0.3%	0.5%	0.0%	0.2%
Nuclear	-3.3%	-1.3%	-7.3%	-2.0%	1.9%	-7.4%
Natural Gas	10.5%	2.6%	1.5%	4.0%	1.3%	3.5%
Coal, Coke	-8.2%	-2.5%	-5.2%	-3.7%	-16.6%	-4.2%
Oil	1.1%	0.2%	0.8%	0.3%	1.5%	1.2%
Total	**0.8%**	4.9%	**-0.2%**	7.5%	**0.6%**	6.8%

[5] Large Hydro is constrained in the model to currently announced projects including Site C and Muskrat Falls. Conawapa is also included in Manitoba but Manitoba is building a smaller project Keeyask not Conawapa. Offsetting this is that Quebec completed Romaine 3 in 2017 and will complete Romaine 4 in 2020. Large hydro is constrained due to no other large new projects in the preconstruction phase currently in Canada and the long construction lead time.

Current policies in the fossil dominated provinces[6] are increasing non-emitting deployment, but fossil generation still dominates. Figure 7 provides the provincial shares of non-emitting generation in 2010 and 2030 for the *current policies scenario*. Clearly, recent policy in Alberta, Saskatchewan, New Brunswick and Nova Scotia are adding more non-emitting generation to their grids, yet the simulation indicates fossil generation will continue to dominate the supply mix. In Ontario, while natural gas increases in generation as nuclear is refurbished, the share of non-emitting generation stays constant given a significant increase in renewable generation.

Figure 7: Current Policies: Share of Non-Emitting Generation and Gap to 90% Target, by Province



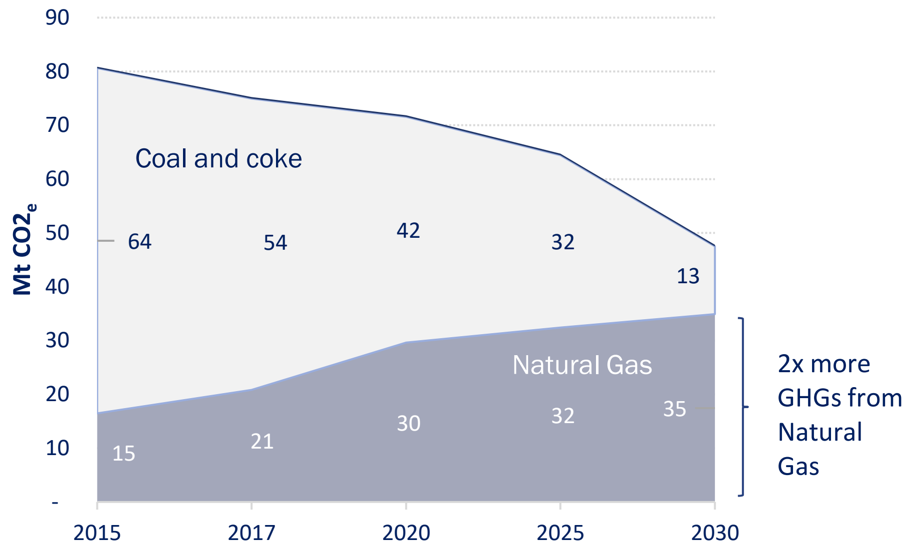
	BC	AB	SK	MB	ON	QC	NB	NS	PE	NL
2010	93%	4%	23%	100%	90%	100%	35%	18%	70%	100%
2030	93%	30%	45%	100%	90%	100%	71%	33%	67%	100%

2.3 GHG Emissions in Current Policies

GHGs fall 36% between 2017 and 2030 in the *current policies* case, from 75 Mt to 48 Mt or -3.4% per year. Over the simulation period, coal and coke emissions are falling rapidly at an average rate of 11% per year from 2017 to 2030. At the same time, total emissions from natural gas rise about 4% annually, accounting for three quarters (or 35 Mt) of all electricity sector emissions in 2030, up from about 30% (or 15 Mt) in 2017 (Figure 8).

