Shifting Power

Zero-Emissions Electricity Across Canada by 2035

May 2022

Clean Power PATHWAYS

DAVID SUZUKI FOUNDATION

Shifting Power: Zero-Emissions Electricity Across Canada by 2035

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This report is the product of more than four years of work and represents the ideas, contributions and collaborations of dozens of people who've been generous with their time, imagination and knowledge.

The David Suzuki Foundation would like to thank the Clean Power Pathways expert advisory committee for their insights, feedback and support throughout this project. Current and former members include: Patricia Lightburn, Binnu Jeyakumar, Patrick Bateman, Travis Lusney, Dan Woynillowicz, Robert Hornung, Shakti Ramkumar, Meredith Alder, Jean-Francois Nolet and Natalie Irwin.

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The electricity system modelling work was completed by an independent team of academic researchers from the Sustainable Energy Systems Integration & Transitions (SESIT) group at the University of Victoria's Institute for Integrated Energy Systems. Led by Madeleine McPherson, the SESIT modelling team members who contributed to the Clean Power Pathways database development and modelling include Reza Arjmand, Mohammad Miri, Mohammadali Saffari, Rick Hendriks, Madeleine Seatle, Robert Xu and Lauren Stanislaw. This modelling collaboration was enabled in part by a Mitacs partnership, project IT14846. Demand-side modelling was conducted by Dave Sawyer of EnviroEconomics and Navius Research. Bradford Griffin undertook post-processing of model outputs to report out on financial indicators for the scenarios. The David Suzuki Foundation is solely responsible for defining the pathways to be modelled, for the integration of insights from different research teams and for drawing conclusions.

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EXECUTIVE SUMMARY

> Recent years have seen many positive developments, indicating that the global energy transition is well under-way. Renewable power capacity additions and energy transition investments have reached new heights, while costs have continued to come down. Energy efficiency investments have increased, and energy intensity has improved. End-use electrification, especially through the sale of electric vehicles, has accelerated... despite these positive developments, the pace of change is still not enough.
>
> — *International Renewable Energy Agency*[1]

It's impossible to imagine modern life without electricity. It lights and heats our homes, powers our factories and allows us to communicate. In the face of a climate emergency, people living in Canada overwhelmingly support a fast transition to an efficient, zero-emissions electricity system.[2] However, we don't always agree on where to focus our efforts or which pathways to a clean grid will be most reliable, affordable and desirable. To advance electricity decarbonization, the federal government has announced a Clean Electricity Standard will be developed that will require net-zero emissions in the electricity sector by 2035.[3]

Now is the time to accelerate climate solutions, begin a managed decline of all fossil fuels and ensure that no one is left behind in this transition. One key climate solution will be the shift to clean electricity. As one of the Intergovernmental Panel on Climate Change's recent reports states, "Any further delay in concerted anticipatory global action on adaptation and mitigation will miss a brief and rapidly closing window of opportunity to secure a liveable and sustainable future for all."[4] It is from this place of urgency that this report explores the role that deploying renewables and using clean electricity can play in helping zero out Canada's emissions and in meeting the Paris Agreement's ambition of staying below 1.5 C of warming. The report demonstrates how reliable, affordable, zero-emissions electricity by 2035 in Canada is possible and how the demand for electricity can be met even as the economy grows and further electrifies out to 2050.

This is the first report of its kind in Canada. Through electricity system modelling, it explores the potential for a transition to clean electricity by focusing investment in grid-connected renewables, energy storage and transmission. No other Canadian modelling study has explored pathways that meet 100 per cent zero-emissions electricity by 2035 by prioritizing wind, solar, energy storage and interprovincial transmission, while also accounting for the aggressive electrification of other sectors. Each of the two scenarios presented in this report reach 100 per cent zero-emissions electricity by 2035. The "Zero" scenario uses baseline load growth published from utility forecasts across Canada, while the "Zero Plus" scenario explores greater levels of electrification in buildings, transportation and industrial sectors, as well as giving greater priority to energy efficiency and building retrofit options.

