The Path Towards Net-Zero Greenhouse Gas Emissions in Canada's Electricity Sector

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Abstract

This article explores alternative scenarios to achieve net-zero emissions in Canada's electricity sector. Those scenarios reveal technological pathways for deep-decarbonized electricity supply under increased demand due to electrification.

Introduction

As a signatory to the 2015 Paris Agreement, Canada is committed to achieving net-zero greenhouse gas (GHG) emissions by 2050. Canada has set targets to reduce the country's GHG emissions by 40-45% below 2005 levels by 2030 and to achieve net-zero GHG emissions by 2050 (Government of Canada, 2022). Over 82% of Canada's GHG emissions are from energy producing and consuming processes. Transformational changes are required in how Canadians produce and consume energy to achieve net-zero emissions by 2050. The electricity sector is at the forefront of Canada's efforts to achieve net-zero emissions by 2050. Canada's federal, provincial, and territorial governments have implemented many programs and policies to reduce GHG emissions from the electricity sector and to electrify end-use energy services. The Canadian federal government is envisioning to achieve a 100% net-zero electricity system by 2035 (CER, 2021; Government of Canada, 2022).

In pursuit of net-zero emissions, the electricity sector in Canada has an early advantage. About 82% of Canada's electricity already comes from non-GHG emitting sources such as hydro, nuclear power, wind, and solar (CER, 2021). This share has been growing, and emissions associated with the remaining generation have declined significantly over the past two decades. The GHG emissions intensity of Canada's electricity generation has declined by 45%, from 220 grams CO_2 equivalent (gCO_2e)/kWh in 2005 to 120 gCO_2e/kWh in 2019 (ECCC, 2021).

Despite the cleaner generation base, there are uncertainties in the path forward to achieve net-zero emissions in Canada's electricity sector. Several Canadian provinces currently have fossil fuel dominated generation fleets. In all provinces, including those with a lower emission generation fleet, achieving net-zero emissions while satisfying increased electricity demand due to electrification of end-use energy services can be challenging.

This article explores six scenarios that explore pathways to achieving net-zero emissions in Canada's electricity sector. The six scenarios are developed in *Canada's Energy Future 2021* report, which is the most recent installment of the Canada Energy Regulator's (CER's) long-term energy supply and demand projections (CER, 2021).

Net-Zero Electricity Scenarios for Canada

The six net-zero electricity scenarios are developed based on the primary energy supply and demand scenario of Canada's Energy Future 2021, which is called the Evolving Policies Scenario (EPS). The central premise of EPS is that action to reduce the GHG intensity of our energy system continues to increase at a pace similar to recent history in both Canada and the world. The EPS implies lower global demand for fossil fuels and greater adoption of low-carbon technologies than a scenario with less action to reduce GHG emissions. The EPS assumes a significant level of electrification for many end-use energy services. For example, in EPS, significant uptake of passenger electric vehicles leads to a 17% electricity demand increase by 2050 compared to the current total electricity demand. Similarly, the electricity demand in the residential sector increases by about 22% by 2050, where a key driver is the adaptation of heat pumps for space heating. The overall electricity demand grows by 44% by 2050, compared to current levels.

The net-zero electricity (NZE) scenarios assume more stringent climate action in the form of a higher carbon price than the EPS. The expected result is that a sufficiently high carbon price will drive the electricity sector towards net-zero emissions. Furthermore, the NZE scenarios assume a higher electricity demand level in Canada than the EPS to capture an increased level of energy end-use electrification consistent with expectations of a net-zero future. Given the uncertainty around the costs and viability of different low-carbon technologies, there are many potential pathways to achieve a net-zero electricity system. The six NZE scenarios explore those uncertainties. The main NZE scenario explored here is called the NZE Base scenario. Starting from NZE Base, five other alternative scenarios are developed by varying key inputs such as demand, carbon prices, and technology availability. The premise and main characteristics of the NZE Base and other alternative scenarios are presented in Table 1. A core set of assumptions, including technology costs, fuel prices, and hourly demand profile shapes, were held constant across scenarios.

