HORIZON
2060

Canadian Energy Outlook

– 2021 –

Executive summary

INSTITUT
DE L'ÉNERGIE
TROTTIER

e3cHub
HEC MONTRÉAL
Environment, energy and circular economy

Modelling

ESMIA
Energy Super Modelers and International Analysts

Financial support

FONDATION FAMILIALE TROTTIER FAMILY FOUNDATION

Analysis and writing
Institut de l'énergie Trottier – Polytechnique Montréal
- Simon Langlois-Bertrand, PhD
- Normand Mousseau, PhD
- Louis Beaumier, M.A.Sc.

e3c Hub – HEC Montréal
- Olivier Bahn, PhD

Modelling
ESMIA Consultants inc.
- Kathleen Vaillancourt, PhD
- Marie Pied, M.Sc.

Graphic design
- Norman Terrault
- Morteza Asgari (Figures design and programmation)

Acknowledgments
The authors would like to thank the Trottier Family Foundation for their financial support producing this report, and for supporting previous initiatives related to energy and climate change, some of which have directly inspired this work. Our thanks also go to Natural Resources Canada, for their financial contribution and their precious collaboration throughout the project, and to Environment and Climate Change Canada, for numerous exchanges related to this work.

Citation
Langlois-Bertrand, S., Vaillancourt, K., Beaumier, L., Pied, M., Bahn, O., Mousseau, N. (2021). Canadian Energy Outlook 2021 — Horizon 2060, with the contribution of Baggio, G., Joanis, M., Stringer, T. Institut de l'énergie Trottier and e3c Hub [Web] http://iet.polymtl.ca/energy-outlook/ (page visited day/month/year)

About the Institut de l'énergie Trottier (IET)
The *Institut de l'énergie* Trottier (IET) was created in 2013 thanks to a generous donation from the Trottier Family Foundation. Its mission is to train a new generation of engineers and scientists with a systemic and trans-disciplinary understanding of energy issues, to support the search for sustainable solutions to help achieve the necessary transition, to disseminate knowledge, and to contribute to discussions of energy issues. Based at Polytechnique Montréal, the IET team includes professor-researchers from HEC, Polytechnique and Université de Montréal. This diversity of expertise allows IET to assemble work teams that are trans-disciplinary, an aspect that is vital to a systemic understanding of energy issues in the context of combating climate change.

About the e3c Hub
The e3c Hub is a multidisciplinary research, transfer and training center of HEC Montréal, specializing in environment, energy and circular economy. Its mission is to contribute to a transition towards a sustainable society and economy, in conjunction with various stakeholders. To do this, the e3c Hub conducts research, runs a scientific program, and designs and organizes training courses and summer schools.

About ESMIA Consultants
ESMIA offers a cutting-edge expertise in 3E (energy-economy-environment) integrated system modelling for the analysis of optimal energy and climate strategies. ESMIA puts forward a scientific approach guided by sophisticated mathematical models. The goal behind our implication is to offer solutions that allow achieving energy and climate goals without compromising economic growth. For 20 years, the ESMIA consultants provide a full range of services for the development of economy-wide energy system models for high-profile organizations worldwide. They also provide advisory services that focus on analyzing complex problems such as energy security, electrification, technology roadmap and energy transitions. ESMIA benefits for this purpose from its own integrated optimization model: The North American TIMES Energy Model (NATEM).

Version 20211006

EXECUTIVE SUMMARY

This Outlook is a modelling effort that analyzes possible transformation pathways required to achieve net-zero GHG emissions in Canada, with a special focus on the energy system. Produced by independent researchers, it first presents an up-to-date portrait of Canada's energy production and consumption sectors. It then builds on extensive techno-economic modelling to analyze the trends occurring across the country, as well as the possible province by province cost-optimal transformation of the energy sector and overall GHG emissions over the next decades according to current and soon-to-be implemented policies, as well as national net-zero GHG emission targets.

This technologically deep modelling exploration of optimally costed scenarios—which integrates emissions outside of energy-related sources, such as those from agriculture, waste and industrial processes, as well as fugitive emissions from the oil and gas production sector—enables comparisons with how similar net-zero challenges are met around the world by identifying commonalities and distinct features.

Results underline that:

i. A net-zero target profoundly changes the nature of the challenge of transforming Canada's economy;

ii. Currently implemented and publicly announced measures at the federal and provincial level are insufficient to reach 2030 GHG emission targets;

iii. From a cost-optimal perspective, oil and gas, industry and electricity production should bear the largest share of emissions reduction in the coming years;

iv. Yet, with rapid technological improvements and appropriate measures, the transition to a net-zero economy is affordable and could even be economically beneficial.

Since the evolution of energy production and consumption in Canada is targeted by most climate policies, this summary will focus on the link between GHG emissions and the energy sector departing from the main report's more traditional structure.

Table ES.1 – Energy in Canada: world ranking for reserves/capacity, production and exports (2019)

Energy Resource	Proved Reserve/Capacity	Production	Exports
Crude Oil	3	4	4
Uranium	3	2	4
Hydroelectricity	3	3	-
Electricity	8	6	3
Coal	16	13	7
Natural Gas	17	4	6

The particular characteristics of the Canadian energy system

The Canadian energy system has several unique characteristics that make it stand out on the world scene, despite the country's relatively small population and economy. Canada is one of the world's largest energy producers and exporters and is among the world's top six producers and exporters of crude oil, uranium, electricity, and natural gas (Table ES.1). It is also among the leading countries in terms of the share of low-carbon sources in its electricity production (80%). However, significant variation exists across provinces in each type of energy production, as is the case for the energy mix used by the various sectors.

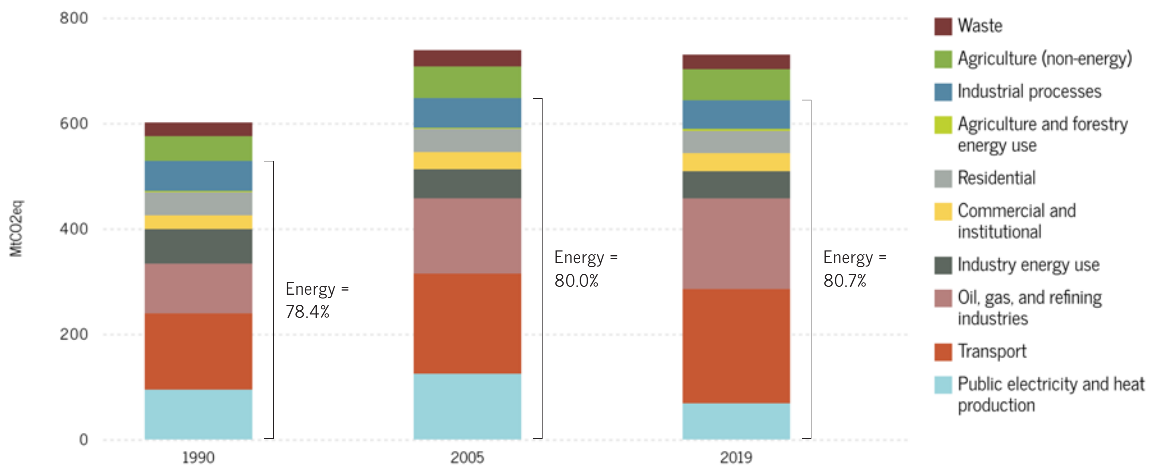
Given the country's size, a significant share of production is exported, including first and foremost oil and gas, as well as electricity and uranium. Most of this trade occurs with the United States, while limited interprovincial electricity infrastructures and political relations result in the exchange of small quantities among the provinces. In recent years, considerable interest from low-carbon Canadian utilities was given to efforts to decarbonize electricity generation in the US.

