Canadian Energy Outlook

2018

horizon 2050

Executive Summary

INSTITUT DE L'ÉNERGIE TROTTIER

e3Hub HEC MONTRÉAL Expertise in Energy and Environment

Modelling
ESMIA Energy Super Modelers and International Analysts

Financial support
FONDATION FAMILIALE TROTTIER FAMILY FOUNDATION

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Disclaimer

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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 e3 Hub

e3 Hub is a multidisciplinary platform whose mandate is to identify and transfer knowledge and best practices in energy management to various audiences. This mandate is based on several strategic axes, in particular the study of best practices in energy efficiency within companies, and the realization of economic analyses to understand the different issues related to the production and the consumption of energy.

Based at HEC Montréal, e3 Hub not only draws on the School's academic resources, but also develops partnerships with various organizations to carry out its mission. It is also a platform for networking, where academics and practitioners can share their knowledge and learn from each other.

About ESMIA Consultants inc.

ESMIA offers expert services in the development and application of 3E optimization models (Energy-Economy-Environment) for strategic decision making at local, regional, national and global scales. Specialized in the development of integrated energy models, the ESMIA consultants have been providing a full range of support services for clients who want to develop their own model or learn how to use existing models. They have participated in the development of numerous models for prestigious public and private organizations worldwide. ESMIA consultants also provide consulting services for the analysis of complex and long-term energy-related issues, including the energy transition to a low-carbon economy, the impact of emerging technologies and climate policies. ESMIA benefits for this purpose from its own North American model.

Since the beginning of the industrial revolution, energy has been at the core of economic development, supporting the natural resources, agricultural, industrial and manufacturing sectors, as well as providing services essential to move people and goods, heat buildings and ensure the efficient operation of society as a whole.

With the competitive exploitation of non-conventional fossil fuels, the rapid cost reduction of intermittent renewable energy sources and worldwide efforts to reduce GHG emissions – produced in Canada at more than 80% by the energy sector – energy issues have never been more important, since the oil crises in the 1970s, to further understanding of what current and expected developments mean for Canada's future and help enlighten policy and investment decisions.

The proposed Outlook

For some 30 years, Natural Resources Canada has produced an Energy Outlook that attempts to look at the impact of current and expected energy-related conditions on possible futures for the country. This tradition was abandoned 12 years ago, in 2006, two years before shale gas and oil shattered the North American and world energy market. In parallel, since 1967, the National Energy Board (NEB) has been producing an Energy Futures report historically focusing on supply and distribution in support of its own mandate. However, in its last report, published in 2017, the NEB Energy Futures considers the impact of carbon pricing on demand for the first time. A few non-profit initiatives have also examined Canada's energy future. The Trottier Energy Futures Project (TEFP),[1] published in 2016, focused on the impact of various GHG reduction scenarios on the 2050 horizon. In May 2018, David Hughes, supported by the Parkland Institute and the Canadian Centre for Policy Alternatives, proposed an analysis of Canada's current energy and GHG reduction situation.[2]

This Outlook complements and expands these efforts. It adopts a traditional form: comparing four GHG-reduction scenarios with a reference case, it projects Canada's energy production and consumption into the next decades based on the NEB's demand scenario. These scenarios, analyzed using the North American TIMES Energy Model (NATEM),[3] are as follows:

*The **B**usiness-**A**s-**U**sual or reference scenario **(BAU)**.* This scenario presents results using no GHG reduction targets. It is aligned with the reference scenario used in the National Energy Board's Canada's Energy Future 2017 Outlook, imposing no additional constraints in terms of GHG emission reductions.

Energy issues have never been more important for Canada since the oil crisis of the 1970s.

*The **PRO**vincial scenario **(PRO)**.* This reduction scenario imposes individual provincial targets for emissions – when they exist. It gives an idea of the evolution of the country's emissions if provincial leadership were to be the dominant factor, with little to no involvement from the federal government.

*The **F**ederal scenario with **I**nternational carbon **M**arket purchases **(FIM)**.* This reduction scenario imposes the federal government's stated 2030 and 2050 targets, which aim for 30% and 80% reductions from 2005 levels respectively. In this scenario, 25% of these reductions come from international carbon market purchases, in line with Canada's recent 7th National Communication and 3rd Biennial Report submitted to the United Nations Framework Convention on Climate Change. As a result, this scenario's central aim is to use the current federal government's plan and projections for 2030 and extend them to 2050.

*The **FED**eral scenario **(FED)**.* This reduction scenario uses the same federal government 2030 and 2050 targets as FIM (30% and 80% with respect to 2005), but all reductions must be achieved domestically – i.e., without the option of purchasing credits

1 http://iet.polymtl.ca/tefp

2 https://energyoutlook.ca

3 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.

elsewhere. As in FIM, this puts the federal framework for GHG reductions at the center of the scenario but shows what achieving these targets without the help of foreign jurisdictions would require.

*The **80 P**ercent scenario (**80P**).* This last reduction scenario is the most aggressive in terms of emission reductions, aiming at 80% reduction, but this time from 1990 levels, by 2050, corresponding to an 83% reduction with respect to 2005. This provides a perspective in relation to the Kyoto Protocol, where most parties' targets were set using 1990 levels as a reference (see UNFCCC Kyoto Protocol).

These scenarios allow us to:

- Identify possible pathways to reach medium- and long-term targets in terms of GHG emission reductions.
- Ensure a thorough discussion of cross-provincial variations within these pathways.
- Provide a special focus on the transportation sector, varying demand evolution, where challenges to reducing emissions and problems in transforming the sector's energy profile go hand in hand.

The current situation

The Canadian energy system stands out when compared to that of other countries around the world. On the production side, Canada is one of the world's leading energy producers (6th) and net exporters (5th), accounting for close to 7% of the country's gross domestic product (GDP).

Ranked 8th in the world for overall consumption, Canada also stands out when it comes to energy consumption. Provinces differ in their consumption patterns, most notably in the share occupied by the industrial sector, whereas the transport, commercial and residential sectors are more similar.

In 2015, 81% of Canada's electricity production was low carbon emitting (15% from nuclear, 60% from hydro, 4% wind, 2% biomass and 0.5% solar). With the exception of Brazil, only much smaller countries in terms of population and territory have larger shares of renewable sources in electricity generation.

Overall, Canada's energy system plays a significant role in the country's economy, given the importance of energy production and the country's large consumption levels. Variation in the provinces' energy profiles are key to this portrait.

This particularity creates strong national trends such as the overwhelming importance of oil in the transport sector; strong ties with the United States as the primary customer for energy exports; and the dominant energy consumption of the industry and transport sectors in almost all provinces.

Several events have reconfigured energy issues over the past year. In particular, pipeline development has proceeded through the advancement of several projects, although not without substantial debate; carbon pricing initiatives have continued to evolve in some areas of the country with significant opposition from Saskatchewan and Ontario; and uranium production has been hit by the suspension of activities at several sites.

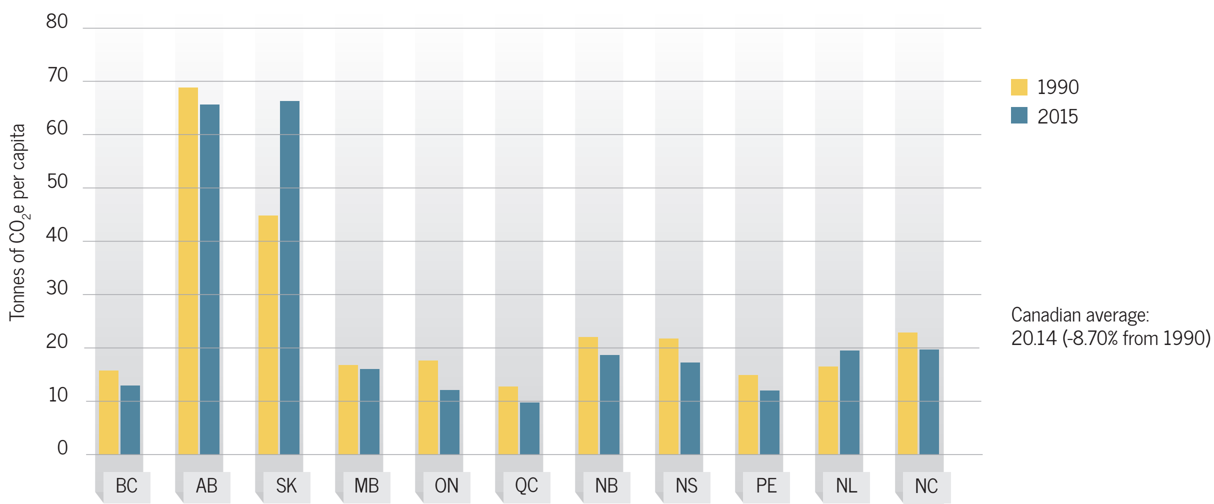
Canada is an energy powerhouse ranking 6th in the world for its production and 5th as net exporter. The energy sector represents close to 7 % of its GDP.