[6] Alberta, Saskatchewan, New Brunswick and Nova Scotia.

Figure 8: Current Policies: Electricity Generation GHGs, 2015 to 2030



3 The 90% Benchmark Scenario

In this section, we contrast the *current policies scenario* with the *90% benchmark scenario* to provide insight on progress towards a pathway consistent with achieving the 90% non-emitting generation by 2030. Recall the 90% benchmark is a scenario that provides the least cost pathway to achieve the 90% non-emitting target by 2030. The scenario enables a tradeable intensity standard between provincial electricity systems to achieve the 90% target.

Comparing the *current policies scenario* to the *90% benchmark* reveals the following insights,

- **Natural gas generation is well above a level consistent with the 90% target.** The current policies scenario has about 2 times more natural gas generation compared to the 90% benchmark scenario.
- **Renewables are about 30% below target for 90%,** with annual growth in generation needing to double above the current trajectory to be consistent with the 90% target.
- **Coal generation in the current policy scenario is well above a pathway** consistent with the 90% target.

More detail on these insights is provided below.

3.1 Generation Mix 2030

Renewables penetration is low relative to the 90% benchmark pathway, whereas natural gas and coal are significantly above the pathway to the 90% benchmark. In Figure 9 we present a simple index that compares the generation under *current policies* with the *90% benchmark*. If the index is below 1, there is not enough generation in the current policies case relative to the 90% benchmark, and if the index is above 1, there is too much generation. Major observations include:

- **Not enough renewables**. In Figure 9 we see that renewables generation in the *current policies case* is considerably off the *90% benchmark*. This is especially the case in the early part of the simulation with just 74% of the level needed to achieve the 2030 90% non-emitting target.
- **Natural gas is significantly overbuilt**, with the simulation showing about twice as much natural gas generation relative to the *90% benchmark*.
- **Coal remains despite policy.** Despite significant policy to phase-out coal by 2030, our simulations suggest coal generation under current policies is high relative to the 90% benchmark, especially in 2030. This has much to do with equivalency agreements between the federal government and Nova Scotia and Saskatchewan allowing coal generation to continue past 2030.

Figure 9: Generation in Current Policies Relative to 90% Benchmark (100% = 90% benchmark)

	2020	2025	2030
Renewables other than Large Hydro	74%	88%	91%
Other non-emitting (Large Hydro, Nuclear)	98%	91%	89%
Natural Gas	143%	190%	210%
Coal and Coke	109%	112%	129%
Oil	100%	100%	100%

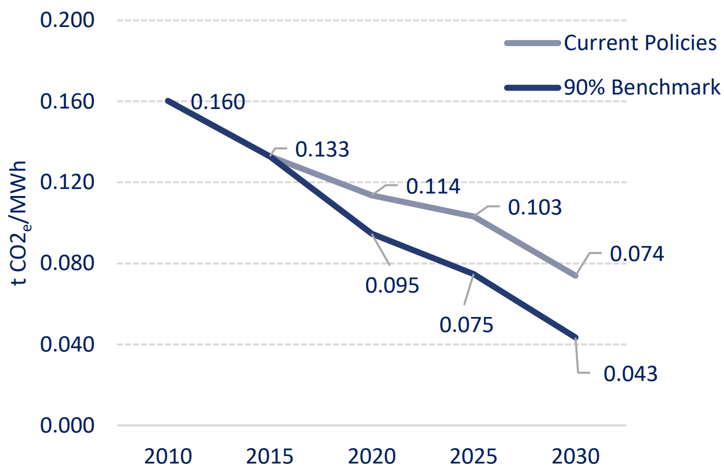
3.2 GHG Emissions

The current policies GHG trajectory is off the 90% pathway, with an average annual decline rate in GHG emissions about half of that needed for a pathway consistent with the 90% target (Figure 10). Figure 11 shows the target trajectory for the national grid emission intensity to 2030. As can be seen, the *current policies case* is significantly off the pathway, with about 70% higher grid intensity in 2030 than the *90% benchmark*. This shortfall has much to do with the large amount of natural gas generation in the *current policies case* but also a function of the remaining coal and oil that are still operating later in the simulation.