Overall, the energy sector contributes 10.2% to the country's GDP, although only 4.4% of its employment. Oil and gas exports constitute the energy sector's largest contribution, largely because of the $122 billion exported in 2019. These export revenues are subject to variations, mainly due to the sector's vulnerability to changing market conditions in the United States. Owing to the high value of exports in the oil and gas sector, investments in the renewables sector has had a greater impact on job creation despite making a smaller contribution to GDP.

GHG reductions and the policy environment

Canada, which is in eighth position globally in terms of overall energy consumption, uses more energy per capita than any other OECD country except Iceland. This consumption is also associated with a high energy intensity throughout the Canadian economy. Here, a large part of the variation in per capita consumption levels across provinces stems from significant differences in industrial profiles, as well as from diversity in freight transport, agriculture, space heating and transport choices.

Figure ES.1 – GHG Emissions in Canada by sector



Source: ECCC 2021

However, one area of commonality is that contrary to almost all other sectors, energy consumption in the transport sector continues to increase, having grown 12% over the past decade as demand for transport services for passengers (+26%) and freight (+20%) has outpaced efficiency improvements (Figure ES.1). Over the same period, the increase in transport-related energy expenditures has led to higher-income households having a significantly higher carbon footprint than lower-income households, while these expenditures represent a heavier burden for the latter.

As energy-related GHG emissions contribute over 80% of the total, this energy production and consumption profile is associated with a stagnation of Canada's overall emissions between 2005 and 2019 (-1.1%). The transport sector (29.7% of total emissions in 2019) and the oil and gas industry (23.6%) emit the majority of the country's GHGs. They also presented the most rapid emission increases in absolute terms from 1990 to 2019.

While the net-zero target announced by the federal government is new, the provinces and the federal government have adopted a proliferation of GHG reduction targets in recent years. However, action plans and strategies have been less successful than hoped, since details on how targets would be reached—including costs, technologies, sectoral targets and pathways—have often been lacking. As a result, most of these strategies have so far failed to translate into reality.

The fact that Canada is a federation adds a layer of complexity to Canada's emission reduction efforts given that programs led by the federal government require actions by actors at the provincial level. Strong disagreements with some provinces on carbon pricing reached the Supreme Court, which confirmed the constitutionality of the federal policy in 2021, eliminating some of the uncertainty respecting the management of GHG-related efforts. While this development is welcome, many other areas still present coordination challenges in emissions mitigation, notably the increase in low-carbon electricity production, the upgrading of grid capacity, and interprovincial trade, as electricity demand is projected to increase significantly if GHG emissions across the economy are to be reduced to any serious extent.

We note that data on energy production and consumption as well as related GHG emissions are still lagging in Canada, limiting the capacity to evaluate the transformation of this sector and the effect of technology changes, investments, climate plans and measures.

Scenarios toward net-zero emissions

Throughout this Outlook, we consider three GHG emission reduction scenarios leading to net-zero in different years, a reference scenario for the business-as-usual case which includes policies already in place, and an additional reference scenario that takes into account the impact of the recently announced carbon pricing schedule to 2030 (as described in Table ES.2). All scenarios are analyzed through the North American TIMES Energy Model (NATEM).

Table ES.2 – Description of the reference and GHG reduction scenarios used in NATEM modelling[1]

Name	Description
REF	*The reference scenario.* This scenario presents results using no constraining GHG reduction targets. Macroeconomic assumptions (GDP, population, oil and gas export prices) are aligned with the reference scenario used in Canada Energy Regulator's Energy Future 2020 outlook (CER 2020), imposing no additional constraints in terms of GHG emissions reductions, but including policies already in place.
CP30	This scenario takes REF and adds the carbon pricing increase schedule announced by the federal government in late 2020, with a price reaching \$170/tCO_2eq in 2030.[2] To accelerate the impact of carbon pricing, this scenario also lowers the hurdle rate with respect to standard practice.
NZ60	This scenario imposes a net-zero emissions target on total CO_2eq by 2060, a 30% reduction by 2030, and an 80% reduction by 2050 (with respect to 2005). This reflects the prior Canadian targets, extended to reach net-zero in 2060.
NZ50	This scenario imposes a net-zero emissions target on total CO_2eq by 2050, and a 40% reduction target by 2030 (with respect to 2005). It corresponds most closely to the current government's targets.
NZ45	This scenario imposes a net-zero emissions target on total CO_2eq by 2045 and a 45% reduction target by 2030 (with respect to 2005).

[1] NATEM is an energy systems optimization model implemented by ESMIA Consultants Inc. It makes use of The Integrated MARKAL-EFOM System (TIMES) model generator developed and distributed by the Energy Technology Systems Analysis Program (ETSAP) of the International Energy Agency (IEA) and used by institutions in nearly 70 countries.

[2] Two adjustments were necessary to incorporate this schedule: first, a discount rate was used to transform prices proposed by the government in the schedule into their equivalent for the year when they are applied (for instance, $170 announced this year is worth $131 in constant dollars for 2030, when adjusted for inflation); second, this maximum price reached in 2030 is then adjusted for inflation for the remainder of the period, i.e., until 2060.