Uniquely, our report on the Canadian electricity system combines these elements:

- Pathways that achieve zero emissions in the electricity sector in 2035 and maintain zero emissions through 2050 while electricity demand increases with economic growth and more electrification.
- Pathways to zero emissions by 2035 in the electricity sector that do not rely on carbon capture technologies, carbon offsets or negative emissions technologies to achieve "net-zero" emissions.
- Pathways that rely primarily on wind and solar for new generation while expanding interprovincial transmission and energy storage.
- Pathways that do not require any new large hydroelectricity or new nuclear generation, including small modular nuclear reactors, and that phase out all fossil fuel generation by 2035, avoiding the need for expensive and immature carbon capture and storage technologies in the electricity sector.
- A deep electrification pathway with ambitious levels of electrification to replace fossil fuels in transportation, buildings and industry that delivers emissions reductions and improved energy efficiency. Additional energy efficiency is achieved through deep retrofits and other measures.
- Pathways that are modelled by an independent team of academic researchers using purpose-built models that combine high spatial and temporal resolution and account for how wind and solar resources vary across the country and through each hour of the year.

At a time when energy security and affordability are top of mind for many Canadians, this report shows that a clean electricity pathway based on renewables offers an affordable option for ambitiously reducing emissions while meeting increasing electricity demand. It demonstrates that a zero-emissions electricity system with very high penetrations of variable renewable energy generation supported by existing hydroelectric reservoirs, interregional transmission and energy storage can work reliably across Canada by 2035 and beyond. The results challenge those who claim that renewables can't play a leading role in the clean electricity transition. The sun may not always shine and the wind may not always blow, but the combination of solutions that are modelled in this report shows how a grid largely powered by renewables can deliver clean electricity reliably where and when it is needed throughout the country.

Several aspects of Canada's existing advantages, recent technology and economic improvements and emerging opportunities have combined to make the scenarios presented in this report reliable, affordable and possible for the Canadian electricity system's pathway to zero emissions by 2035:

- **Wind and solar are proven technologies.** In 2020, the International Energy Agency declared wind and solar the cheapest sources of new electricity generation in history,[5] and their cost continues to drop.[6]
- **High levels of variable renewable energy production** are possible in Canada, thanks in part to Canada's extensive capacity of existing hydroelectric generation.
- Investments in **interprovincial transmission** can help add reliability and flexibility within and between grids with high shares of variable renewable electricity.
- Additional possibilities for deployment of wind and solar can be unlocked by investments in rapidly **improving energy storage technologies**.[7]
- Further **investments in energy efficiency** reduce the overall need for energy and the cost of Canada's future electricity system.
- Consumers and businesses also benefit from the efficiency gains that come when **clean electricity replaces fossil fuels**, such as when a natural gas furnace is replaced with a high-efficiency electric heat pump.
- Canada has a **good foundation to build on**, with favourable wind and solar resources,[8] a mature renewable electricity industry and momentum toward an emissions-free electricity system.

While our report is intended to show that a focus on renewables is possible, the underlying analysis was necessarily cautious. The modelling did not consider a range of additional technologies and approaches, such as demand response, distributed renewables and emerging storage technologies that are likely to lead to increased efficiencies and further reductions in costs when moving to a zero-emissions electricity system.

In each of the two pathways presented in this report, it will take an unprecedented effort to transform and improve Canada's electricity system and decarbonize other parts of the economy. This is consistent with other modelling efforts in Canada, even among those that do not meet net-zero emissions targets, or among those that employ significant amounts of non-renewable resources. In nearly all recently modelled scenarios for reducing the carbon intensity of the Canadian electricity system and expanding supply, wind and solar play an unprecedented role.[9] Planning, consultations and investments are essential to renewable generation at the scale and speed needed to respond to the climate emergency.