Finally, Natural Resources Canada, which is responsible for the energy transition at the national level, launched Generation Energy in early 2017, an online consultation that ended with a large gathering in Winnipeg in October 2017. While the consultation was a success, reaching more than 380,000 Canadians according to the report presented by Minister Carr, no clear path of action has followed.

Energy-related GHG emissions

Energy-related emissions make up 81.3% of Canada's total GHG emissions. While total emissions increased by 18% from 1990 to 2015, emissions relating to energy grew more rapidly, climbing by 21.6%.

Figure 1 – Evolution of per capita GHG Emissions in Canada



Note: NC stands for Northern Canada, i.e. Yukon, Northwest Territories and Nunavut

Although some sectors of activity, such as electricity and heat production, have managed to reduce their emissions, this has been more than offset by increases mainly in the transport sector and the oil and gas upstream and refining industries.

The importance of the evolution of the industrial sector – and, in particular, oil and gas production – explains a large part of the wide discrepancy in per capita emissions between Alberta and Saskatchewan on the one hand, and all other provinces on the other (Figure 1). Larger per capita figures for the transport sector, as well as a greater presence of fossil fuels in electricity generation, also contribute to this discrepancy.

Overview of GHG reduction strategies

Like much of the rest of the world, the provinces and the federal government have adopted various GHG emission objectives, targets and strategies that reflect a diversity of approaches and ambitions and underline the challenge of establishing a coherent national program.

A majority of provinces now have a medium-term objective that includes a target for one or both GHG emission reduction and renewable energy, as well as a long-term view (2050) for GHG reductions. There has been a clear acceleration of such strategies since 2016, following Canada's signature of the Paris Agreement and the announcement of the Pan-Canadian Framework on Clean Growth and Climate Change (PCF). In addition to the PCF, the Government of Canada introduced the Pan-Canadian Approach to Pricing Carbon Pollution, which gives the provinces the flexibility to implement an explicit price-based system (e.g., a carbon tax or levy) or a cap-and-trade system, while providing a backstop option to ensure a minimum price on carbon across the country.

Energy-related emissions, making up to 81.3% of Canada's total GHG emissions, have been reduced in some sectors, like electricity and heat production, but those reductions have been more than offset by increases in the transport sector and the oil and gas industries.

The Canadian government has also presented other plans, including the phasing out of coal in electricity generation, a Clean Fuel Standard to reduce the carbon footprint of transport fuels, and a Federal Sustainable Development Strategy.

Figure 2 – Final energy consumption by source

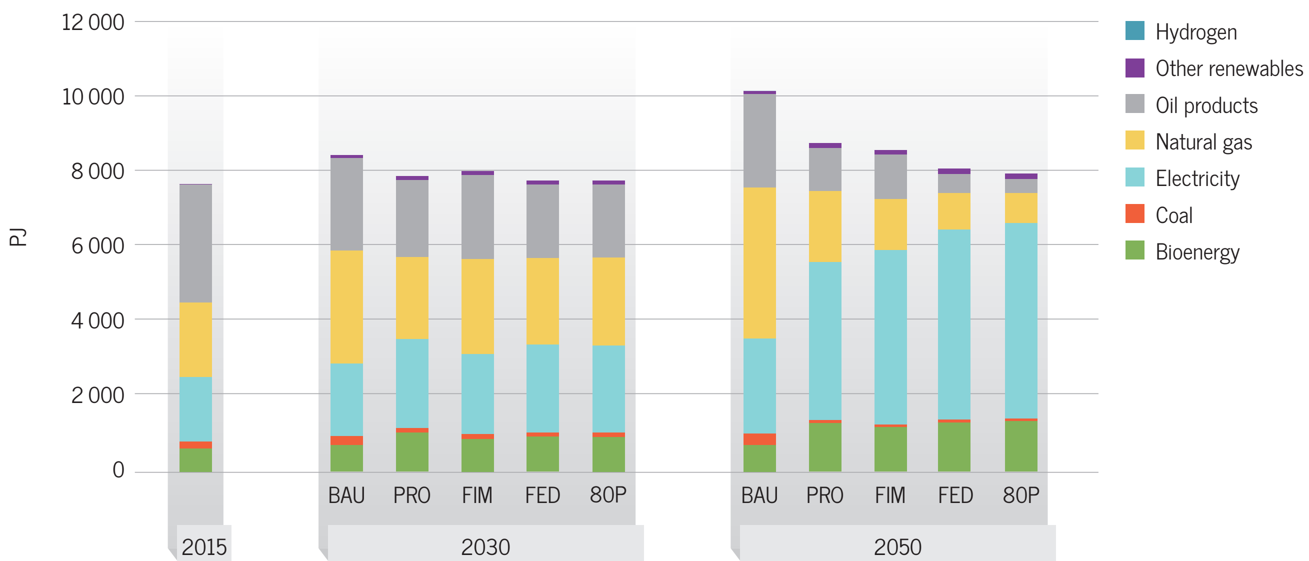
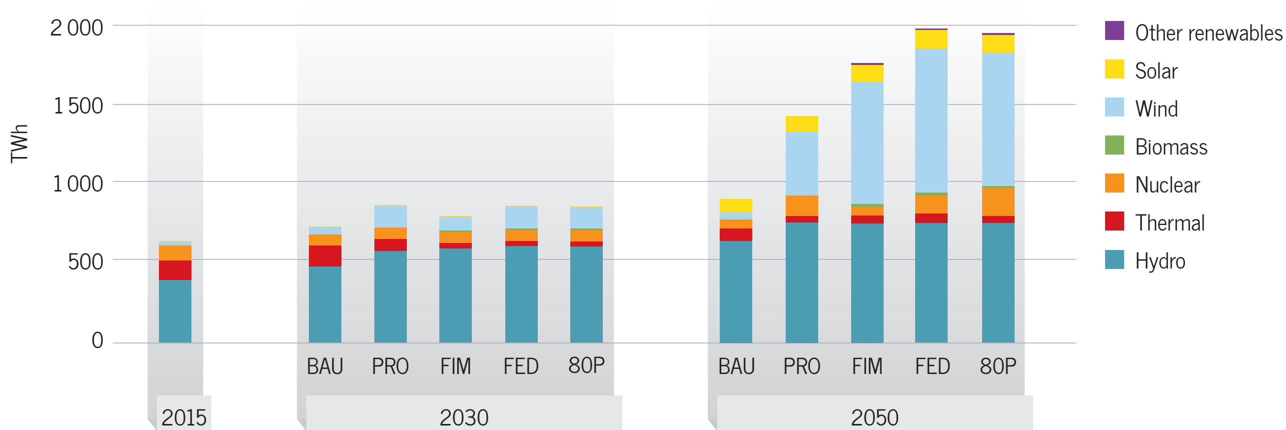


Figure 3 – Electricity generated by source



A closer look at federal and provincial programs quickly reveals many important caveats to this proliferation of action plans and strategies:

- In general, details on how targets will be reached, including costs, technologies and pathways, are scant or entirely lacking;
- Many action plans and similar documents can be reversed by a change in government — the decision by the newly elected Ford government in Ontario to withdraw from the cap-and-trade system illustrates the reversibility of these policies, even those with more solid legislative footing;
- Even if the entire set of current policies is fully implemented and works as intended, Canada will still fall short of its 2030 GHG reduction target by 30%, as expressed in Canada's recent 7th National Communication and 3rd Biennial Report submitted to the United Nations Framework Convention on Climate Change;
- Disagreements on priorities among provinces and the federal government will add to the

difficulty of delivering on the adopted targets across Canada.