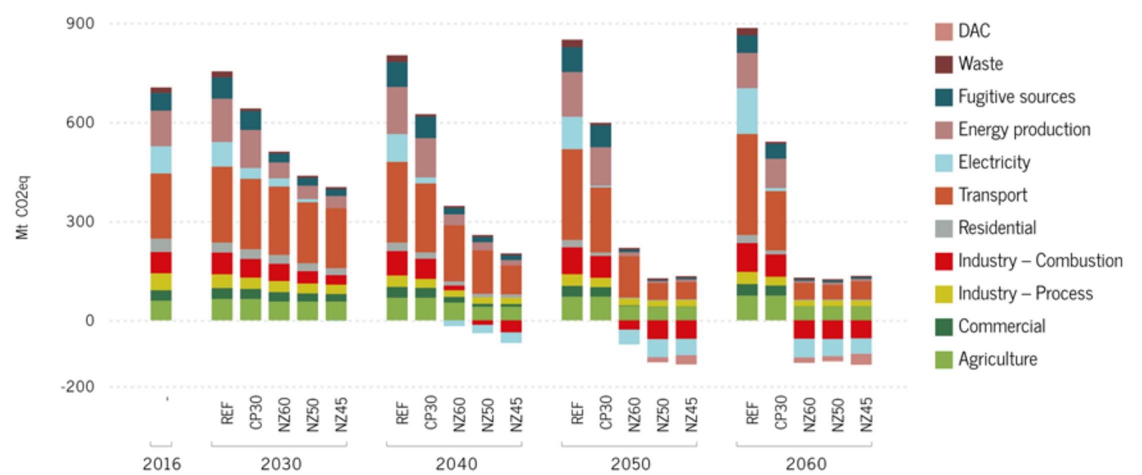
Decarbonization in all economic sectors

A first observation from the modelling results reveal is that a deep decarbonization of all sectors is necessary to reach net-zero at a reasonable cost as the challenge of reaching net-zero emissions requires not only reducing emissions to their lowest possible levels, but also compensating for remaining emissions that are too costly to eliminate. The latter includes specific applications where decarbonization is very costly or where technology is not yet available, but where demand is not projected to be eliminated. Moreover, non-energy emissions become the majority of what remains once carbon neutrality is reached, representing a different challenge from that of reducing emissions from energy consumption since it necessitates disruptive technological innovations, which are difficult to predict.

These transformations require a major change in the energy sector's historical trends. Currently implemented policies, coupled with historical economic and population growth (REF scenario), translate into a projected 7% increase in GHG emissions by 2030 with respect to 2016, reaching a total of 885 $MtCO_2eq$ (+25%) in 2060 (Figure ES.2). For its part, CP30 leads to a 9% reduction from 2016 (13% with respect to 2005) by 2030 and leaves 541 $MtCO_2$ (-23%) by 2060. Net-zero (NZ) scenarios impose more substantial transformations even before 2030 in some sectors. After 2030, the main difference across scenarios is largely due to the degree of energy demand reduction over time (compared with REF), with NZ scenarios showing the largest decreases in demand compared to the starting point of the period. A large part of this is due to gains in efficiency from electrification, as well as from lower overall demand associated with higher energy prices.

In all NZ scenarios, sectors decarbonize at very different speeds. The most challenging sectors are transport, which will require considerable attention from decision makers, and industry, as many solutions are dependent on heavy infrastructure development. Other sectors, such as buildings and industrial combustion, appear to be relatively low-hanging fruit and will mainly require regulations to force an acceleration of their transformation.

Figure ES.2 – Total GHG emissions by sector

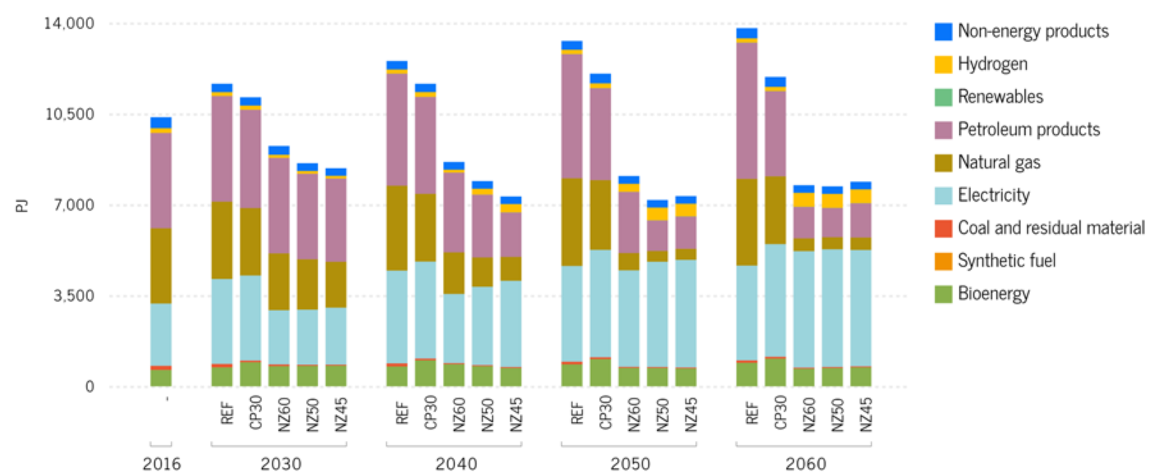


The transformation of energy services

With REF, the energy demand shows a relatively uniform evolution for all sources in response to the expected economic and population growth (Figure ES.3). The inclusion of the impact of the proposed carbon tax until 2030 (CP30) results in a relatively slower growth than REF, with more electricity, but a stabilization in the demand of oil and gas at 2016 levels. Direct constraints imposed in scenarios NZ60, NZ50 and NZ45 have a much larger impact on energy consumption, with an overall reduction in demand for all energy sources in these three scenarios between 2016 and 2030. After 2030, the main difference across scenarios is largely due to the degree of energy demand reduction over time (compared with REF), with NZ scenarios showing the largest decreases in demand. A large part of this is due to gains in efficiency from electrification and from the lower overall demand associated with higher energy prices.

The share of fossil fuels drops markedly for all NZ scenarios, starting before 2030 and accelerating rapidly between 2030 and 2040. By 2060, oil and gas consumptions represent 32% and 16% respectively of 2016 demand levels. **Given the rapid pace of transformation needed, natural gas cannot serve as a transition energy**.

Figure ES.3 – Final energy consumption by source



Financial barriers in the building sector

Overall, the replacement of fossil fuel-powered systems by electricity in space heating is a key contribution to GHG reductions for the commercial and residential sectors, even within a short time horizon (-32% in 2030 with respect to 2016 for NZ50; -97% in 2050). This suggests that the building sector can be decarbonized at relatively lost cost with current technologies. For example, combining heat pumps with energy efficiency measures could replace natural gas in most provinces, as well as oil products and biomass in some others.

However, as seen in CP30, carbon pricing alone is not sufficient to even accelerate the transformation by 2030 (-5% in 2030 with respect to REF, 13% below 2016). The slow rate of transformation can be explained in part by the financial barrier of upfront investment needed to replace fossil fuels with electricity and the lack of incentives to alleviate the situation.