Figure 10: Change in GHGs in Scenarios, percent change

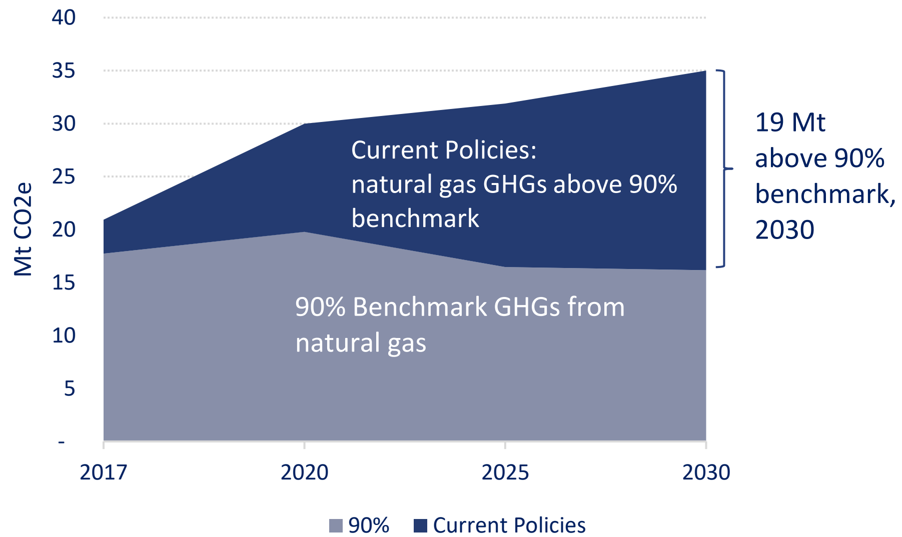
	% Change from 2005	Average Annual Growth Rate, 2017 to 2030
Current Policies	-59%	-3.2%
90% Benchmark	-76%	-5.8%

Figure 11: National Grid Emission Intensity under Scenarios



Natural gas emissions are about 19 Mt higher than the 90% benchmark scenario. When comparing natural gas emissions against the 90% benchmark, *current policies* are delivering about half the needed reductions. Figure 12 shows the total emissions under *current policies* relative to emissions in the 90% benchmark, with natural gas GHGs 19 Mt above a level consistent with the *90% benchmark* in 2030.

Figure 12: Change in Natural Gas GHGs in Scenarios



4 Conclusion

In this paper, we presented modeling and analysis to take stock of the effectiveness of current and developing policy at further decarbonize Canada's electricity sector. We used a regionally explicit electricity sector model to simulate the impact of provincial and federal policies on non-emitting generation to 2030. As a benchmark to gauge success, we use the federal government's stated objective of 90% non-emitting generation by 2030. Specifically, we asked,

Is Canada on a pathway to achieve 90% non-emitting electricity by 2030?

In assessing this question, we conclude the following:

- **Canada is not on target to achieve 90% non-emitting electricity generation by 2030.** Our analysis suggests Canada is significantly off a pathway to the 90% target, with 2030 non-emitting generation forecast at 80%, which is slightly above the current level of 78%.
- **Natural gas generation is well above a level consistent with the 90% target.** Even with current clean energy and GHG policies to 2030, there is about twice as much natural gas generation relative to a scenario that achieves the 90% benchmark.
- **Coal and oil generation are not shedding generation on a pathway consistent with the 90% target**. Current policies, while significantly reducing coal generation to 2030, are not enough to fully remove coal from Canada's electricity mix by 2030. Oil

generation is generally not constrained by policy, indicating a potential hole in current GHG policy.