Meeting energy demand while reducing GHG emissions

As shown in Figure 2, the evolution of the total energy demand in Canada, as computed by the NATEM model, is largely independent of the various reduction scenarios and increases only slightly over time, a significant departure from historical trends. This corresponds to an economy that, in order to meet the imposed GHG emission reduction targets, moves from less efficient (fossil fuels) to more efficient (electricity, in particular) energy forms, able to provide more services for the same number of joules while continuing to improve overall energy efficiency.

These results lead to three main observations:

- The demand for oil products is set to decrease – even in BAU – as early as 2030, a trend unlikely to be limited to Canada, even without a significant increase in market prices.

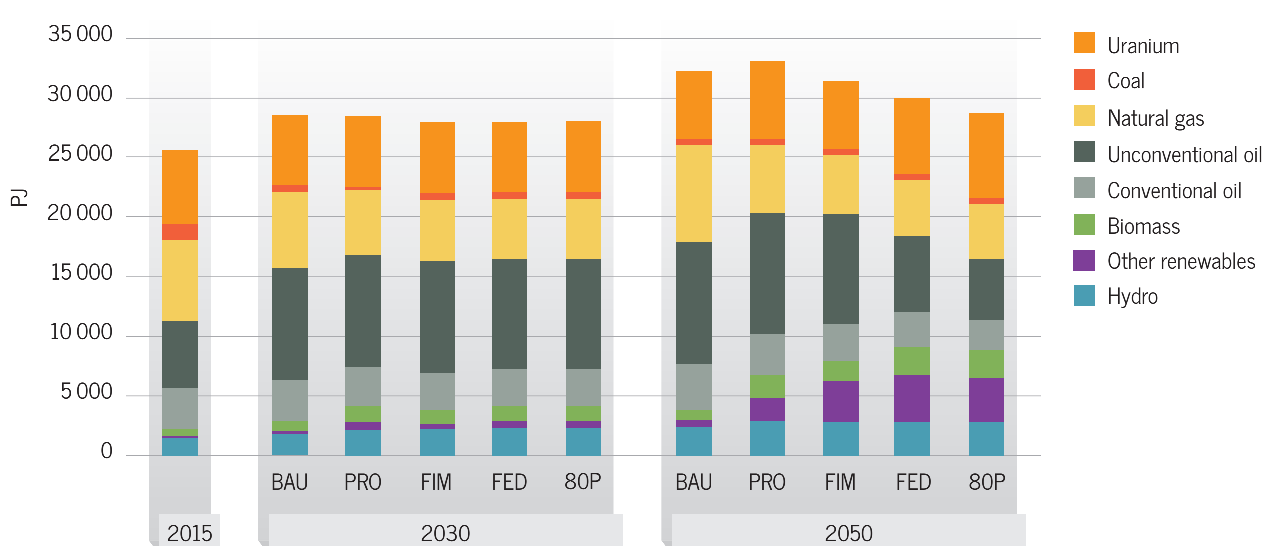
- The demand for natural gas increases to practically the same level across all reduction scenarios for 2030, but declines in all of them for 2050. Although it returns to 2015 levels in PRO, it falls by at least 30% in other scenarios and by almost 60% in 80P.

Even if the entire set of current federal and provincial policies is fully implemented and works as intended, Canada will still fall short of its 2030 GHG reduction target by at least 30%.

- To achieve even the least stringent GHG emission reduction targets, electricity will need to take a larger share of the mix – as much as 66% of all energy used by 2050 – and be mainly generated from non-GHG emitting sources, as shown in Figure 3.

In the coming decades, Canada should undergo a major transformation of its energy sector that will not, however, affect access to energy for consumers in any sector. The most important hardships will be noted in the oil and gas sector, which is expected to experience a significant reduction in demand, requiring some provinces to reconfigure their economy and retrain their workforce. In contrast, however, meeting the increased demand for electricity will trigger massive investments required to generate, distribute and use this form of energy.

Figure 4 – Primary energy production



Energy consumption per activity sector

In the residential, commercial and agricultural sectors, total energy consumption increases only slightly, with electricity playing a much larger role in all GHG-reduction scenarios; while natural gas delivers 45% of the energy consumption for BAU. However, it all but disappears in 80P, where electricity and bioenergy compensate.

Results for the industrial sector show a similar increase in the use of electricity at the expense of natural gas and coal and coke in 2050. All scenarios clearly present a lower overall energy demand than BAU in 2050, illustrating the importance of direct and indirect energy efficiency, mainly through electrification. Important gains in this sector will require breakthroughs in new technologies and processes for which costs cannot be easily evaluated.

The transportation sector shows the most significant variation in energy demand across scenarios. In 2050, energy demand decreases sharply in all GHG-reduction scenarios. This reduction is due to energy efficiency gains resulting from increased use of electric motors instead of internal combustion engines rather than to a decreased demand for transportation.

Space heating represents more than half the final energy demand in both the commercial and the residential sector. Currently largely ensured by natural gas systems, in the more aggressive reduction scenarios by 2050, we observe a steep increase in electric heating systems with a near complete elimination of any alternative, including natural gas.

Evolution of energy production

As Canada is a major energy producer and exporter, its energy production will be affected by both changes in the demand and constraints on GHG emissions. Not all sectors will be impacted in the same way: some will have to reduce their production, while others will see major growth. This growth will differ on a per province basis.

Total energy production (Figure 4) is expected to rise slightly over the next few decades in all scenarios, primarily due to increased unconventional oil in the short term and, in GHG reduction scenarios, biomass production in the longer term.

Canada should undergo a major transformation of its energy sector that will not, however, affect access to energy services for consumers in any sector.

Canada should remain an important producer of fossil fuels. Production is expected to increase by 5% to 15% by 2030, with the growth coming from oil sands as coal and natural gas production falls. For 2050, the federal emission target imposes a decrease in fossil fuel production, mainly capping oil around current production levels, while effecting a one-third reduction in natural gas extraction.

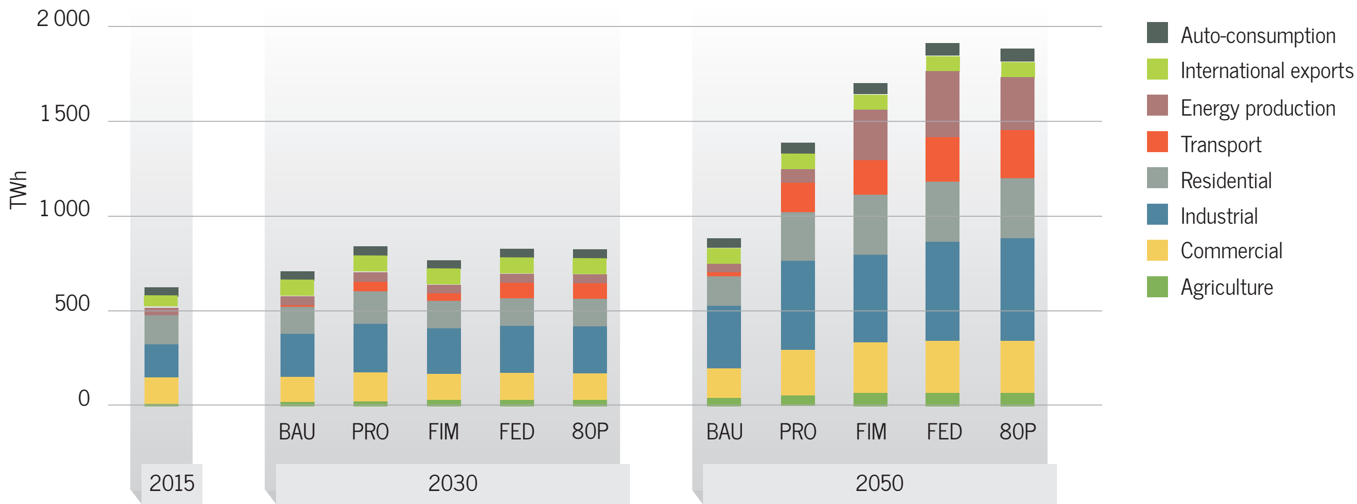
This leaves considerable fossil production, even in the most stringent reduction scenario: between 12,000 PJ (80P) and 19,000 PJ (PRO), respectively 22.5% below current production levels and 21.5% above. In percentage, fossil fuels represent 70% of primary energy for BAU and 45% in the most ambitious reduction scenario (80P).