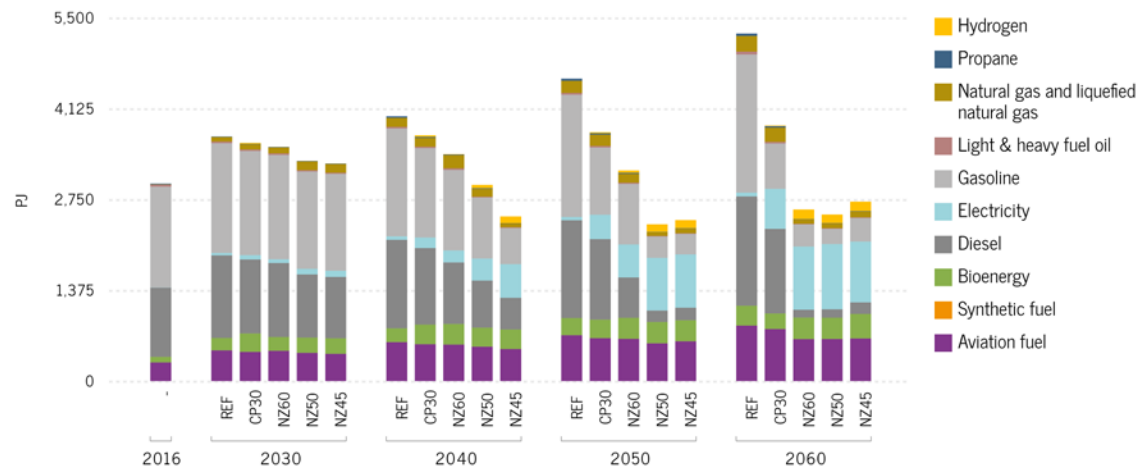
As a result, it is clear that policy and regulatory incentives could rapidly ensure this evolution away from business as usual and could even be made to pursue more aggressive targets than the net-zero 2050 trajectory (NZ50) to achieve these reductions—particularly by encouraging a massive shift to electric heat pumps.

Challenges in the transport sector

The transport sector accounts for 30% of Canada's GHG emissions and has seen its share steadily grow over the last 20 years. Current trends and measures (REF) project a 23% growth in energy demand for transport by 2030 and 73% by 2060 with respect to 2016 (Figure ES.4), with GHG emissions growing slightly more slowly (+16% and +55%) due to increased electrification of passenger vehicles. Although CP30 is insufficient to stop the growth in energy demand for this sector, it manages to stabilize emissions to 2016 level in 2050 and reduce them by 9% in 2060.

While central to GHG emission reduction efforts, transformations in transport are difficult and will take time due to higher costs and technological challenges involved in moving freight, making it the most challenging sector to decarbonize today.

Figure ES.4 – Final energy consumption for the transport sector



Once they reach net-zero emissions, **NZ scenarios show a more than 80% reduction in gasoline and diesel consumption**. Biofuels provide a contribution in the short term but are rapidly set aside for electricity in personal vehicles and small-size commercial road transport. Their role is reserved for areas where electric technologies struggle, such as maritime and off-road transport. However, this takes time. Although electricity plays a very large role in replacing gasoline and diesel consumption by 2050, particularly in personal vehicles (80% of the total) and commercial road transport (44% of the total), especially small and medium vehicles, emissions in the transport sector decrease by only 6% for NZ50 in 2030, reaching a reduction of 74% of 2016 emissions by 2050.

Outside of small and medium road vehicles, **other areas of transportation are much more difficult to decarbonize** because of higher costs and the difficulty of substituting low-carbon technologies for other sources in some applications. Heavy commercial transport shows a slow transformation. Many longer-term options are competing, including EVs, catenary, hydrogen, and biofuels. Given the infrastructure needed to support each technology, accelerating this transformation will require early convergence on a subset of these.

Strategy mixes in industry

The energy mix in industry is diverse, with biofuels and electricity accounting for 55% of its energy needs. This percentage is projected to remain largely constant over the coming decade in REF, as total energy consumption grows by 31% between 2016 and 2060. Since industry is sensitive to pricing, the introduction of a higher carbon price (CP30) is sufficient to push this percentage to 60% by 2030 and keep it at this level afterwards, with a similar growth in total energy use.

For the NZ50 scenario, the industrial sector reduces its emissions by 42% in 2030 and becomes net-negative in 2050 (-134% with respect to 2016). This reduction is achieved through the use of low-carbon energy sources for heat production and the transformation of industrial processes.

Results from the modelling show that decarbonizing industry requires a mix of strategies, including but not limited to carbon capture. These strategies include: technological innovation, fuel switching, product switching, emission capture, and a significant share of biomass-fired energy production coupled with carbon capture and sequestration (BECCS).

However, if carbon capture allows for significant emission reductions, it cannot be scaled down to cover small emitting units and all industrial processes. Thus, industrial process emissions are challenging to decarbonize, short of technological innovation or demand substitution.

While some production reductions are necessary to add to these transformations, **innovation is essential to sustain these sectors, either through technology and processes or through a better integration of heat production and consumption systems**. The design of effective strategies and policies to reach net-zero for the industrial sector (outside of energy production) will be based on common threads among the challenges faced by many subsectors of varying sizes and needs that extend beyond traditional energy efficiency objectives.

A higher emission share for agriculture

While agriculture is able to decarbonize its energy use, with an overall GHG reduction of at best 31% in all NZ scenarios, non-energy emissions remain significant for this sector: **at 42 MtCO_2eq, agriculture constitutes a third of all remaining emissions by 2050**. Short of drastic changes in production methods and quantities, these emissions cannot be avoided and cannot be captured on site. This is an area where considerable research should be carried out to consider the GHG reduction potential of better land-use management, dietary changes and alternative production methods. Otherwise, **these emissions must be compensated by negative emission activities or DAC**.

Canada's energy production in a net-zero economy

Following current trends, Canada's energy production (Figure ES.5) is set to continue to grow until 2040, dominated by oil production (+54% in 2030 and +75% in 2040 with respect to 2016), before retreating to 2016 levels in 2060 due to a lowering of exports. Natural gas sees a slow growth until 2050 (+22%) before also returning to 2016 production levels in 2060. Over the next decade, an increased carbon price (CP30) has relatively little effect on oil production, which is largely exported or used in transport, with few alternatives. However, natural gas production is projected to drop by 40% by 2030 and then slowly recapture part of the energy mix, as this scenario caps carbon price at 2030 prices.

All NZ scenarios present a very different trend in which oil and gas production are set to reduce deeply. For NZ50, oil production falls by 50% in 2030, reaching 94% in 2050, while gas diminishes by 59% and 90% over the same periods as variable renewable and biomass production are multiplied respectively by 4 and 2 in 2030 and 20 and 4 in 2050.

A net-negative power sector

With diminishing costs for electricity production, storage and electric technologies, the power sector is projected to expand in all scenarios (Figure ES.6). For REF, the share of electricity in the energy mix rises from 23% to 25% in 2030 and remains at that level until 2060. CP30 sees faster evolution, to 26% in 2030 and reaching 26% by 2050. Not surprisingly, electrification is even more important for NZ scenarios. For example, in NZ50, electricity accounts for 27% of all energy consumed in 2030, 57% in 2050 and continues to grow to 59% in 2060.

This consumption is met by a dramatic expansion of low-emission electricity production expected in all NZ scenarios, most of which will come from variable technologies with careful consideration for grid resilience. The role of storage (outside of hydroelectricity reservoirs), particularly over the medium term (weeks) and long term (months), could greatly affect this expansion.