Under each of the six NZE scenarios, the operations of electricity systems of all ten Canadian provincesare assessed using the hourly electricity module of the

Table 1: Premise and Characterizing Features of Net-Zero Electricity Scenarios

Scenario	Scenario Rationale	Allowable Capacity Expansions	Other Features
NZE Base	Continually increasing Canadian climate policies may lead to a higher carbon price and a higher level of end-use energy demand electrification than the assumptions made in the Evolving Policies scenario.	Generation technologies: natural gas fired combined cycle, natural gas fired simple cycle, and natural gas fired combined cycle with carbon capture and storage (CCS)* units, wind, solar, hydro, conventional nuclear, and SMR Electricity storage Inter-provincial transmission	Electricity demand is 10-30% higher than the Evolving Policies Scenario, depending on the province. Carbon pricing is higher than the Evolving Policies Scenario, reaching $2020 300/ tonne(t) CO2 by 2050
Higher Carbon Price	It is plausible that more aggressive climate action is needed to drive the energy systems towards net-zero, leading to a higher carbon price than the value assumed in the NZE Base scenario.	Same as NZE Base	Same electricity demand as Base Carbon pricing reaches $2020 800/ tCO2 by 2050.
Higher Demand	A higher level of electrification is possible due to uncertainty around specific climate action and technology development.	Same as NZE Base	Electricity demand is 15-45% higher than the Evolving Policies Scenario, depending on the province. Same carbon pricing as NZE Base.
Limited Transmission	Interprovincial transmission expansion is costly, and the timing of investments is uncertain. Therefore, new interprovincial transmission development may not be feasible.	Same as NZE Base, but no new inter-provincial transmission is allowed.	Same electricity demand and carbon pricing as NZE Base
Hydrogen	There is a high level of interest in hydrogen as a technology path to decarbonize the economy. Accordingly, there is the possibility of low-cost low/zero carbon hydrogen being available for electricity generation.	All NZE Base options and hydrogen fired generation technologies.	Same electricity demand and carbon pricing as NZE Base
BECCS	Negative emissions technologies feature prominently in previous net-zero scenarios. Within that scope, biomass-fired electricity generation with CCS is attractive as it simultaneously produces electricity and removes carbon dioxide from the atmosphere. Therefore, it is plausible that biomass-fired electricity generation with CCS is available in the near future.	All NZE Base options and biomass CCS* generation technology.	Same electricity demand and carbon pricing as NZE Base

*CCS technologies, including natural gas with CCS and BECCS, are only allowed to be built in the provinces of Alberta and Saskatchewan due to the greater availability of proven geological potential to store CO2 and availability of active CCS projects.

CER's Energy Futures Modeling System. The hourly electricity module optimizes the provincial electricity systems' operations at one-hour intervals and expands the generation system as needed. Interprovincial electricity trade is also modelled. Under the particular scenario assumptions, the main objective is to construct and operate an optimal generating unit fleet that would minimize the total cost of satisfying electricity demand in a given Canadian province. The scenario assessment was conducted for the period 2030-2050. The scenario assessment discussed in this article does not force the electricity sector to be purely non-emitting in any year. Rather, carbon pricing is served as a proxy for the cost of carbon removal and potential technology options to determine the ultimate carbon emissions of the electricity sector.

This article presents the results for 2030 and 2050, the two years for which Canada has set major emission reduction targets. Furthermore, the results presented here are aggregated across the provinces.

Electricity Supply in Net-Zero Electricity Scenarios

Figure 1 shows installed capacity by technology in different scenarios. In the NZE Base scenario, non-emitting generation technologies (i.e., hydro, nuclear, solar, and wind) and electricity storage account for 80% of the installed generation capacity in 2030. By 2050 that share increases to 89%. At a combined capacity of 134 GW, which is about 41% of the installed capacity, solar and wind dominate the electricity generation fleet in 2050. Compared to the current levels, wind capacity doubles by 2030 and is five times greater by 2050. Compared to the current levels, the solar capacity is twenty times larger by 2050. Electricity storage is installed to facilitate the operations of variable renewables and support grid operations. New hydropower capacity additions are relatively small and only see a cumulative new capacity addition of about 4.2GW in the period 2030 - 2050, a 5% increase from current levels. Similarly, the growth of nuclear power is also comparatively small. All new nuclear additions are through small modular reactor (SMR) technology. About 6.6 GW of SMR units are added by 2050. In combination,