For 2050, the federal emission target imposes capping oil production around current levels while effecting a one-third reduction in natural gas extraction.

Renewable energy production experiences major growth in most scenarios. From 2,200 PJ in 2015, total renewable production could vary from 3,900 PJ (BAU) to 9,000 PJ (FIM, FED, 80P).

Biomass production is expected to be multiplied by three in all GHG-reduction scenarios by 2050, particularly in the transportation sector. In fact, with the prices of intermittent renewable electricity falling rapidly, outside of this sector, bioenergy is expected to play a smaller role in energy transition than predicted even a few years ago.

Figure 5 – Electricity consumption by sector



Energy trade

Canada is considered a major energy exporter given that a significant portion (close to 60%) of the energy it produces is directed to foreign markets, chiefly the USA.

Although internal fossil fuel consumption varies significantly between scenarios, coal, gas and oil exports are only slightly affected, as the NATEM model leaves (by assumption) the rest of the world on the same trajectory irrespective of Canada's choices. If the rest of the world follows a trajectory similar to that promised by Canada, with aggressive GHG reductions around the planet, international demand for oil and gas products will fall, directly affecting Canada's energy exports.

Energy imports diminish noticeably in the reduction scenarios in 2050 due to the almost total elimination of natural gas imports. While crude oil imports are smaller in 2050, imports of oil products increase across scenarios. This suggests that part of the efforts to reduce Canadian GHG emissions in aggressive scenarios will consist in shifting oil refinery emissions elsewhere (overwhelmingly to the United States).

Impact at the provincial level

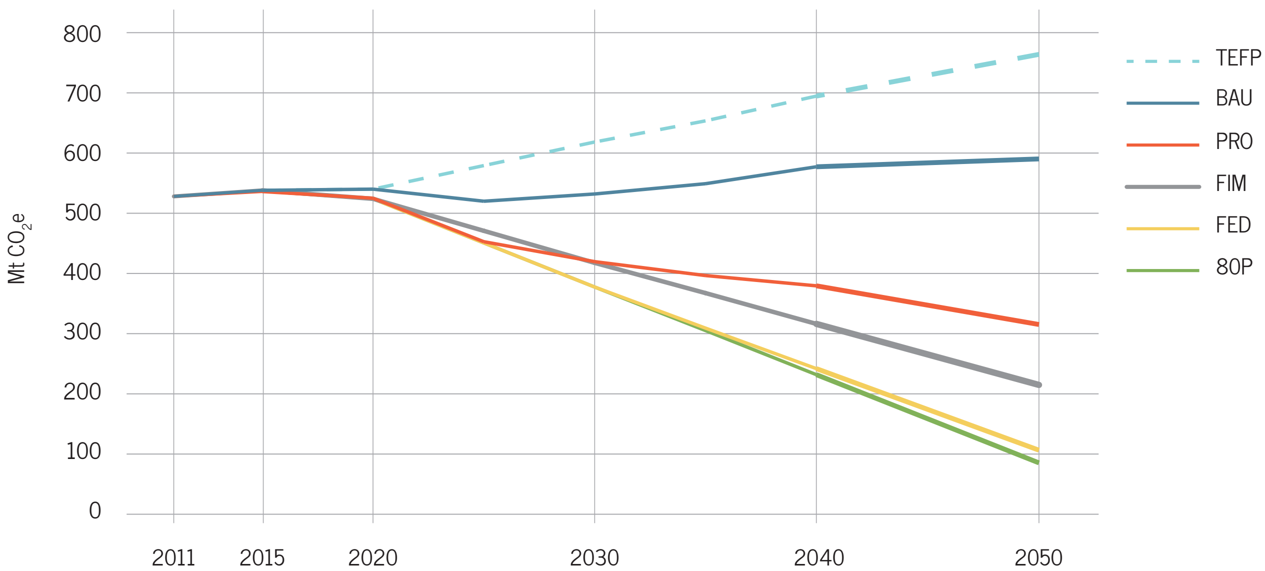
The evolution of most provinces is anchored in their current production mix and resource endowment, which remains reflected in spite of significant changes in all 2050 scenarios.

Increases in renewable electricity (hydro, solar and wind) are mainly found in New Brunswick, Nova Scotia, Ontario, Quebec and Prince Edward Island, where it serves both to replace current thermal electricity generation and to meet the larger electricity demand. Biomass production also increases, with the largest share coming from Ontario and Manitoba.

If the promised aggressive GHG reductions take place around the planet, international demand for oil and gas products will fall, directly affecting Canada's energy exports.

The importance of fossil fuel production in all scenarios in 2050 follows distinct provincial profiles as well. The quantities produced in Alberta and Saskatchewan remain considerable in 2050, although with variations across scenarios. Unconventional oil in Alberta in particular shows much smaller quantities produced in the more aggressive scenarios. The situation is different for Newfoundland and Labrador's oil production and – to a somewhat lesser extent – British Columbia's natural gas production, which are

Figure 6 – Energy-related GHG emissions



Note: The TEFP line reproduces the marginal reduction costs for scenario 8a of the Trottier Energy Future Project, which leads to a 70% GHG reduction from 1990 by 2050.

expected to decline significantly by 2050. The striking difference between scenarios for these two provinces demonstrates the effect of long-term GHG emission reduction objectives on the most emission-intensive sectors of energy production.

With energy production much more unevenly distributed across the country, many of the current energy-poor provinces will gain significantly from the energy transition. However, provinces relying heavily on fossil fuel production, such as Alberta, Newfoundland and Labrador and Saskatchewan, will have to diversify their economy, especially if worldwide demand for their products falters.

The important role of electricity

Canada's current electricity generation is dominated by hydro and nuclear generation, making it one of the OECD countries with the lowest GHG emissions per kWh generated. Over the coming decades, the transformation of Canada's energy system will see an increase in its overall generation of electricity. Most of the generation increase will occur after 2030, ranging from 124% (PRO) to 209% (FED) by 2050.

On a per technology basis, the major national trends observed are as follows:

- With a strong flexible base-load generation and considerable hydroelectric reservoirs, Canada will not be required to build up as much renewable capacity as other countries.
- Wind generation becomes dominant over the next three decades in all scenarios but BAU, rising from 27 TWh today to between 405 and 918 TWh, surpassing hydroelectricity — 43% of the total electricity could be produced by wind capacity, representing 46% of total installed capacity.
- Some additional hydropower generation is seen in all scenarios for 2050. While this technology is possible from an economic point of view, there is considerable opposition to it, both from communities directly affected by the dams and flooding and from the general public. Limiting new hydroelectric developments while maintaining GHG emission targets will require accelerating the development of other low-carbon energy sources or reducing demand.
- Although all scenarios show a decrease in nuclear energy for 2030, generation will likely

increase in absolute terms for 2050. As a proportion of total electricity generated, nuclear energy is nevertheless expected to fall from 15% currently to 3% to 9% across scenarios.