Figure ES.5 – Primary energy production

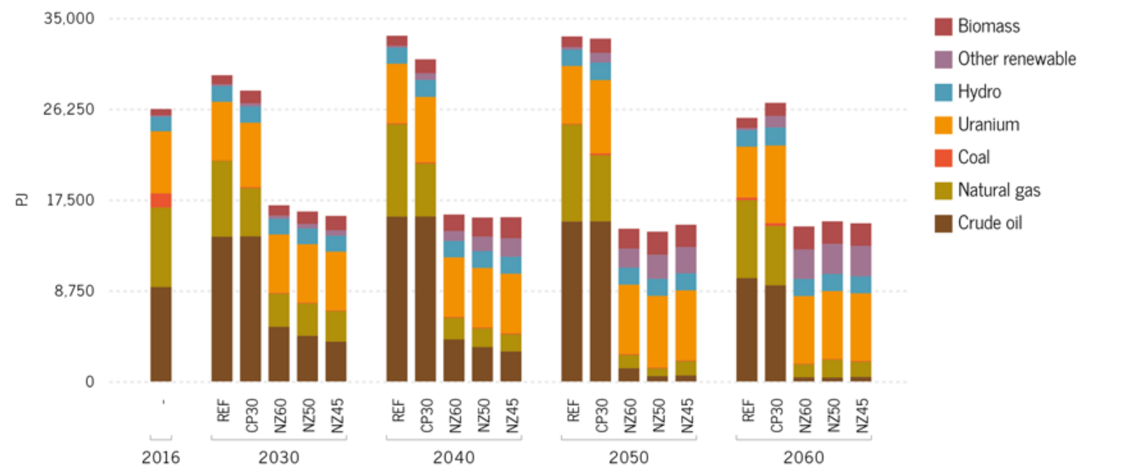
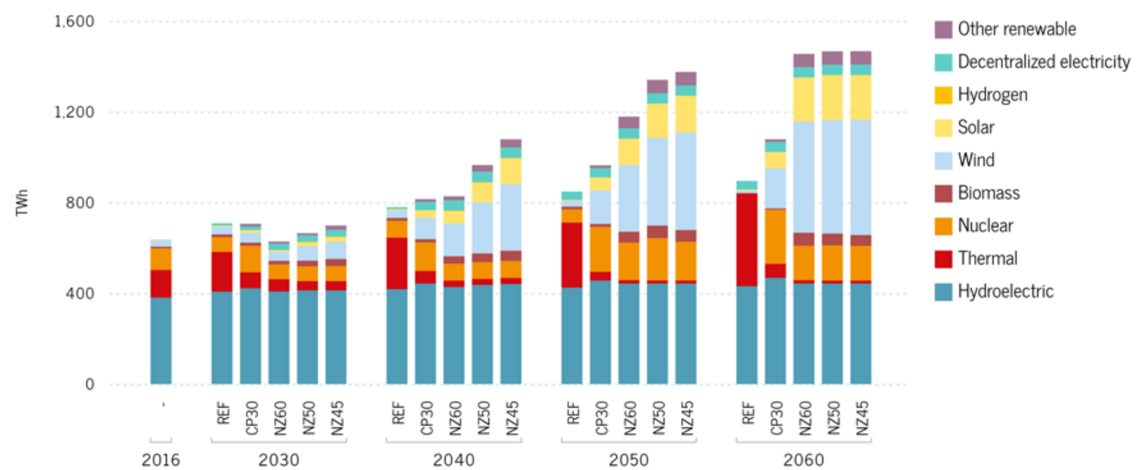


Figure ES.6 – Electricity production



Canada's large hydroelectricity installations are significant in helping it accommodate the more than tripling of electricity generation capacity resulting from the increase of variable solar and wind in NZ scenarios, reducing the need for new storage and the overall cost of these technologies. However, given the absence of detailed assessments for new hydroelectric projects or potential costs and low social acceptability, no new project is included, even though Canada still has considerable potential for this energy source.

Given the very large share of wind and solar energy in NZ scenarios and current technical constraints affecting other storage technologies, hydrogen and nuclear energy may play an important role. Notably, **SMRs could grow and support the expansion of uranium mining to supply it, and the technical potential of hydrogen may be of interest when long-term storage is needed. However, their respective role is difficult to ascertain precisely at this time given the considerable unknowns** as to costs, specifications, required infrastructures, safety concerns, and social acceptability. It is likely that their contributions will depend more on policy choices than simply on costs..

NZ scenarios show a rapid and almost complete elimination of both coal and natural gas. A relatively small quantity of electricity is produced from biomass with carbon capture (BECCS), a negative emission production which takes advantage of the natural capture of GHGs effected by biomass, which are re-captured when it is burned to power turbines. As a result, the power sector becomes net negative in its GHG emissions, helping compensate a part of what remains in other sectors after net-zero is reached.

The oil and gas production paradox

Canada is a major **energy producer and exporter. As such, its energy production and export profile will be deeply affected both by changes in demand and by constraints on GHG emissions**. As CCS is not cost-competitive with projected energy prices, oil and gas production decreases significantly (-62% in NZ50) even before 2030 in order for production emissions to remain compatible with longer-term net-zero objectives. Thus, in a cost-optimal net-zero pathway, oil and gas production bears the brunt of reductions before 2030.

The challenge of maintaining fossil fuel production in a net-zero pathway is underlined by sensitivity scenarios that impose higher oil and gas production levels. These show that maintaining respectively 84% and 52% of 2016 oil and gas production levels by 2030 requires electricity production to be net-negative within the next decade, with significantly accelerated decarbonization of the industry, building and transport sectors over the already rapid transformations needed in the NZ50 scenario.. Therefore, **in order to allow for a greater fossil fuel production (destined to exports) in 2030, domestic consumption in 2050 would need to be lower (by more than 10%) than in NZ50**.

Maintaining oil and gas production without direct CCS imposes higher (direct) costs than for NZ50 as GHG reduction efforts are transferred from the oil and gas production sector to other parts of the economy, including other industries, buildings and transport, and require a greater use of direct air capture (DAC) to compensate for the higher GHG emission left from economic activities.

An evolving role for bioenergy

In all scenarios, bioenergy is expected to rapidly play an expanded role, especially in transportation. This role could be crucial to achieve reductions in the short term, while keeping costs in check and without impeding later transformations. However, beyond a certain point, the availability of biomass and the remaining emissions associated with it combine to limit its role in approaching net-zero emissions.

Bioenergy's growing role in all scenarios is not more of the same: the mix of sources of biomass changes significantly (mainly with agricultural residues taking shares away from forest residues), as do its main applications, as biofuels and electricity production with carbon capture increase their use of this resource.