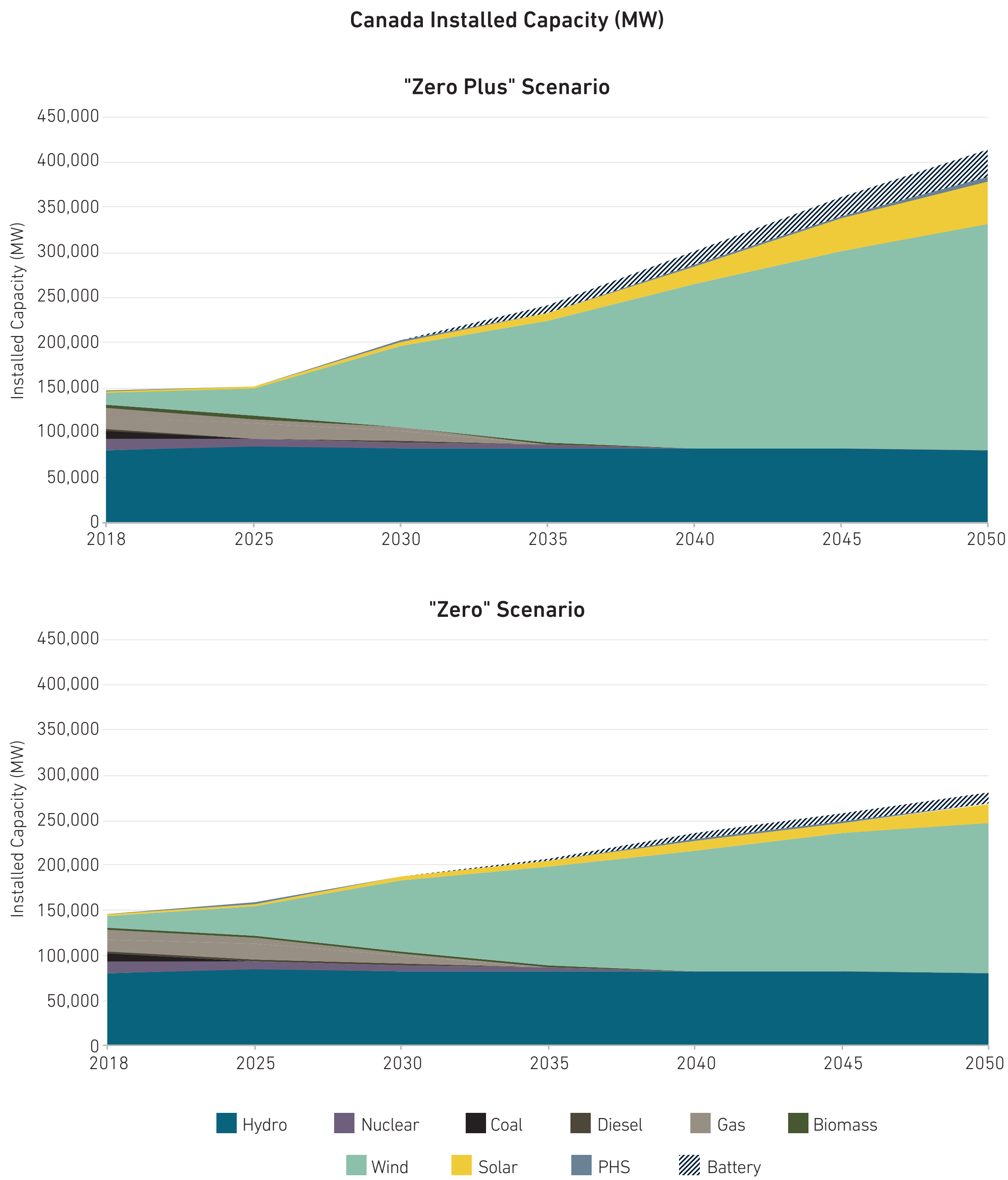

Figure ES-1: Electricity capacity expansion of the Clean Power Pathways scenarios

According to the Canadian Renewable Energy Association, the most wind and solar energy capacity built in Canada over a five-year period was 9,200 MW between 2011 and 2015.[10] In the most ambitious pathway presented here, every five years on average, more than 50,000 MW of new wind and solar will need to be built — quintupling the previous record.