- **Renewables are about 30% below target for 90% target to be attained,** with annual growth needing to double above the current trajectory to be consistent with the 90% target.
- **GHG emissions will continue to fall**. GHG emissions from fossil fuel sources are forecast at 48 Mt of $CO2_e$ in 2030, or 39% below current levels and 63% below the peak in 2001. The main driver of this drop is provincial and federal effort to shutter coal generation.
- **Natural gas will offset somewhat the emission reduction gains.** Our analysis suggests natural gas GHGs will more than double current levels by 2030, accounting for three quarters of GHG emissions from the sector, up from 30% today. This is 19 Mt more GHGs than a scenario that achieves the 90% non-emitting target with a grid GHG intensity that is 70% higher.

Annex A: How the IESD Model Works

IESD is effectively two separate models:

- **A supply module**. One that simulates the addition to electricity generation capacity and hourly dispatch (generation) decisions in the electricity sector; and,
- **A demand module.** Another that simulates decisions by end-users that affect electricity demand (e.g. technology and fuel choice).

For a given policy scenario, the IESD national model provides detailed insight into:

- Capacity and electricity generation by unit and fuel type;
- GHG emissions from the electricity sector;
- Electricity trade between regions;
- Electricity consumption by sector and end-use; and,
- Wholesale electricity prices.

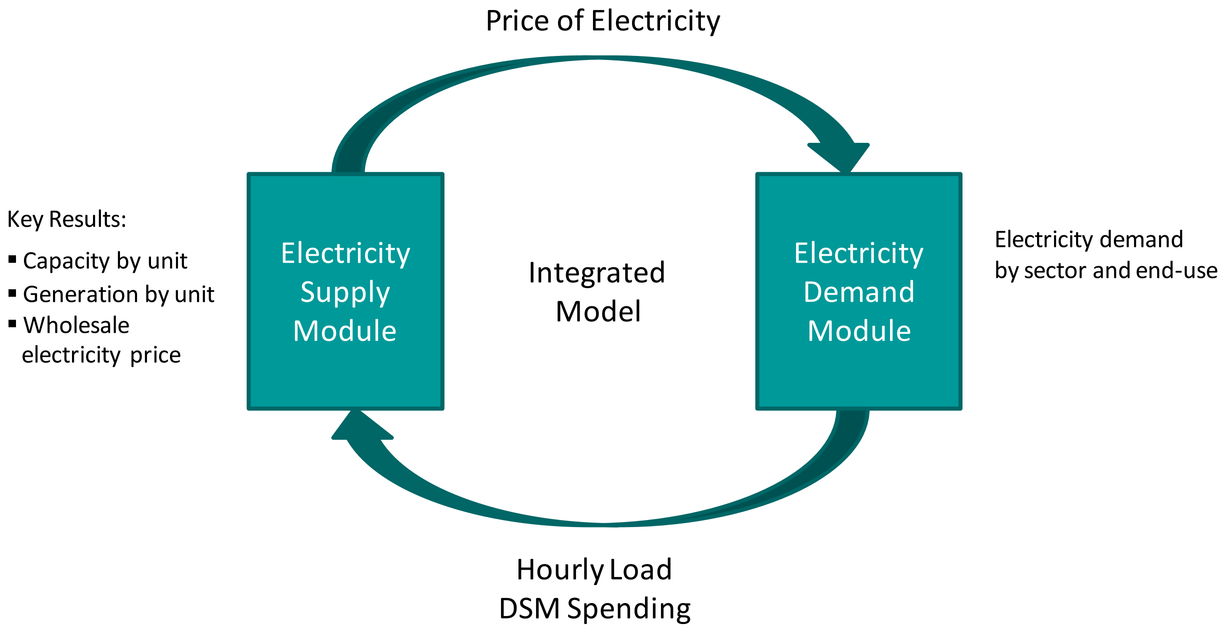
Significant non-policy drivers of technology deployment in the model include,