Variations in provincial contributions to net-zero

It is important to remember that the GHG constraints in our scenarios are applied at the national level rather than by province and territory in order to optimize total spending. Accordingly, **depending on their energy profiles, some provinces and territories where decarbonization options are cheaper can move into net-negative emissions, while others can retain an overall higher fraction of their emissions**. For instance, changes to energy production will differ from one province to the other in correlation with resource distribution, availability and the evolution of the import/export market, which is particularly important as more than half of Canada's primary energy production is destined for export.

Great provincial diversity in energy production and consumption leads to different challenges, for both the short and the longer term, in participating in the national effort to reach net-zero emissions at lowest cost. For instance, provinces with a decarbonized electricity system and a small industrial sector must approach the costliest sectors (such as transport) early on; the opposite is true for provinces with emission-intensive industries (such as oil and gas production) or carbon-intensive power generation since emissions reduction from these activities can be achieved rapidly at relatively low cost. Similarly, because of the high cost of transporting biomass, the availability of feedstocks in each province plays a large role in determining whether the results include BECCS electricity and/or hydrogen production in a specific province—and, as a result, the quantity of negative emissions for the province.

Even though many solutions are local or remain in the hands of the provinces, there is considerable common ground in some challenges and a crucial role to play for national efforts. Transportation, for instance, should be viewed from a national perspective. Some specific applications, such as space heating in buildings, can also be decarbonized early on across all provinces. Furthermore, provinces that currently have a highly emission-intensive electricity generation and little hydroelectric baseload generation face more significant grid infrastructure development challenges; a national plan to support cross-provincial interconnections would facilitate the required transformation of electricity generation, especially for these provinces.

Adopting a global approach to GHG emissions

Deep reductions vs. net-zero emissions

Overall, NZ scenarios show a significant quantity of emissions remaining from all sectors combined (between 155 and 167 $MtCO_2eq$ annually), underscoring the essential role of carbon capture and storage (CCS), including direct air capture (DAC), to help compensate. **Compared with simple reduction scenarios, the net-zero constraint thus profoundly changes the evolution of energy consumption.** This observation also helps highlight one of the key differences between the two reference scenarios (REF and CP30) and NZ scenarios as very little capture takes place in the former.

This is because even when achieving deep reductions in emissions wherever technology allows, a significant quantity of emissions remain that cannot be avoided, reduced or captured with current technologies. These include first and foremost non-energy emissions from agriculture and waste, as well as most industrial process emissions. However, even within the broad category of energy-related emissions, which today account for over 80% of Canada's emissions, some sectors, particularly transport (which contributes 40% to remaining emissions in 2050 in NZ scenarios), are difficult to decarbonize fully.

CCS reserved for unavoidable emissions

Modeling results suggest that **on-site CCS will first and foremost be applied to industrial processes for which CO_2 production is largely unavoidable, as well as to biomass-based heat, hydrogen or power production where the net impact on emissions is largely negative**. BECCS is based on available technology and its use results in either electricity or hydrogen production, as well as heat for industrial applications.

Carbon capture occurs mainly in industry and BECCS hydrogen and electricity production. This is largely because **targeting net-zero instead of simple GHG reductions changes where capture will be used since any carbon leakage (i.e., emissions not captured when CCS is applied) has to be compensated by negative emissions elsewhere, thus increasing the total cost of capture and favouring non-emitting approaches over CCS and, even more, CCU**.

While relying on carbon capture is a central part of the scenarios to net-zero, both costs and technological uncertainties serve as an important warning that projections may be too optimistic and that an even greater quantity of direct air capture (DAC) and negative emissions energy production (which is constrained by biomass availability) may be required to compensate for optimism about the share of emissions that can be captured. This adds to the risks and current unknowns of continued large-scale storage, especially since life does not end at net-zero: the required quantities of GHGs to store in order to achieve neutral emissions in 2050 must be captured every year thereafter. **While technological improvements may temper some of these risks over time, devoting at least as much effort to innovation in emission reductions as to capture seems essential.**

Key uncertainties for important technological pathways

This Outlook analyzes key technological pathways that are mainly constrained by GHG emission targets. By the nature of the exercise, these **pathways are based on a large number of educated assumptions about the evolution of technologies and associated costs**. Yet over the last few years, many of the recent certainties about GHG emissions, including the role of nature-based solutions, have undergone massive re-evaluations. Similarly, technical developments have often been shown to be fickle: some promising technologies fail to deliver on a large scale, while unexpected new approaches transform entire economic sectors.

Due to this uncertainty, this Outlook also explores how some transitions could proceed should certain assumptions turn out differently. Beyond oil and gas production, which have been discussed above, sensitivity analyses are presented for three pathways: electrification, bioenergy and hydrogen.

Accommodating variable renewable electricity

Variable renewable electricity provided by wind and solar generation constitutes virtually all of the very significant increase in electricity generation needed to meet demand in the NZ scenarios explored in this Outlook. Strong dependence on variable energy sources for electricity requires a massive increase in capacity for production and storage to compensate for lower capacity factors and misalignments between production and consumption.

Depending on assumptions, imposing constraints on storage and variable generation can favour nuclear or hydro generation with much strengthened interprovincial connections from a cost-optimal allocation perspective. This latter option helps reduce the need for a significant quantity of electricity generation and production capacity installed to balance variable renewables. This leads to different sectoral profiles where hydrogen and natural gas use are also increased. All these pathways, massive variable electricity production with storage, small nuclear modular reactors (SMRs) and expanded hydroelectricity generation with increasing interprovincial electricity trade, come with their own social and political acceptability issues in addition to technical and economic uncertainties about nuclear SMRs, utility-scale battery storage, and ancillary costs for grids with high levels of variable generation.

If the selected pathway will be determined by a combination of political orientations, technological developments and pure fate, the massive increase in total demand for low-carbon electricity that comes with a net-zero society will need to be met one way or another and planning and investment will have to start very soon.

Constraints for bioenergy

The assumed available quantities of biomass greatly affect the energy system, including the transport sector and electricity and hydrogen production in NZ scenarios, as biomass electricity generation, coupled with carbon capture and sequestration (BECCS), provides a relatively cheap solution for negative emissions.

In a sensitivity analysis where a greater quantity of biomass is available compared with current estimates, larger quantities of available biomass led to more BECCS, reducing pressure for the use of DAC when approaching net-zero. The opposite is true for a future with less biomass available, underlining the need for careful management of this resource. In the transport sector, increasing biomass availability does not have a uniform impact over all subsectors: passenger transport is mainly affected in the longer term, rail, maritime and off-road transport are affected only in the short term, while merchandise transport is affected at all times.

Irrespective of these assumptions about biomass availability, the role of bioenergy in efforts to reduce emissions underlines how critical it is to very carefully manage this resource if its potential is to be tapped into, especially given competing non-energy applications.

Hydrogen's unclear pathway

In NZ scenarios, **modelling grants hydrogen only a small share of the total, even in 2060, in part due to current difficulties in assessing the various technical roles it could play. However, a sensitivity analysis forcing minimum levels of penetration shows its increased use in most transport applications as well as in some industrial sectors**.