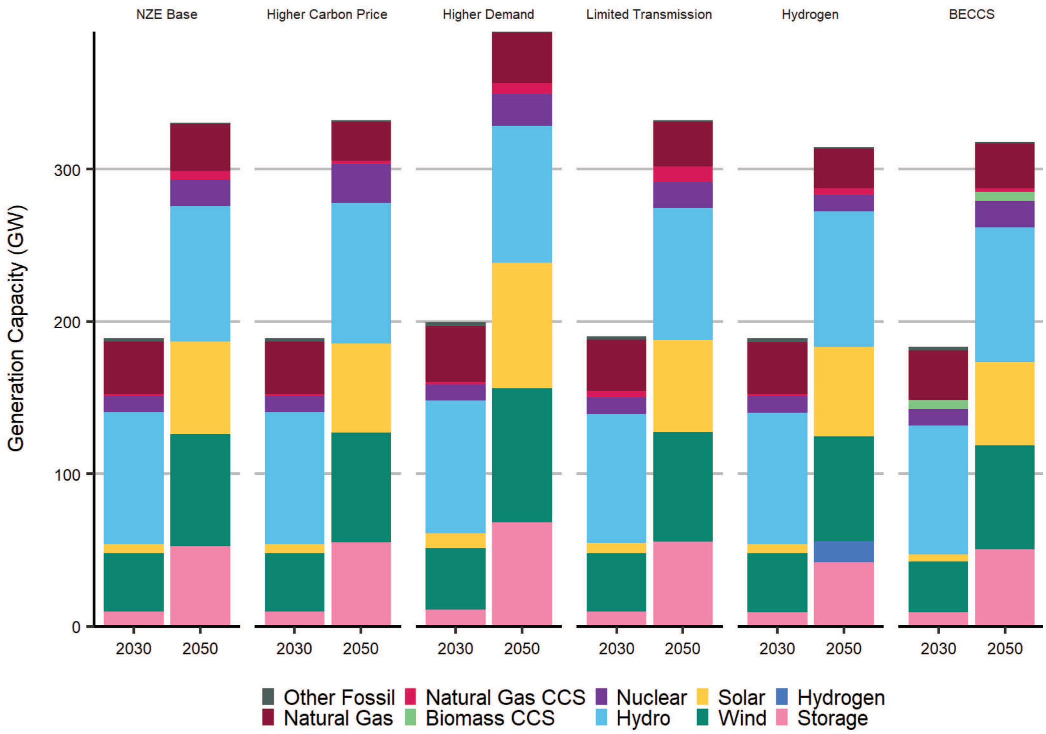

Figure 1: Installed Capacity by Technology in Different Scenarios

hydropower and nuclear represent 5% of new capacity additions. Low-emitting natural gas CCS units are built in the provinces of Alberta and Saskatchewan, where CO2 storage is known to be available. In the Base NZE scenario, 5.6 GW of natural gas CCS units are added by 2050. In the Base NZE scenario, fossil fuel-based technologies, mainly natural gas units, represent approximately 20% of total generating capacity in 2030 and decline to 11% by 2050. Natural gas unit additions are dominated by simple cycle gas turbines that primarily provide grid balancing.

Figure 2 shows the amount of electricity generation by technology in different scenarios. In the NZE Base scenario, non-emitting generation (e.g., hydro, nuclear, solar, and wind) produces 93% of electricity in 2030 and 97% in 2050. Overall, by 2030 94% of electricity is generated by low- and non-emitting technologies (renewables, nuclear, and CCS-enabled fossil fuel), rising to 99% in 2050. Hydropower and nuclear power provide the largest share of the electricity supply in both periods. However, the amount of electricity provided by those two technologies remains relatively unchanged from 2019 levels, at roughly 50 TWh throughout the projection period. New demand growth is primarily satisfied by wind and solar.

The current share of fossil fuel-based electricity generation is 19%, and that decreases over the projection period, reaching 3% of the electricity supply by 2050. By the end of the projection period, about two-thirds of the fossil fuel fired generation comes from natural gas units equipped with CCS technology. The remainder consists of natural gas simple cycle units that provide some grid balancing services to maintain system reliability.