- Zero emitting sources in the model include renewables (solar, wind, biomass, small scale hydro, tidal and geothermal), large hydro and nuclear.
- Renewables, and notably wind and solar compete on a cost basis and are tied to resource constraints by region. This implies that there are differing levels of renewables penetration given differential resource potentials and costs. For both wind and solar, the assumed rate of annual cost decline is about 4.1% between 2010 and 2030, or a 47% cumulative drop in capital costs.
- Large Hydro is constrained in the model to currently announced projects including Site C ,Muskrat Falls and Conawapa.(see note 5 on page 8).
- Nuclear follows Ontario's latest Long-Term Energy Plan, with unit refurbished starting after 2020.
- Natural gas generation is driven primarily by a low forecast price for natural gas, following the latest NEB, 2016 natural gas price forecast.
- Coal and coke, while enjoying low fuel costs, are effectively squeezed out of the market by policies not related to market conditions (discussed in more detail below).

The IESD model simulates:

- How utilities meet electric load by adding new capacity and by dispatching new and existing units on an hourly basis, and
- How each sector alters its electricity consumption in response to the price for electricity.
- The figure below depicts the key components of IESD's simulation process.

Figure 13: Conceptualization of IESD model simulation



IESD's simulation process begins with the Electricity Supply Module, which includes a detailed representation of the different units available to generate electricity in each region, including their unique costs and generation constraints. The electricity supply simulation determines new capacity additions, hourly dispatch of each unit to meet electric load over the course of the year, GHG emissions from the electricity sector and the wholesale price for electricity.

The price for electricity is then sent to the Electricity Demand Module, which simulates how households and firms change their electricity consumption. The resulting electricity consumption by end-use is used to adjust the magnitude and shape of the hourly load profile. Total load and total demand side management spending are then sent back to the Electricity

The Electricity Supply Module

The electricity supply module of IESD is a linear programming model that simulates how the electricity sector makes capacity and dispatch decisions based on the hourly load profile, energy prices and the cost of installing and operating different units. The electricity supply module endogenously adds and dispatches electricity units such that the total costs of the electricity system are minimized, system revenues are maximized and load in each hour is met.

Fuel prices are calibrated to the 2016 NEB energy price forecast.

Representative Hours

The national version of IESD represents around 1000 representative hours throughout the year that vary by 1) season, 2) load, and 3) wind capacity utilization (i.e., how much wind power is available in each hour of the day). Selecting a sample of hours, rather than simulating all hours of the year, ensures that the model's run time is tractable. A disadvantage of this approach is that the model cannot represent the adoption of electricity storage technologies (i.e., because the model does not solve over consecutive hours).

Capacity Additions

The electricity supply module endogenously adds electricity generation units to supply energy (i.e. consumption over the year) and capacity (i.e. consumption at a given moment) such that the costs of the electricity system are minimized. Each type of electricity generation resource is characterized by its cost profile (i.e., capital costs, fixed operating costs, variable operating costs), heat rate (i.e. energy efficiency) and maximum capacity utilization. The model can simulate specific policy decisions that may promote or constrain the use of a given technology (e.g. a performance standard that constrains coal power, a portfolio standard that requires renewable energy).

Dispatch and Capacity Utilization

Thermal generation (i.e. fossil fuel or biomass combustion) can be dispatched at any time when it will minimize total system costs subject to any existing policy constraints. However, we assume cogenerated electricity is not dispatchable and is produced when heat is required by the thermal host.

Electricity from intermittent resources must be used when it is available, either consumed, exported or stored. As stated above, the hourly wind energy is based on the installed capacity and the hourly capacity utilization in each hour of the representative day being simulated. Solar capacity availability varies for each month of the year (e.g. lowest in winter, highest in summer) but changes each hour according to the movement of the sun through the sky (e.g. zero at night, low the morning, highest at noon).