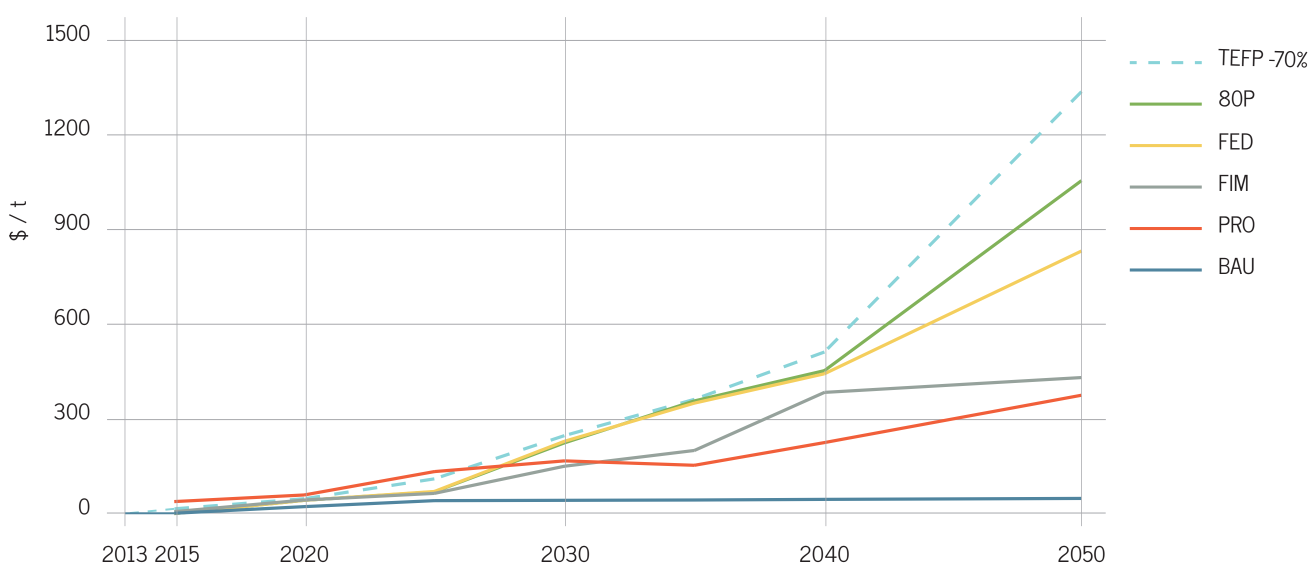
- Photovoltaic is expected to contribute only a relatively small fraction of the total electricity generation in 2030, but should pick up in the following decades, surpassing nuclear in all scenarios but PRO, while remaining well below 10% of total generation.
- In spite of their current role in Saskatchewan, carbon capture and storage technologies (CSS) do not appear in our scenarios due to their considerable cost and the uncertainty surrounding their development.
- The role of self-generation in the electrification process is very much an open question at present. The scenarios presented here lack the information to account for this aspect.

The transformation of electricity production is first and foremost a provincial matter, with extensive differences based on historical choices and access to local natural resources. Although these differences will remain, all scenarios show that new generation in all provinces will primarily stem from renewables:

With a strong flexible base-load generation and considerable hydroelectric reservoirs, Canada will not be required to build up as much renewable capacity as other countries, yet 43% of total electricity could be produced from wind, explained by higher capacity factor.

- As electricity demand is expected to triple by 2050 in almost all reduction scenarios, most provinces where thermal sources dominate will see their generation substantially modified, chiefly due to massive wind generation by 2050.
- Low-carbon electricity producers will continue in this direction even while increasing their production. In Manitoba and Newfoundland and Labrador, the expected new generation for 2050 is still almost exclusively derived from hydropower, in contrast to British Columbia and Quebec, where it comes predominantly from wind.
- While its current generation is negligible, Northern Canada is expected to become an

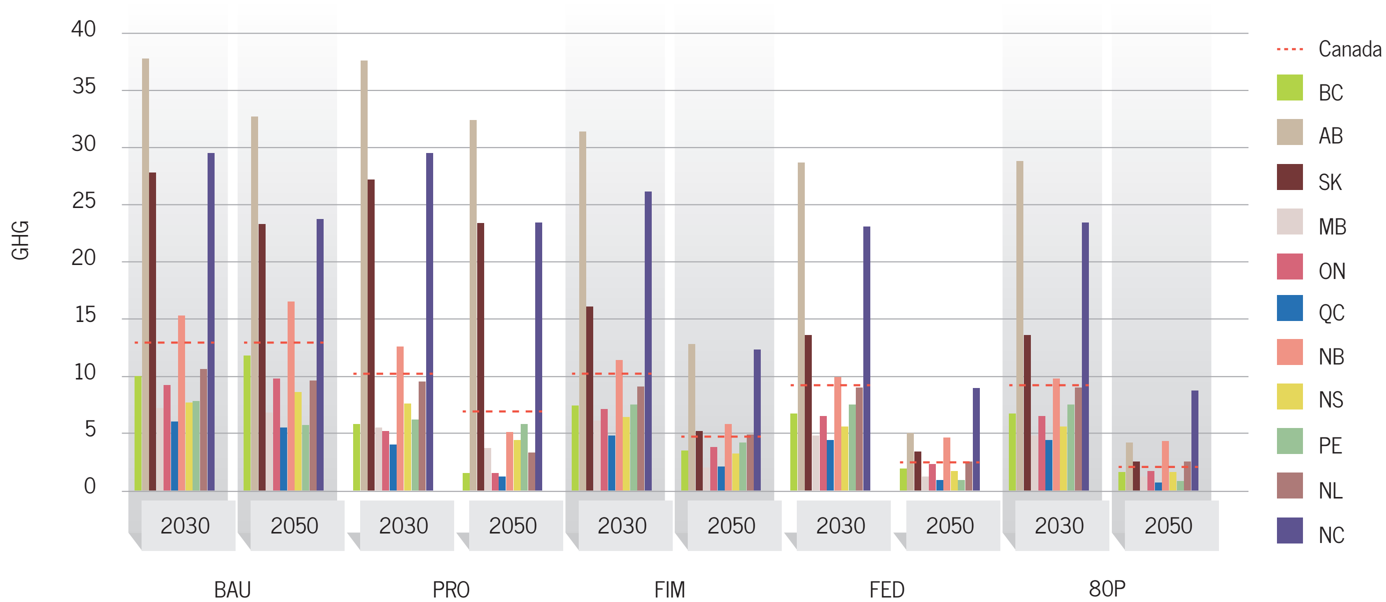
Figure 7 – Marginal reduction costs



Note: The TEFP line reproduces the marginal reduction costs for scenario 8a of the Trottier Energy Future Project (TEFP), which leads to a 70% GHG reduction from 1990 by 2050.

[4] Under FIM, FED and 80P, each province will have the same marginal reduction cost (which would be the equivalent here of a federal carbon tax imposed in each province), but will reach differentiated reduction levels (in percentage, based in particular on the reduction options available in each province).

Figure 8 – Energy-related GHG per capita by province



Notes: Due to the absence of provincial/territorial targets, the BAU curve for Alberta, Saskatchewan and Northern Canada is identical to PRO. The horizontal lines indicate the Canadian per capita emissions.

important electricity producer, increasing from 1 TWh to between 70 TWh and 115 TWh by 2050. Most of this will come from hydro and wind, and will serve to meet demand in neighbouring provinces.

Even if the total energy demand remains almost constant in all reduction scenarios between now and 2050, the demand for electricity will at least double over that same period, and could almost triple in the most aggressive scenarios. This shift to electricity will require new tools, machinery and infrastructure that open up considerable opportunities for development and innovation. Figure 5 clearly illustrates the substantial energy transformation that the Canadian economy must undergo to reach its GHG reduction targets.

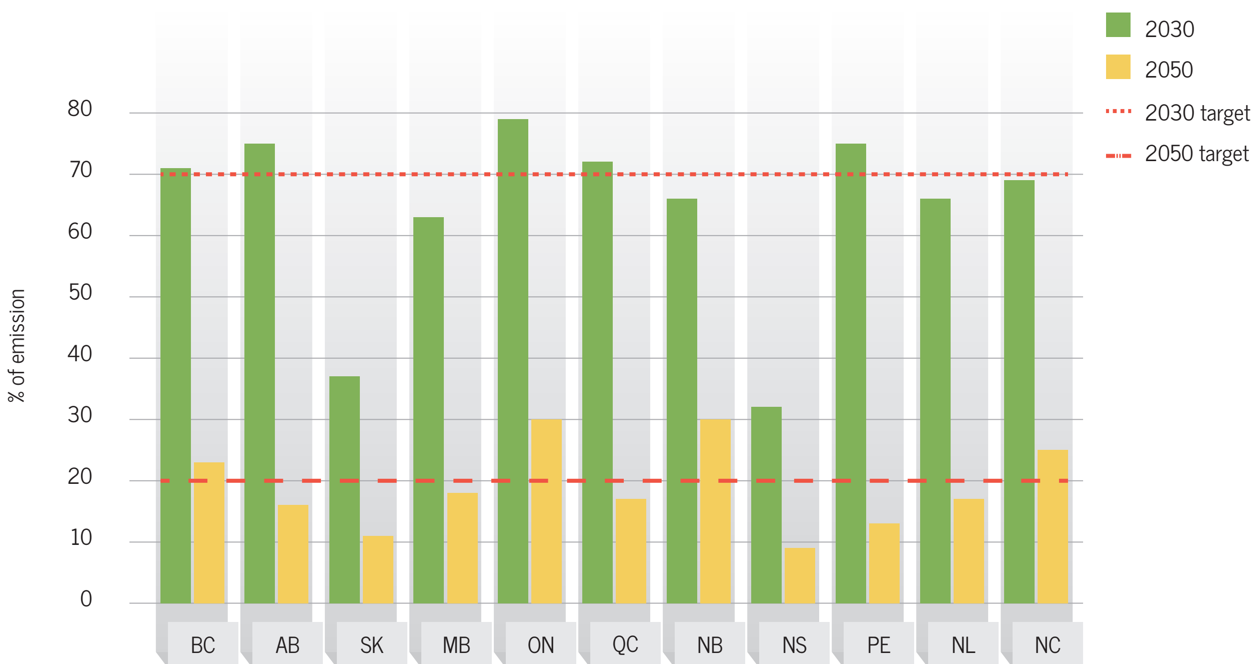
All sectors will be affected at various levels by this transformation: the electrification of space heating can be carried out relatively cheaply with well-established technologies, while heavy industry, particularly mining and oil and gas, which currently rely almost exclusively on fossil fuels, will have to adapt and develop production technologies capable of providing sustained high-power energy in the remote regions where it operates.