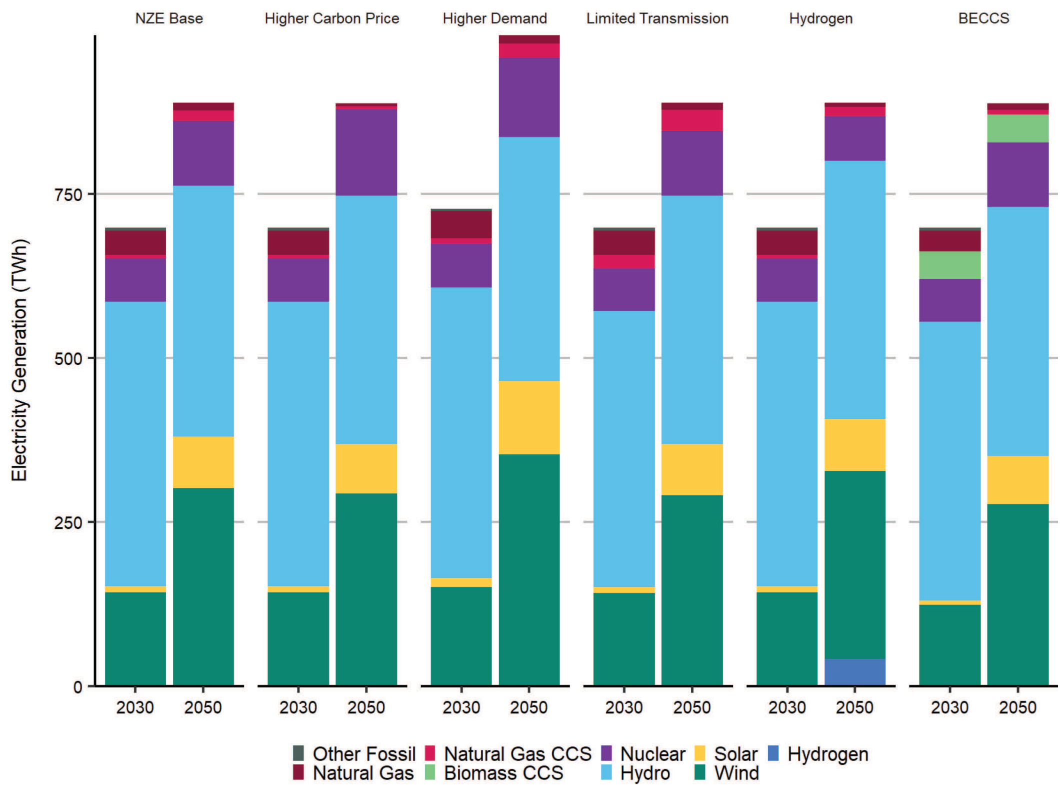

Figure 2: Electricity Generation by Technology in Different Scenarios

Installed capacity and generation in the other five scenarios are similar to those of the NZE Base scenario, with some noteworthy observations.

The Higher Carbon Price scenario sees reductions in capacity and electricity generation by natural gas units in 2050 compared to the NZE Base scenario. Cumulative new natural gas capacity additions are 30% lower than NZE Base by 2050. Compared to NZE Base, natural gas-fired generation is 60% lower in 2050. Due to the residual CO_2 emissions that are not captured by the CCS process (10% of the combustion emissions), natural gas CCS is also impacted by the higher carbon price. That makes natural gas CCS less competitive. Compared to NZE Base, natural gas CCS cumulative capacity additions are 60% lower, and electricity generation is 70% lower. The reductions in natural gas fired generation capacity are offset by increased hydropower and nuclear SMR.

The Higher Demand scenario assumes a higher level of electrification and, therefore, about 12% higher electricity demand overall in 2050. In 2050, the higher electricity demand in this scenario is satisfied by increased solar (+ 33 TWh), wind (+51 TWh), nuclear (+23 TWh), and natural gas CCS (+5 TWh) generation compared to NZE Base.

The Limited Transmission scenario only sees notable changes in the four western provinces. In the NZE Base scenario the hydropower resources in British Columbia and Manitoba partially provide system flexibility to manage variable wind and solar power supply in the neighbouring provinces of Alberta and Saskatchewan. This process is facilitated by the addition of new inter-provincial transmission capacity. The Limited Transmission scenario inhibits new transmission capacity additions, and consequently, the combined wind and solar power generation decline by about 5% relative to NZE Base. That reduction in the electricity generation is filled by a higher level of natural gas CCS units. The Limited Transmission scenario sees a doubling of natural gas CCS capacity and generation compared to NZE Base.

The Hydrogen scenario assumes the existence of a relatively mature market for hydrogen in Canada, where hydrogen production costs through electrolysis and natural gas with CCS have fallen significantly. Under the assumed conditions, hydrogen technologies have lower overall economic costs than all natural gas technologies. Consequently, the Hydrogen scenario sees a 25% reduction of non-CCS natural gas capacity (i.e., combined cycle and simple cycle) compared to NZE Base in 2050. Furthermore, the GHG emissions intensity of some hydrogen technologies is lower than that of natural gas CCS. Therefore, natural gas CCS sees a 20% capacity reduction in 2050 compared to NZE Base. The Hydrogen scenario also sees a 10% reduction in wind and solar capacity relative to NZE Base in 2050. The overall economics of the use of hydrogen for electricity supply is more favourable than building wind, solar and the additional flexible capacity they necessitate to balance supply and demand.