The amount of wind and solar electricity in Canada would increase more than 18-fold by 2050 to meet our high electrification, zero-emission scenario. This pathway would require an average annual build-out of wind and solar electricity projects never before seen in Canada: An average of more than 2,200 new four-MW wind turbines would be installed every year and more than 160 new 10-MW solar farms would be built each year. Interprovincial transmission will also need to expand at an unprecedented rate. Although the scale of this transformation is daunting, with real challenges that need to be overcome, it is possible to deploy these technologies at this pace and scale. The most ambitious scenario in this report requires about 250,000 MW of new wind electricity by 2050. Examples around the globe show this is possible. Across the U.S., 44,000 MW of solar and 27,000 MW of wind generation are expected to be added to the grid in 2022.[11] Similarly, as of December 2021, more than 930,000 MW of wind and solar capacity and 427,000 MW of storage capacity were at various stages of application, review and development processes for connection to the grid in the United States.[12] Before Russia's invasion of Ukraine, the IEA projected that the EU would add 300,000 MW of renewable electricity between 2021 and 2026.[13] Since this aggression, the EU has announced an even more ambitious plan to accelerate the shift to renewables.[14] The case of Germany is instructive. By early 2022, with only 1/15 the surface area of Canada's provinces, Germany had installed 28,000 onshore wind turbines, reaching a total wind capacity of about 56 GW. By 2025, the country expects to be adding 10 GW of wind annually — an equivalent rate of deployment to what the scenarios evaluated in this report suggest.[15]

Making this transition to clean electricity through renewables would have significant climate and employment benefits. The boldest pathway presented in this report would save more than three billion tonnes of greenhouse gas emissions between now and 2050, leading to more than 200 million tonnes of annual emissions reductions. These savings are the result of a clean electricity system underpinning emissions saved by switching energy needs from fossil fuels to electricity in the transportation, buildings and industrial sectors.

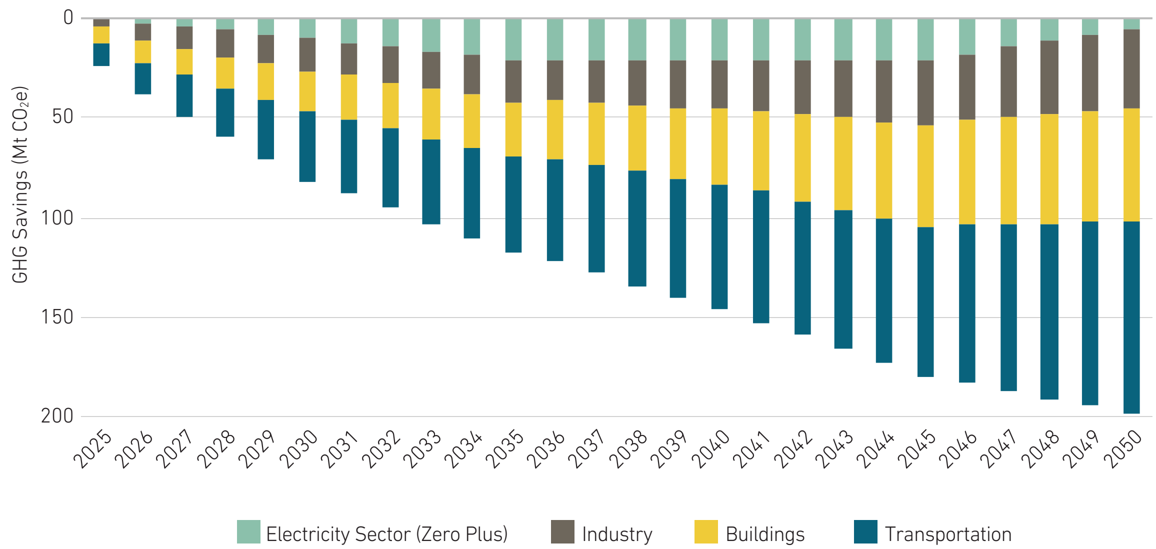

Figure ES-2: Total GHG savings from clean electricity and electrification by sector (Annual Mt CO_2e)

There would be more than 1.5 million person-years of direct employment resulting from the construction, operation and maintenance of new wind, solar and transmission lines alone between 2025 and 2050, growing to support over 75,000 full-time jobs each year. This estimate of labour requirements does not include the additional jobs that could be created if wind turbines and solar panels were manufactured in Canada, nor the induced jobs supported by the broader electricity sector. If the renewables industry had high levels of confidence that wind, solar and storage were going to be built out at the scale envisioned in these pathways, it is likely that more companies would find it worthwhile to locate some of their manufacturing in Canada.