From a GHG emissions perspective, biomass availability (for BECCS production) and the cost of electrolysis will be determining factors in the emissions profile of hydrogen use should this reach more substantial levels than NZ50 results suggest.

The study of modified assumptions for hydrogen development illustrates how many technological pathways do not exist in isolation: biomass availability not only increases the ability to deal with short-term reductions where technology remains expensive, but also results in the opportunity to produce more hydrogen with negative emissions, increasing its overall consumption. More hydrogen helps decarbonize applications where electricity struggles and could provide an alternative in terms of storage. The importance of social acceptability issues surrounding nuclear facilities and the construction of additional large-scale hydroelectric dams may also affect prospects for a greater use of biomass. Resolving these uncertainties will thus take time and strategic choices over which pathway(s) to focus on may be required before they are entirely eliminated.

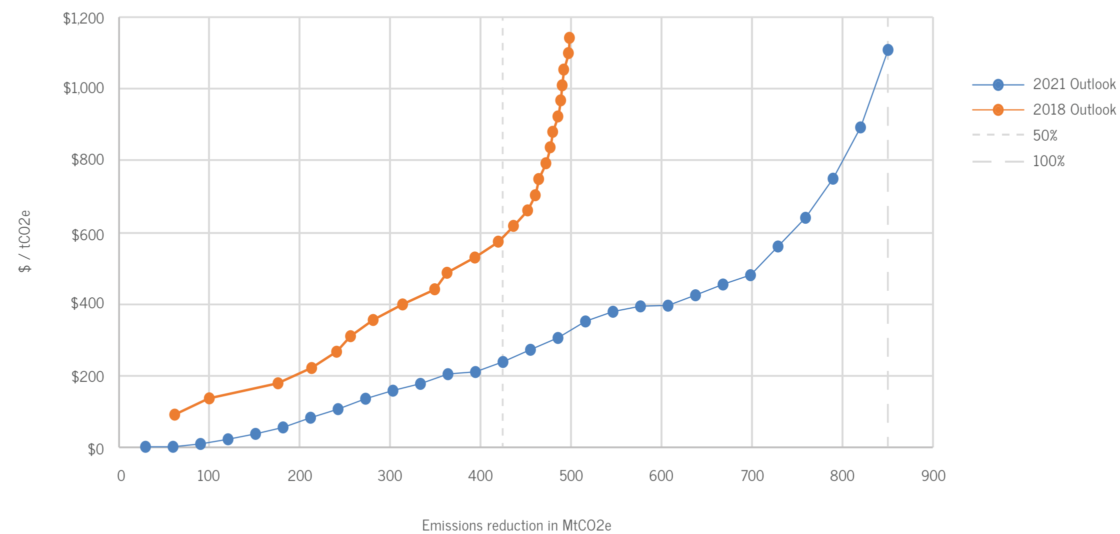
The decreasing costs of net-zero pathways

Since no country has yet completed the shift from fossil fuels to low-carbon sources of energy, the economic implications of these transitions are uncertain. Diverging assessments suggest that energy transitions may either fuel future prosperity or become an economic burden. Transitions will call for important investments but will also generate savings.

An assessment of the net cost of electrifying the primary energy supply by comparing the investments for low-carbon electricity production, transmission and storage with the savings from reduced consumption of fossil fuels show that REF and CP30 scenarios are not projected to generate annual savings in the next decades. However, all three NZ scenarios suggest considerable annual savings may be possible from 2050 onwards. **Even doubling the projected cost of electricity transmission infrastructure while halving the cost of combustibles with respect to the main hypotheses still leaves annual savings of CAD $23 billion in favour of NZ scenarios.**

Overall, the projected cost of decarbonizing Canada's economy is falling rapidly as technologies progress faster than anticipated. **While the marginal cost of the last ton for decarbonizing 65% of Canada's economy by 2050 was projected to be above $1,000 in the Canadian Energy Outlook 2018, current projections estimate that the marginal cost of decarbonizing 80% and 100% of Canada's economy by 2050 is $400 and $1,100, respectively** (Figure ES.7). Although a precise comparison is not possible since the current model includes a more comprehensive coverage of emissions and the evolution of the reference scenario is also different, the order of magnitude is unmistakable. Technological developments since the previous Outlook, which help not only with providing emission reduction solutions, but also with reducing uncertainties about technological paths and their costs, have in less than three years resulted in a very significant marginal cost reduction. This is while the 80% reduction is achieved earlier than 2050 for NZ50 as compared to 80P. As a result, **marginal costs on the longer term are then reduced; but more importantly, the higher levels estimated for the last tonne reduced become less relevant since they affect a smaller proportion of reductions**.

Figure ES.7 – Evolution of GHG reductions marginal costs



Notes: 1. 2021 Outlook's costs are for NZ50 scenario
2. 2018 Outlook's scenario projected an 80% reduction of energy-related emissions

Limits of individual actions and choices

One overarching conclusion from the modelling is that **reaching GHG reduction targets by 2030 will first and foremost require transformations on the industrial and commercial front rather than in citizens actions**, including the decarbonization of industrial processes, a significant reduction in oil and gas production, and aggressive reductions in fugitive emissions.

When considering the 2050 and 2060 horizons, the role of citizens' daily actions in reaching net-zero targets is very limited, affecting only a few sectors. Due to the structure of Canada's economy, less than 20% of all GHG emissions can be directly assigned to citizens' direct choices, including residential heating (6%) and personal transport (including individual vehicles (11%) and airplanes (1%)). Indirect emissions associated with consumption can be significant, but for the large fraction of imported goods, these emissions are not assigned directly to Canada.

It is therefore important for governments to focus their actions first and foremost on industry and the energy and private sector in general.

Situating this Outlook among other net-zero modelling around the world

Over the last few years, detailed net-zero reports have been produced for a number of regions and countries. A few general areas of consensus emerge from a comparison with this Outlook: notably, massive electrification is required to reach net-zero, calling for investments in grid resiliency and expansion; negative-emission technologies should be used only to compensate the sectors that are hardest to decarbonize (i.e., where no carbon-free technologies are foreseeable); transport is particularly difficult to decarbonize and requires early orientation to support specific infrastructures; oil and gas production have to decline; and decarbonizing industry is challenging and demands significant research and development efforts. Moreover, while governments need not choose every specific technology to favour, they must nevertheless make early decisions on which infrastructure to help develop in a way that enables some flexibility to account for future innovations.

With an already largely decarbonized electricity production, a strong oil and gas production and a diverse industrial basis, the comparison also suggests that Canada must transform its economy more quickly than most of the other OECD countries to reach its climate goals.