Increased usage of electricity will require new tools, machinery and infrastructure that open up considerable opportunities for development and innovation.

Given the extent of the electrification of Canada's energy systems, it will not be possible to wait until 2040 before taking action. However, unless Canada's pathway becomes clearer, it will remain difficult for investors to accurately evaluate the costs of the various options and to make the most cost-effective decisions from both short- and long-term perspectives.

Unless Canada's energy pathway becomes clearer, it will remain difficult for investors to accurately evaluate the costs of the various options and to make the most cost-effective decisions from both short- and long-term perspectives.

Figure 9 – Provincial percentages of emissions with respect to 2015 for the FED scenario



Impacts of the reduction scenarios on GHG emissions

Figure 6 presents results for energy-related GHG emissions for Canada obtained for the five selected scenarios. Emissions from agriculture waste and industrial processes are not addressed in this Outlook and not included in the results presented below; fugitive emissions are also excluded from the following discussion.

The policies already in place are barely sufficient to keep emissions roughly constant until 2030, and without additional measures, emissions would even increase by almost 10% from 2030 to 2050. Yet they constitute a significant departure from a similar reference scenario produced in 2016 as part of the TEFP. This reflects not only a change in National Energy Board's projection, but also the addition of several recent federal and provincial policies aimed at reducing GHG emissions.

Further observations are worthy of note:

- The absence of 2050 targets for some provinces (notably Alberta and Saskatchewan) means that provincial targets result in smaller reductions for this time horizon than any federal targets, bringing Canada merely halfway towards the international objective of 80% reduction for developed economies by 2050.

- The three federal reduction scenarios presenting relatively constant emissions suggest that the 2030 targets do not constitute a discontinuity on the path to the 2050 projections.

- The significant discrepancy in 2050 GHG emissions between federal and provincial scenarios suggests that it will likely be politically difficult, from a purely federal perspective, to impose additional reductions to those already planned at the provincial level.

- The difference between FIM and FED is due to the purchase of emission rights on an external market (currently California) for an amount corresponding to 25% of the GHG reduction targets. This requires California to exceed its own reduction target of 40%, to reach 55%.

The cost of reducing emissions

Figure 7 presents the marginal reduction costs under the different scenarios. For PRO, the figure indicates the average marginal cost for each province to reach its respective target. For FIM, FED, and 80P,[4] it shows the Canadian marginal cost (taking into account the GHG reduction targets imposed at the national level).

While these marginal costs may seem high, putting them in perspective suggests the opposite:

- The scenario with the lowest target (PRO) leads to marginal costs that are half those of that with the highest target (FED); this indicates that there is a considerable set of significant actions that can take place between $150/t and $225/t by 2030 and between $375/t and $830/t by 2050.
- The 2050 marginal cost in the most stringent scenario (80P) is significantly lower than that evaluated only a few years ago as part of the TEFP ($ 1400/t) for a less ambitious scenario (-70% from 1990 for 2050, scenario 8a), suggesting that marginal costs associated with deep decarbonization are rapidly decreasing.

Those observations indicate both how rapid technological changes can modify the cost of transition and how Canada could move rapidly to guarantee that it benefits from and contributes to these technological changes.

Emissions at the provincial level

The various scenarios underline the deep divide between provincial and federal targets and objectives. Depending on the scenario, the provinces will be diversely affected by GHG reductions (Figure 8).

As expected, the more stringent targets affect all provinces significantly. A difference remains, however, due to varying marginal costs across the provincial economies, explaining differences among provinces in reductions achieved by 2030 with regard to national targets. By 2050, however, the importance of the targets is such that profound changes must be made to the economy across the country and almost all provincial reductions must be aligned with the national targets.

Reducing the national targets by allowing up to 25% of the emissions to be bought on an international market mainly allows the largest industrial provinces (British Columbia, Alberta, Ontario and Quebec) to retain higher emissions, whereas this has much less impact on Saskatchewan, Manitoba, the Maritimes and Northern Canada.

Buying up to 25% of the national reduction target on an international market allows the largest industrial provinces to retain higher emissions; this requires California to exceed its own reduction target of 40%, to reach 55%.

We can also compare the reduction in each province with respect to the national targets (Figure 9) as an indirect measurement of the relative reduction cost for each economy. For 2030, reductions would take place disproportionally in Saskatchewan and Nova Scotia. For 2050, contrary to expectations based on the provincial targets, British Columbia, Ontario, New Brunswick and Northern Canada would all reduce their emissions by less than the federal target, due to higher reduction costs – higher than in Alberta notably.

Marginal costs associated with deep decarbonization are rapidly decreasing and rapid technological changes can further reduce them; Canada could move rapidly to guarantee that it benefits from and contributes to these technological changes.

Emissions by sector

Emission reductions by sector lead to a number of observations:

- Even in the absence of constraints on GHG emissions (BAU):
  - Emissions from electricity generation are expected to decrease partly

due to the planned closure of coal power plants and also to the falling prices of renewable electricity;

- The industry and energy production sectors will be responsible for most of the growth in GHG emissions – with emissions from the industrial sector doubling between 2015 and 2050, and those from energy production rising by 30%, to represent 50% of all energy-related emissions.

- The most stringent scenarios (FED and 80P) imply an almost fully decarbonised electricity system by 2030, leaving more time for the rest of the economy to decarbonise.
- Although transportation is expected to decrease its emissions slightly by 2030, due to current fuel efficiency standards, this reduction will last only for a decade or so: in the absence of stricter regulations, emissions will rise again by 12% between 2030 and 2050.
- Because of its sheer size, transport must be addressed over the long run. Nevertheless, this sector must start transforming immediately to achieve a reduction of 32% to meet the 2030 federal goal.
- Since provincial targets leave the structure of the energy production sector largely unaffected, including oil sands and electricity generation, the transformation must take place in energy consumption.
- Industry seems to be more difficult to transform as it retains 60% of its current GHG emissions, even in the most stringent scenario (80P).

Even as the cost of energy production and energy consumption technologies falls, the transportation, space heating and industrial sectors require considerable time – and more research – to transform. It is important for these sectors to provide long-term objectives and programs, as well as to support research and industries that will be able to plan their long-term investments in both personnel and technologies.

Integrating provincial transformations into a national movement

A differentiated analysis of the impact of the various scenarios on a provincial level underlines the need to clearly identify transformations that should be implemented, on either a regional or a national level.

In Canada, there are promising avenues for the federal government to facilitate cooperation on challenges that cut across provinces, notably space heating, transportation, and interprovincial electricity demand management.

The significant discrepancy in 2050 GHG emissions between federal and provincial scenarios suggests that it will likely be politically difficult, from a purely federal perspective, to impose additional reductions to those already planned at the provincial level.

Still, there are promising avenues for the federal government to facilitate cooperation on challenges that cut across provinces, notably space heating, transportation, and interprovincial electricity demand management.