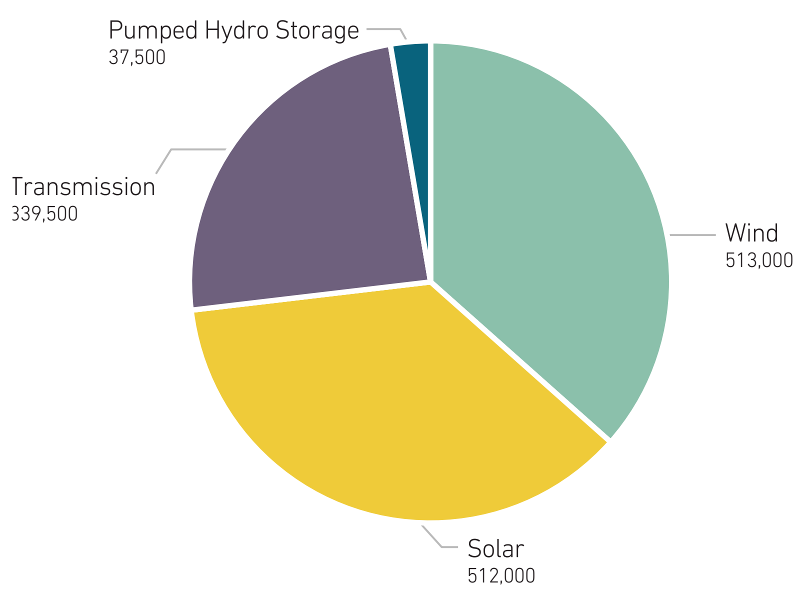

Figure ES-3: Total labour requirement (FTE-years) for construction, operation and maintenance for the Zero Plus scenario 2025-2050

Regardless of the pathway chosen, all existing and future energy projects in Canada are located on either unceded Indigenous territories or treaty lands. Mindful of this reality, the David Suzuki Foundation commissioned Neegan Burnside and Dean Jacobs to gather Indigenous perspectives on the transition to clean energy. The important perspectives and insights they collated are described in a companion report titled "Decarbonizing Electricity and Decolonizing Power: Voices, Insights and Priorities from Indigenous Clean Energy Leaders".[16] Drawing on these conversations and other research, Neegan Burnside and Dean Jacobs set out six principles for upholding Indigenous rights and ensuring community benefits during the transition to emissions-free electricity. We incorporate these principles as an integral part of this report's recommendations.

Achieving zero-emissions electricity across Canada by 2035 will require all levels of government to play a role. Our study, like others, shows that increased investments in interprovincial transmission facilitate adding high levels of wind and solar generation to the grid. Provincial governments and their utilities must cooperate and invest in the infrastructure to enable clean electrons to flow across provincial borders. Beyond putting in place a stringent Clean Electricity Standard, the federal government must facilitate provincial collaboration and support investments to strengthen east-west interconnections.

Our report offers a unique perspective on what is possible in Canada's electricity future and the broader work of meeting ambitious climate goals without turning to nuclear or fossil generation with CCUS. Ultimately, we hope that this report contributes to the conversation in Canada for how we can best meet ambitious clean electricity goals. Our collective efforts must rise to meet this moment — through presenting ideas, speaking with communities and developing and revising clean electricity pathways.

KEY FINDINGS

1. Expanding wind and solar electricity should be the foundation to achieving **100 per cent zero-emissions electricity across Canada by 2035** and meeting growing electricity demand to 2050.

2. Energy efficiency, energy storage, existing hydroelectricity and grid connections between provinces work together to deliver **reliability and flexibility** for pathways with high levels of wind and solar generation.

3. Pathways that rely primarily on renewables like wind and solar are an **affordable** way to meet climate targets and the growing demand for electricity. These pathways have comparable, or even lower average costs of electricity when compared to business-as-usual pathways.