Characterizing generation from variable renewable sources

To characterize wind resources by province, we rely on CanWEA data describing the location and hourly capacity factor of 5000 potential sites across the country.[7] Each site is grouped by generation profile and the cost of transmission access. Each grouping of sites is then included in the model as a potential wind resource that can be developed.

To incorporate variability in solar generation profiles into IESD, we use multiple linear regression to estimate the impact of different weather patterns (as observed in Environment Canada weather data) on decreases in solar insolation. Thus, predicted solar insolation is described by the equation:

$$S_{predicted} = S_{max} - D_{weather}$$

Where S_{max} is the maximum theoretical solar insolation for the site and $D_{weather}$ is the decrease in insolation caused by the weather at that specific date and time. Inclusion of weather data means predicted values do not align with theoretical maximums, but instead vary in a more realistic fashion.

The Electricity demand module

The demand for electricity is based on load forecasts from provincial utilities and electricity regulators. If these forecasts did not extend for the full model simulation period (as was

[7] CanWEA, 2017, *Wind Data from the Pan-Canadian Wind Integration Study*, available from: www.canwea.ca

frequently the case), we linearly extrapolated demand through 2035. We then scaled demand by end-use based on results from Navius' CIMS technology simulation model.

The IESD model uses a projection of electricity demand to "shape" the load curve for electricity demand/generation. The load curve is informed by hourly load data for all jurisdictions in North America (over 200 utilities) in 2010, the model's base year.

Sectors and end-uses in the electricity demand module

- The electricity demand module aggregates end-uses from CIMS into several end-uses in each major sector of the economy. The end-uses for residential and commercial buildings are:
- Space heating;
- Air conditioning;
- Lighting;
- Other multi-fuel end-uses (water heating, cooking, clothes dryers);
- Other electric-only end-uses (refrigerators, freezers, dishwashers, clothes washers, computers, televisions, etc.)

The model also represents industrial electric loads. However, they are represented in less detail. Industrial load is not broken down by end use (e.g. compression, pumping etc.) and we assume it is a base load that is relatively constant over every hour of the year.

Annex 2: The Current Policies Scenario

The policies contained in the *current policies scenario* include:

- The existing federal coal-fired electricity regulations.
- Alberta's accelerated coal phase-out by 2030.
- Renewable portfolio standards where legislated:
    - British Columbia's clean energy act requiring that 93% of electricity produced in the province to come from renewable sources.
    - New Brunswick's Renewable Portfolio Standard requiring that 40% of electricity consumed come from renewable sources including from renewable-sourced imports.
    - Nova Scotia's Renewable Portfolio Standard requiring that 40% of the province's electricity consumption come from renewables by 2020, allowing for renewable imports.
- Ontario's planned addition of 10,700 MW of non-hydro renewable electricity by 2021.
- Saskatchewan renewable capacity standard of 50% by 2030.
- Alberta with a legislated target of 30% of electricity coming from renewable energy by 2030.
- Federal carbon price floor on production and consumption. We assume the electricity generating sector faces a price on only a fraction of its emissions, consistent with the federal benchmark carbon price paper (output based pricing). We are not assuming full auction as in Ontario (except in Ontario and Quebec). The federal carbon price schedule flat lines at $50 per tonne (nominal) after 2022.

Existing provincial carbon pricing policies include:

- British Columbia's provincial carbon tax on combustion emissions, maintained at $30 per tonne (nominal). The recent update to $35 is not included in the baseline.
- Alberta's updated Specified Gas Emitters Regulation (output based allocations) and provincial carbon levy on combustion emissions, following the federal floor.
- Ontario and Quebec's WCI-linked cap-and-trade policy applied on combustion and non-combustion emissions (price rising to $43 (real) per tonne by 2030).