As the federal government has jurisdiction over airways, railways and waterways, it has a major role in bringing Canadians and goods towards low-carbon transportation modes. Similarly, although electricity generation is under provincial jurisdiction, the federal government has authority over interprovincial electricity transmission. A national plan to sustain the greening of the electric grid through planning and support of cross-provincial interconnections would go a long way to facilitate the development of a stronger green electricity generation sector on which the rest of the energy transition can rely.

Observations by province

The energy transition will affect each province and territory in unique ways.

British Columbia sees its GHG emissions go up significantly in BAU, by more than 10% by 2030 and even 43% by 2050, mainly due to the growth of its gas sector. As a result, the province would not meet its own reduction target. If the province wants to protect its gas production, with an electricity generation that is already largely decarbonised, it will have to rapidly and aggressively target emissions from space heating and transportation. However, by 2035-2040, it will be impossible for the province to meet national or provincial objectives unless it finds ways to significantly reduce GHG emissions from its gas sector. In fact, marginal costs for PRO are above the national average, suggesting that British Columbia would clearly benefit from a national integration of targets. In terms of energy production, in addition to gas, BAU shows a slight growth in intermittent renewables. GHG reduction scenarios project a significant growth in bioenergy, which could climb by as much as 63%, representing more than 25% of energy consumption by 2050.

Alberta's importance in the oil and gas sector's energy consumption accounts for more than half of final energy consumption. In BAU, its energy-related GHG emissions are planned to remain roughly constant until 2050, at around 200 $MtCO_2e$, representing almost two thirds of Canada's emissions at that point and more if other provinces achieve their own targets. The three scenarios with national objectives (FIM, FED and 80P) propose a very different pathway, with GHG emissions falling by 10% to 30% in 2030, and by as much as 85% in 2050. While this maintains a high per capita emission level, it is in line with the current proposition for Canada's emissions. This can be achieved only through carbon capture, technological transformations – both affecting costs – and/or through a major decrease in production. If scenarios FIM to 80P reflect what will eventually happen across the planet, it is likely that the overall price for fossil fuels will fall, reducing the importance of this sector for Alberta and pushing the province to accelerate its industrial and economic transformation. Should the rest of the world increase its demand, it will be very difficult for Alberta and Canada to meet their emission targets, as pressure to produce will be substantial.

Saskatchewan presents a distinct production profile given the dominant contribution of its uranium resources. It is also an important producer of conventional oil. Both BAU and PRO forecast a 12 $MtCO_2e$ reduction for 2030 with respect to 2015, largely due to the closure of coal plants following federal requirements (about 8-9 $MtCO_2e$). The rest is essentially from the energy production sector, with a 2-5 $MtCO_2e$ reduction. Other sectors remain largely untouched, a situation that remains unchanged for 2050 where both scenarios even predict a slight growth in emissions. By 2050, FIM to 80P scenarios require all sectors to be almost zero emission except for the oil and gas production and agricultural sectors, while the oil and gas and industry is expected to have reduced emissions by 60% to 75% with respect to 2015. The agricultural sector could remain untouched. Like Alberta, Saskatchewan is a province where the difference between its own target and the national target is greatest.

Manitoba's energy production is dominated by hydroelectricity with little oil and gas production, Its energy system is therefore both straightforward and difficult to transform, although the provincial target expresses a willingness to reduce GHG emissions. While BAU indicates a significant growth in primary energy production, this movement is associated with a fairly constant GHG emission level for the next 30 years due to the large proportion of renewable energy. While the PRO target would reduce emissions by 50% by 2050 with respect to 2005, a reduction well short of the national objective of 80%, it would nevertheless force a considerable decarbonization of Manitoba's economy. Scenarios FIM to 80P impose deeper transformations, primarily in space heating and agriculture, in order to leave some fossil fuels for use in the industrial and transport sectors.

Ontario's profile shows a stark discrepancy between primary energy production and consumption, as the overwhelming share of energy consumed in all scenarios comes from outside the province. This is true even in the most aggressive scenarios for 2050, where production from renewables more than doubles. Provincial targets are more demanding than the current 2030 federal goals (FED) and the 80P levels. However, the most aggressive targets will only be achieved at a relatively high cost if they are to be met within the province only: the marginal reduction cost for PRO is $1085/t by 2050, well above the Canadian FED marginal cost of $800/t and on a par with the $1055/t of 80P, which corresponds to the same target. Ontario is the only province that sees its electricity generation decrease for the national reduction scenarios (FIM, FED and 80P) by 2030, as it turns to nearby provinces to import from cheaper sources. However, electricity generation is expected to grow after 2030 as demand rises to compensate for strong reductions in fossil fuels, roughly doubling by 2050.

Quebec's energy production is expected to remain 100% renewable. While in BAU, production growth is slow, dominated by hydroelectricity, GHG reduction scenarios see a notable growth in other renewables, to about 15% by 2030, and rising above 50% by 2050. Even though 47% of Quebec's energy consumption is already decarbonised, Quebec emissions should decrease by slightly more than the national average for both FED and 80P by 2050 (83% and 87%, respectively) suggesting that there is considerable relatively low hanging fruit for Quebec's decarbonization. In addition, some reductions could be achieved at even lower cost through purchases on the California carbon market, reducing the actual local transformations to be made (FIM). As in Ontario, all sectors will have to contribute to reaching the 2030 GHG reduction targets, except for FIM, where most of the reduction comes from purchased credits. However, by 2050, all space heating and most agricultural activities will have to be low-carbon, leaving some emissions only for oil refining, industry and transportation.

New Brunswick's primary energy production is largely dominated by renewable sources. In all scenarios, however, these are insufficient to support demand even though GHG reductions scenarios suggest a production dominated by wind and solar. Between 2005 and 2016, New Brunswick reduced its emissions by 24% (5% with respect to 1990). In the absence of strong new programs, however, BAU sees a slight increase in GHG emissions over time, mainly linked to industrial energy demand. In 2030, compared to PRO, GHG emission reductions are more significant under the federal reduction regime, as even scenario FIM projects a 1 MtCO_2e additional reduction in comparison to PRO. This gap narrows considerably for 2050, as New Brunswick's targets are in line with FED and 80P. While electricity should be the first sector to decarbonise in all scenarios, agriculture and space heating follow closely, as in most other provinces, with transport taking more time to transform significantly. The PRO scenario leads to relatively low marginal costs for GHG reductions of $36/t in 2030 and $650/t in 2050, well below national levels in FED, suggesting that it should be relatively easy for New Brunswick to work under a national reduction objective without affecting its conventional oil production.

Nova Scotia is one of the only provinces to see its reference emissions (BAU) fall off significantly over the next few years, more than halving between now and 2030, with its coal plants due to be shut down or at least used more sparingly. The province is therefore well ahead of its own plan and should be very close to the national target (FED) in 2030. However, unless new measures are put in place no further gains are planned for the province. As a result, longer-term emissions should remain far above the most demanding 2050 targets, which would require total emissions of about 1.5 MtCO_2e under the federal targets, about 6 MtCO_2e below BAU and 2.4 MtCO_2e below provincial targets (PRO). Similarly to New Brunswick, the province's 2050 targets are relatively close to the federal targets and yet their marginal costs in the PRO scenario are at $244/t, well below the expected national average marginal reduction cost. This suggests that Nova Scotia relies on a number of reduction options that are particularly advantageous.

Prince Edward Island has adopted a very ambitious plan to decarbonise its economy, with already decarbonised electricity generation, supported in part it must be said, by the coal and nuclear electricity of its neighbours. This allows the province's BAU scenario to show an almost constant reduction in GHG emissions until 2050. Moreover, the absence of a long-term target results in full agreement between PRO and BAU for 2050. This level is considerably higher than the federal goal for 2050, meaning that further efforts will need to be made to meet the federal GHG reduction objectives. With little industrial activity, the energy transition will primarily affect space heating and transport. These will largely be reduced in equal proportion by 2030 with a total elimination of fossil fuels by 2050 for the most demanding scenarios.

Newfoundland and Labrador is a major energy producer, exporting massively both oil and hydroelectricity. Over the next decades, with electricity from Muskrat Falls becoming available and oil and gas production falling, all scenarios project that an increasing share of energy production will move to renewables, leading to a notable decrease in GHG emissions for 2030, from 22% in BAU to 30%-34% in the three others. For BAU and PRO, the decrease in oil production accounts for almost half of the GHG reductions. By 2050, all scenarios roughly agree: the only significant sources of GHG emissions should be transport and industry, the rest being electrified. Transport is most sensitive to the reduction goals imposed, and projected emissions vary by a factor of five between 80P and BAU. Yet this effort is far from impossible: for comparable targets in the PRO scenario and in line with FED targets, NATEM computes a marginal reduction cost of $708/t by 2050, very similar to Quebec's $624/t.