4. The labour requirement for this transition is significant. Our scenarios lead to high numbers of new careers in clean energy throughout Canada. Construction, operation and maintenance alone will grow to more than 75,000 jobs annually, resulting in **more than 1.5 million job-years between 2025 and 2050**.

5. By cleaning up the electricity sector and switching out fossil fuels for clean electricity, these pathways support more than 200 Mt CO_2e of annual emissions reductions by 2050, amounting to more than 27 per cent of the total reductions needed to achieve Canada's net-zero goals and totaling **3,200 million tonnes of CO_2e savings from 2025 to 2050**.

6. Indigenous clean energy thought leaders that we heard from emphasize that **decarbonizing electricity requires decolonizing power** and ensuring benefits flow to communities. Since all renewable energy projects and infrastructure take place on either unceded Indigenous territories or treaty lands, this transition will only succeed with full Indigenous consent and participation that upholds Indigenous rights and title.

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INTRODUCTION

> The science is clear. To keep the 1.5-degree limit within reach, we need to cut global emissions by 45 percent this decade... First and foremost, we must triple the speed of the shift to renewable energy. That means moving investments and subsidies from fossil fuels to renewables, now.
>
> — *António Guterres, United Nations secretary general*[17]

The series of IPCC reports released in 2021 and 2022 make it increasingly clear that Canada and the world must lower our greenhouse gas emissions dramatically, and quickly, to avoid the worst of the climate crisis.

Transitioning to clean electricity is one important climate solution. Canada is starting from a good position because its largely hydro-dominant energy grid is already relatively clean.[18] Zero-emitting nuclear in Ontario and New Brunswick, despite considerable environmental challenges with disposal of radioactive wastes and decommissioning plants at their end of life,[19] adds to the existing non-emitting electricity inventory. However, the real challenge lies ahead, as we decarbonize the existing electricity system and make sure that all new capacity added to the system is non-emitting as we aim to more than double the total electricity generating capacity by 2050.

By transitioning our homes, vehicles and businesses off of fossil fuels and on to clean electricity, communities benefit from better air quality, better health outcomes, more comfortable homes and lower overall energy costs. In addition to focused energy-efficiency measures, there is a significant inherent efficiency in switching from burning fossil fuels to use of clean electricity. It takes less energy to power an electric vehicle than a gasoline-powered one, and electric heat pumps are dramatically more efficient than furnaces that burn fossil fuels like gas or oil.

The pace of change in Canada's electricity sector is accelerating and requires unprecedented changes to the way we deliver electricity to Canadians. Just two years ago, some provinces were planning to continue burning coal beyond 2040. Now, all provinces have committed to a 2030 coal phase-out for the electricity sector. While falling prices for solar and wind suggest renewables will play a growing role in supplying electrons to the grid, these trends and current policies are insufficient to secure the needed transition.[20] Indeed, a recent proposal would have added so much unabated gas generation to Ontario's grid as to make the province's emissions in the electricity sector grow 375 per cent from 2017 to 2030,[21] undermining the climate benefits that electrification would offer within the province.

In late 2021, the federal government set the stage for rapid, large-scale transformation in the electricity sector by committing to a Clean Electricity Standard that achieves a 100 per cent net-zero emissions electricity system by 2035.[22] This 2035 goal aligns with policies and goals already in place in the European Union, United Kingdom and United States, and is consistent with a key benchmark outlined in the landmark report released by the IEA in May 2021, "Net Zero by 2050: A Roadmap for the Global Energy Sector."