The BECCS scenario assumes the availability of biomass CCS units for electricity generation in the provinces Alberta and Saskatchewan. Biomass CCS is considered to have negative GHG emissions, and it is assumed that the technology would get credit for carbon removal from the atmosphere. The credit is assumed to be calculated using the full carbon price. As the carbon price increases, biomass CCS units become a negative cost generation option, where its average cost of production in 2050 is -$85/MWh. Therefore, biomass CCS partially displaces all other generation technologies in Alberta and Saskatchewan. Relative to NZE Base, the resulting reduction in natural gas CCS generation in 2050 is 56%, and that of combined wind and solar is about 15%. The cumulative biomass CCS capacity addition by 2050 is 6 GW, the maximum possible biomass CCS capacity due to the limitations in available biomass resources. At higher carbon prices, it may be economically competitive to import biomass for electricity production from other regions into Alberta and Saskatchewan, where suitable carbon storage is known to exist.

GHG Emissions Intensity of Electricity Sector in Canada

Figure 3 shows the GHG emissions intensity of the electricity sector in Canada in 2030 and 2050 in all scenarios we considered, compared to 2005 and 2019 levels.

In all scenarios, except the BECCS scenario, the GHG emissions intensity of Canada's electricity sector reaches about 27gCO_2/kWh in 2030. The value is 78% lower than the electricity sector emissions intensity in 2019. The emissions intensity further reduces in 2050 but varies across scenarios. The NZE Base scenario emissions intensity in 2050 is 8gCO_2/kWh, a 93% reduction compared to the emissions intensity in 2005. The

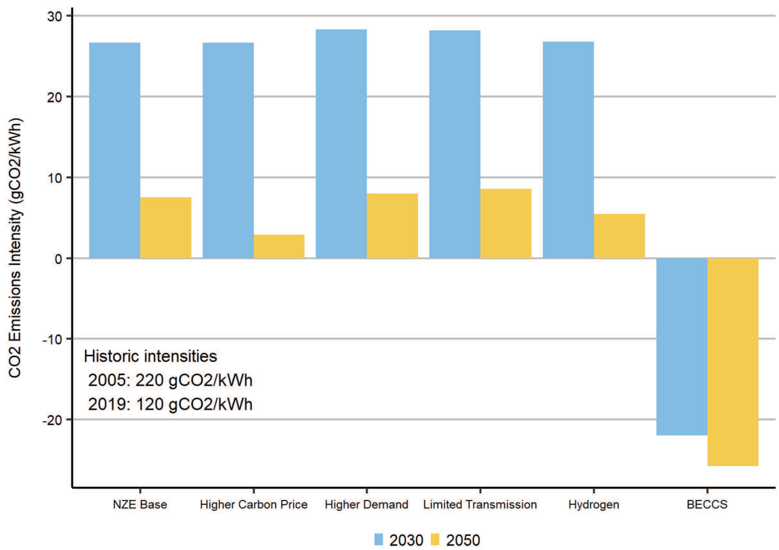

Figure 3: GHG Emissions Intensity of the Electricity Sector in Canada in Different Scenarios

Higher Carbon Price scenario sees the 2050 emissions intensity declining to 3gCO_2/kWh.

While significant emissions reductions are achieved, none of the scenarios, except BECCS, see the overall electricity sector reaching net-zero. In those five scenarios, the emissions from the electricity sector drop dramatically, but a very small amount of emissions remains. Almost all of the remaining emissions come from natural gas-fired conventional units, which generate electricity infrequently, and uncaptured emissions from natural gas CCS units. Despite the increased cost due to carbon pricing, the electricity system analysis module allows those emissions because the value of those generating units in terms of electricity system reliability is high. This allowance reflects that, in the context of a broader net-zero world, the use of carbon removal options could potentially provide more cost-effective options than reducing those last few emissions from the electricity system in 2050.

The BECCS scenario sees the emissions intensity of the electricity sector going net-negative through carbon removal by the biomass CCS units. That would provide some emissions allowances for other economic sectors in Canada's path towards a net-zero future.

Conclusion

The electricity sector could play a pivotal role in achieving net-zero emissions in Canada both by reducing emissions from generating electricity and by reducing emissions in other sectors through electrification. The scenario analysis discussed in this article shows that there are many technological pathways to achieve significant emission reductions in the electricity sector. The majority of technologies required are available today, and Canadian electric utilities have experience in building and operating them. In Canada's pathway towards a net-zero future, the country's electricity sector will have multiple roles, including the supply of energy and potentially carbon removal through investing in negative emissions technologies.

Footnotes

[1] The electricity systems of the three northern territories of Canada are excluded from this analysis.

[2] The full scenario results are available at https://open.canada.ca/data/en/dataset/5a6abd9d-d343-41ef-a525-7a1efb686300.

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