A need for improved regulations, programs and constraints on emissions

Results for the CP30 scenario show that **current regulations, programs and constraints on emissions must be significantly expanded or improved for Canada to reach both its 2030 and its 2050 targets:** the proposed evolution of the federal carbon price up to 2030, with public spending plans and current measures implemented, is insufficient to reach the GHG reductions targeted, with a total decrease of only 13% with respect to 2005 levels. **While not included in the model, adding the projected reduction of emissions from the implementation of the Clean Fuel Standard may bring the reduction only around 3% further**,[1] leaving total reductions at a level considerably less than the 40%-45% federal target. The carbon pricing increase in CP30 does not have a major impact outside of industry, energy and power production and is not sufficient to result in emission reductions.

Moreover, REF and CP2030 are both very far from net-zero in 2050 and 2060, underscoring how the policies in place or announced may be far from enough to steer society toward carbon neutrality. **It is essential that further details on how the federal and provincial plans will transform specific sectors, including information that is not publicly available at the moment, be released to allow for better independent evaluation of their impact on Canada's energy system and projected emissions.**

This demonstrates the urgent need for additional public policies with clear and quantifiable indicators and objectives to correct the course, as discussed in the conclusion of this report. Part of this reflection must focus on the implications of net-zero emissions. These policies should not wait to aggressively target sectors where pace is the only variation across scenarios and where technological uncertainties are the fewest. For instance, this is the case for the buildings sector, where the role of heat pumps in residential dwellings and electric systems in commercial space is similar across all scenarios, replacing natural gas. It therefore seems a safe bet to encourage the rapid adoption of these technologies at little risk and reasonable cost. A similar point can be made for the decarbonization of energy use in the agriculture sector. **Accordingly, a higher price on carbon must be accompanied by rapid planning for decarbonizing electricity production, expanding the grid and addressing other barriers to transforming these sectors.**

Conclusions drawn from this Outlook

The results and analysis presented in this Outlook point to several important conclusions:

1. **Policies and actions must be put in place or rethought with the net-zero objective in mind.** Given the short horizon for net-zero, all efforts and investments starting now must be aligned with a carbon-neutral society and maintain a sharp focus on intrinsic zero-emission for the maximum number of activities.
2. **Reaching net-zero means giving priority to preventing emissions rather than compensating them with capture.** Given the uncertainties, it is at present more cost-beneficial and strategically structuring to limit the capture and sequestration solution to compensate emissions that are almost impossible to prevent, as is the case in agriculture and some industrial processes.
3. **While energy efficiency and productivity are important contributors to the transformation of the energy system, they can in some cases be incompatible with a net-zero objective.** Eliminating GHG emissions can decrease energy productivity, as with the use of hydrogen produced by electrolysis or biomass instead of natural gas in heat production, or by relying on storage to reduce electricity peak demand.
4. **The energy system will continue to evolve after reaching net-zero as relative costs and available technologies change.** Sub-optimal solutions that deliver on net-zero will most likely be updated in the future. There is no need to be perfect the first time—as long as compatibility with net-zero is taken into consideration.
5. **Reaching net-zero by 2050 will be much cheaper than projected.** A marginal cost analysis of NZ50 in 2050 and an analysis of the cost of electrifying the primary energy supply show that reducing emissions is economically viable and could even deliver considerably savings.

[1] ECCC. 2019. Clean Fuel Standard: Cost-Benefit Analysis Framework. Environment and Climate Change Canada.

6. **Achieving net-zero requires strong leadership and making immediate difficult choices.** A number of structural barriers, including ill-conceived programs, regulatory and innovation barriers, risk aversion, the slow pace of technological adoption, inadequate workforce training, financial incongruities, and regional economic fabrics, are preventing even cost-beneficial investments that would accelerate the transformation of Canada's energy production and consumption pattern. These barriers must be lowered or eliminated through a strategic, coherent and integrated approach, led at the highest levels of governments, in order to deliver significant results on a horizon of one to four years from now.
7. **The most cost optimal way to reach 2030 targets is to significantly reduce emissions from the oil and gas sector.** Maintaining current emission levels or obtaining smaller reductions from this sector would require a much faster decarbonization of the other sectors, including electricity, buildings, industry and transport.
8. **In addition to oil and gas, the industrial, commercial and electricity sectors must bear the largest efforts early on.** Governments should therefore focus a major share of their attention on these sectors. To meet their GHG reduction commitments, governments should set targets and develop sector-specific programs for each of the aforementioned sectors.
9. **Transport does not transform as quickly as might be expected.** While some efforts, such as the Clean Fuel Standard, are not compatible with net-zero ambitions, others can only do so much as vehicle fleets typically take 7-10 years to completely renew. Decarbonizing transport also requires early and decisive action at multiple levels to ensure results by 2050. Essential, net-zero compatible urban planning will take decades to have an impact. Similarly, heavy public transportation and infrastructures for decarbonizing freight transport can take a decade to plan and build and will require many years afterward to produce results.
10. **Current international agreements can lead to exports of emissions.** The Paris Agreement definitions favour a strong decrease in national oil and gas production with, in some cases, additional imports of refined fuels for Canada's needs, as production emissions abroad are not added to Canada's GHG balance. Similarly, it also leaves unaccounted emissions associated with goods produced outside of Canada's borders, while assigning emissions from products that are consumed abroad to Canada. Global carbon pricing for goods, which would assign the environmental costs to the final user, would avoid this issue.
11. **Strong general results do not equate to certainty on all changes since details will depend on specific developments.** Modelling results closely depend on the conservative hypotheses that we have adopted about the evolution of technologies, the barriers to investments and the overall costs of the transformation. The specific evolution in the understanding of agriculture and nature-based solutions, as well as of technologies under intense development–such as hydrogen, small nuclear reactors, large scale energy storage, many industrial processes, and heavy transport–is still uncertain and even unknown. Their future is dependent not only on further research and technological progress but also on political orientations and choices that will lock in some of the infrastructure-heavy solutions early on and, by doing so, reduce the number of possible futures to consider.

Reconciling discourse and reality: a shared responsibility

The above observations, drawn from the modelling results as well as an analysis of the recent evolution of Canada's energy system and GHG emissions, should concern all Canadians. Canada's constitution means that the power of defining climate goals and the responsibility for reaching them are shared by many orders of governments. Over the last two decades, these governments have worked mainly in silos, largely ignoring what the level above or below or the other jurisdictions were doing. This approach, which was accompanied by billions of dollars in subsidies and support of all kinds, has largely failed to deliver the promised transformations.

As this Outlook suggests, continuing with this approach will not enable Canada to reach the GHG targets it has adopted. The depth and speed of transformation needed to do so require strategy, coordination and efficiency that is almost unheard of in Canada. Nonetheless, as demonstrated, this is not impossible. From a purely techno-economic point of view, this transformation is affordable and realistic. However, it requires governments, industry and citizens to think and act boldly and in the most open fashion, to accept risk and failure, to embrace change, and to understand that we cannot wait for the perfect solution before we begin to take action.