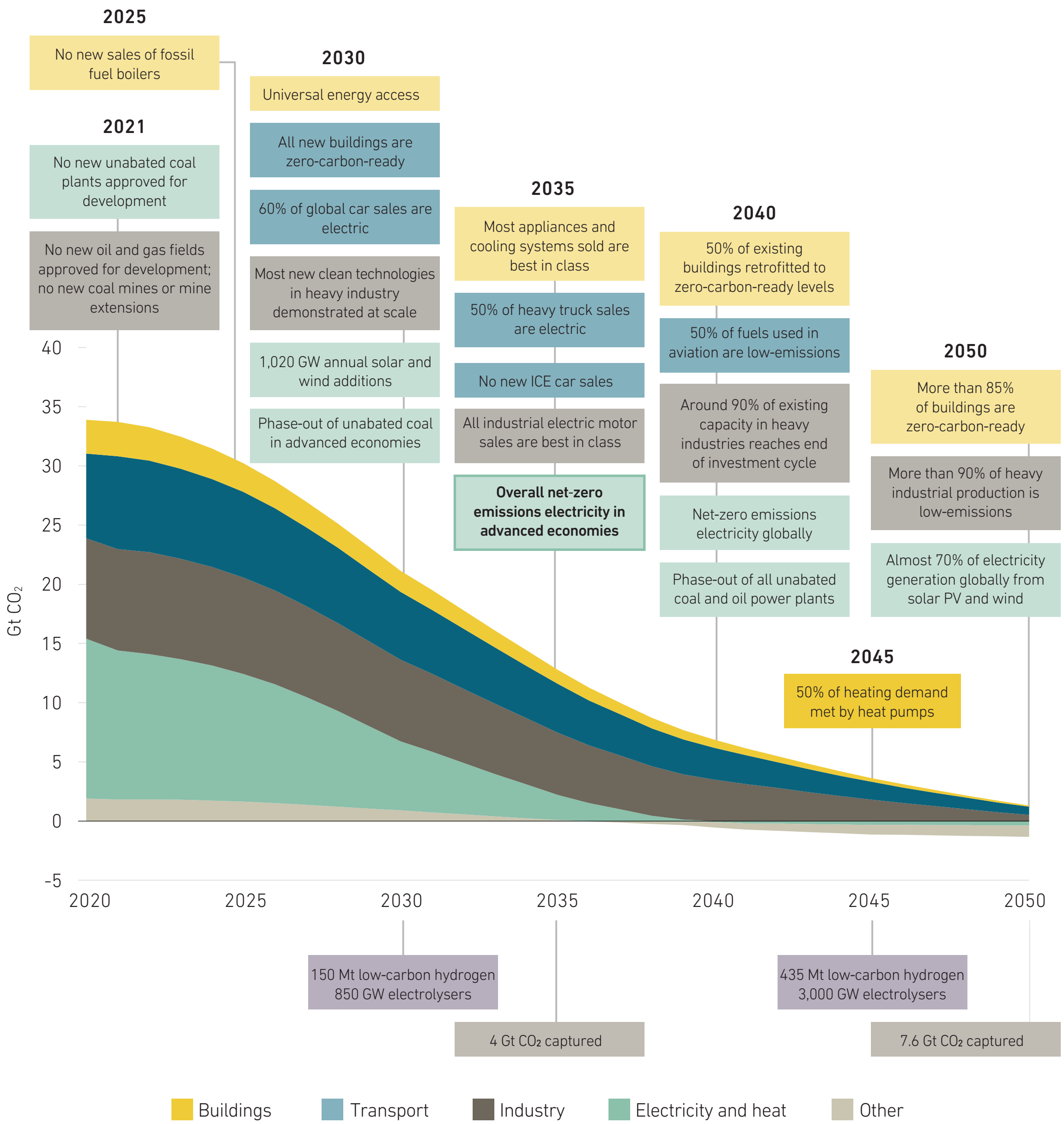


Figure 1: Emissions reduction pathway from the IEA's "Net Zero by 2050: A Roadmap for the Global Energy Sector", May 2021[23]

Meeting this challenge, and aiming beyond 'net-zero" and toward a truly zero-emissions electricity system by 2035 in Canada was central to our thinking in how we developed the Clean Power Pathways modelling scenarios.

To guide the modelling work and policy questions within this report, and with engagement and collaboration from key energy stakeholders, we sought to answer the question: ***Can we meet these ambitious targets while powering Canada's electricity system primarily with renewables?*** We collaborated with energy modellers to find out if achieving 100 per cent zero-emissions electricity across Canada by 2035 is possible by expanding wind, solar, energy storage and transmission. We sought to better understand whether the pathways allowed for maintaining clean electricity to 2050 as electricity demand increases dramatically and other sectors of the economy electrify.[24]

Our study is able to explore how interprovincial and interregional transmission connections can help balance high amounts of wind, solar and existing hydroelectricity to meet the real-time electricity needs of regions throughout Canada. We do this in ways that other modelling efforts in Canada are not able to do.