Northern Canada, which includes the Northwest Territories, Nunavut, and the Yukon, is highly dependent on fossil fuels for all its activities. Without very aggressive targets, its BAU scenario is similar to PRO with real emissions largely dependent on mining and other resource exploitation projects that will be implemented over the coming decade. Following national targets will require a significant restructuring of energy production. To reach the 2050 FIM to 80P objectives, significant efforts will have to be made, particularly in the electricity generation, transportation and industrial sectors. Estimated costs for energy production suggest that this transformation could be beneficial. In reality, the territories could become major low-carbon energy producers and exporters as early as 2030, particularly in the most aggressive scenarios, with production climbing from about 3 PJ in 2015 to 292 PJ in 2030 and even to 425 PJ in 2050 for FED and 80P, comparable to today's energy requirements for the Atlantic provinces.

The challenges of reducing emissions in the transport sector

The transformation of the transport sector, which is key to reaching the various GHG reduction targets, is complex as it affects everyone in society. This explains why this sector remains the most change resistant the world over.

It is possible to envisage passenger transportation in 2050 as very similar to that of today, except for the dominance of zero-emission vehicles.

BAU and the four GHG reduction scenarios assume demand for passenger and freight transportation will continue to grow at current rates. By 2050, demand is expected to increase by 26% for passenger transportation, and more than double for freight transportation. In spite of this growth:

- Total energy consumption will fall for all passenger transportation scenarios and remain relatively steady or even fall slightly for freight transportation in most scenarios, due mainly to systemic energy efficiency gains linked to fuel consumption standards and, more importantly, electrification;

- The NATEM model manages to find realistic solutions in the transportation sector even for the most aggressive GHG targets; respecting federal targets (FED), for example, requires more than half the kilometers travelled by passengers in 2050 to be with clean energy and internal combustion engines to be almost banned by 2050, barely 30 years from now; the transformation may be even more profound in the freight sector, where only 20% of the energy would be allowed to be from fossil fuels by 2050 to respect provincial or federal targets.

The transformation of the freight sector will require a strong and directed approach from governments in order to support new technologies and infrastructure. Because such infrastructure needs standards, planning and investments, rapid action is required.

Even though these scenarios might appear challenging, they are in line with the decision by a number of countries, including China, France and the United Kingdom, to ban new sales of ICE vehicles by 2040. It is therefore possible to envisage passenger transportation in 2050 as very similar to that today, except for the dominance of zero-emission vehicles.

The transformation of the freight sector will require a strong and directed approach from governments in order to support new technologies, some of which could necessitate important new heavy infrastructure, such as catenary lines on highways or railway electrification. Because such infrastructure needs standards, planning and considerable investments, rapid action is required.

A transport-based alternative reduced-demand scenario

With the rapid progress of autonomous vehicles, it is becoming easier to contemplate the optimization of the car and truck fleet and usage with, for example, the increase used of information technology for car sharing and the advent of autonomous vehicles, which can facilitate access to rapid, frequent and high-quality public transport that can collect passengers from larger regions even in low-density areas and optimize freight transportation.

For lack of a clear picture of which technologies will dominate, we consider a scenario where their main effect is to strongly curtail the effective growth of transportation services:

- a flat growth curve for passenger transportation to simulate increased car-sharing leading to a smaller number of vehicles and a significant move in urban areas toward active or public transportation modes;

- a growth reduced by two thirds for freight that would result from both better management and a slowdown in goods consumption.

We combine these changes and analyze results for low-demand variants of the BAU and 80P scenarios (respectively named BAU-Low and 80P-Low).

In passenger transportation, the difference in energy demand between the current trend and the low-demand growth variants is mainly associated with a reduction in the use of fossil fuels in 2030. By 2050, in the BAU-Low case, the reduction in demand will proportionally affect all energy sources, reducing fossil fuels slightly more (-23 %) than renewables (-15 %), while for 80P-Low, bioenergy remains almost untouched as demand for electricity decreases by almost 40%.

A similar picture emerges for freight transportation. Between now and 2030, for the BAU-Low scenario, the reduction in demand primarily leads to a reduction in the use of natural gas, while for 80P-Low, the share of electricity falls more quickly. The same trend is observed for 2050: demand for natural gas is expected to be 40% lower in BAU-Low than in BAU, and 35% lower in 80P-Low than in 80P, a reduction similar to that of electricity in this case, with biofuel demand reduced by only 20%.

Reduced transportation demand largely helps to diminish the cost of meeting GHG reduction targets, but focusing solely on demand reduction might not be the most effective approach.

For BAU-Low, because of the absence of constraints, reduced demand leads only to proportional GHG emission reductions in the transportation sector for both 2030 and 2050, with only minor adjustments in the other sectors. For the 80P scenario, which is constrained by GHG emissions, we see very little transfer of the potential GHG gains to other sectors; the reduction in demand serves primarily to reduce investments in the transportation sector, leaving GHG emissions untouched both by 2030 and by 2050. Reducing demand does not therefore lead to reduced GHG emissions in this scenario, but instead affects the marginal costs of reduction, which falls from $1055/t to $920/t in 2050 with reduced demand for transportation. While this difference is notable, it represents a 13% reduction in marginal cost, a difference that could also be easily overcome by technological improvements.

Thus, overall, when no limits on GHG emissions are imposed, a reduced demand decreases them proportionally. However, when strict limits on GHG emissions are imposed, the reduced demand largely helps to diminish the cost of meeting these targets, without affecting global emissions. Focusing solely on demand might therefore not be the most effective approach to attain ambitious GHG targets.

Towards the GHG targets: the energy challenge

The various energy pathways analyzed in this Outlook suggest that, while the goals set by the various governments are more attainable than ever, they involve profound and intensive transformations that will affect all Canadians.

Two interrelated external factors could contribute to accelerating the transition and reducing its cost, as is already evidenced by the reference scenario:

- The slowdown in the growth of energy demand across almost all sectors of the economy, even with a growing population and economy.
- A general tendency to increase the role of electricity in the life of Canadians.

Yet significant barriers could impede the transition:

- The weight of the oil and gas industry. Even though most of this production is targeted for export, GHG emissions associated with extraction and transport disproportionately affect Canada's goals. However, as Canada contributes to developing and adopting low-carbon emission technologies, the reduction of the oil and gas sector appears more achievable.
- Incompatibility of targets. There is considerable incompatibility between the provincial and federal targets, which can lead to tensions between the various levels of government and confusion in the industry and among citizens and investors.
- Political uncertainties. Even though the science cannot be contested, GHG reduction efforts across Canada remain highly dependent on short-term electoral transitions, at both provincial and federal levels, and on US politics. In most provinces, climate change issues remain politicized to a level that is not seen in most developed economies. The deep divide between provincial and federal targets and objectives is likely to create tension and increase the costs of transforming the Canadian economy.

Acting now

Climate change remains a fact, whether or not it is accepted by all politicians and citizens. As many countries are integrating this reality much more significantly than Canada, they are gaining economic advantages for both today and tomorrows' economy and adapting to changes, decreasing the need for costly reengineering in the decades to come.

While this Outlook shows that the GHG reduction targets are attainable, neither the provinces nor the federal government are on track to deliver them.

At the moment, very little is offered in terms of short-term advantages for citizens to support the energy transition. Yet experiences in Germany, the United Kingdom and Sweden show that in order to garner cross-party support, it is essential for the energy transition to demonstrate clear and concrete advantages to a large segment of society. However, achieving such a consensus requires Canadians to move beyond discussions on carbon pricing and pipelines, and directly address the transformative potential of the energy transition, a potential with benefits that go beyond the sole impact on the energy sector. Correctly implemented, this transition can be leveraged to ensure a better quality of life, including better jobs, better health and a better environment.

Canadians must directly address the transformative potential of the energy transition, a potential with benefits that go beyond the sole impact on the energy sector.

It is time to initiate more positive discussions on this transition and identify the pathway Canadians want to take for this crucial journey.