To model these scenarios, we partnered with the Sustainable Energy Systems Integration and Transition (SESIT) group at the University of Victoria, led by prof. Madeleine McPherson. Their suite of energy models is purpose-built to explore clean electricity pathways with high levels of variable renewable energy. These researchers have published a growing number of academic papers that describe the SESIT models and their application to a range of research questions.[25] During a three-year partnership between DSF and the SESIT modelling team, we worked through an iterative process of defining, reviewing and revising modelling inputs and scenarios to ensure the resulting pathways were feasible while achieving our climate targets and environmental objectives. These scenarios benefited from feedback over many months from the modelling team, dozens of energy stakeholders and the Clean Power Pathways expert advisory committee. Ultimately though, the David Suzuki Foundation's team is responsible for defining scenario inputs and constraints. For instance, though a small number of energy stakeholders in our survey believed small modular nuclear reactors should be included as an option for adding future capacity, we did not include them as a permissible technology because they have yet to be proven, are projected to be much more costly than renewables and, due to the generation of radioactive wastes and proliferation risks,[26] they did not fit our understanding of clean. To complete the demand-side energy modelling, and to develop detailed hourly load profiles for our high electrification scenario, we worked with Dave Sawyer of EnviroEconomics, and Navius Research.

In addition to the energy modelling efforts, we analyzed and compared the scenarios to explore if these pathways are affordable and if they could play a role in creating good jobs in Canada.

We also worked with Neegan Burnside and Dean Jacobs of Walpole Island First Nation to interview Indigenous clean energy leaders to ask whether these pathways could be consistent with respecting Indigenous rights and title, while creating community benefits and minimizing impacts.

All modelling has limitations. Our modelling depends on assumptions about the future that embody implicit and extensive uncertainty, and our work cannot consider the full range of constraints that will ultimately be important to this transition. These modelling efforts are by no means meant to be predictive, but rather allow us to explore potential future scenarios, identify fruitful pathways and avoid unnecessary impacts and dead ends. This work is part of the broader energy transition discussion, not a final word on how we achieve these targets.

Photo : Adobe Stock Images

ABOUT THE CLEAN POWER PATHWAYS PROJECT

Clean Power Pathways has been a multi-year partnership between the David Suzuki Foundation and academic modellers at the University of Victoria that began in 2018. Our collaboration has been aimed at increasing the capacity in Canada for energy modelling and to harness modelling to help support Canada's goals toward ambitious emissions reductions.

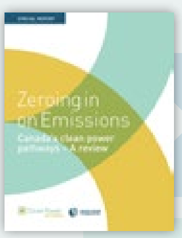
Although this report presents the final results of the Clean Power Pathways modelling work, our collaboration has authored four papers to date, which have each helped to lay the foundation and steer the direction of the modelling work presented in this report.

You can find more information about the Clean Power Pathways projects and read our previous reports at https://davidsuzuki.org/project/clean-power-pathways/.

The Clean Power Pathways team has been fortunate to receive strategic advice from leaders in Canada's clean energy sector.

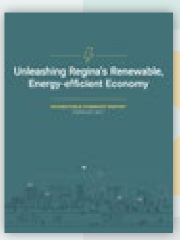
Our expert advisory committee began in 2019 and has included representation from Efficiency Canada, Waterpower Canada, the Canadian Renewable Energy Association, Pembina Institute, the Ecology Action Centre, Student Energy, Clean Energy Canada, Polaris Strategy, Dunsky Energy + Climate Advisors, and Power Advisory LLC.

We are grateful for the continued support, advice and feedback received from the advisory committee and others, but their engagement in this project does not indicate that they endorse the scenarios or findings presented here. The scenarios, analysis and recommendations included in this report are the sole responsibility of the authors and the David Suzuki Foundation. The modelling was conducted by SESIT on the Foundation's behalf and we greatly appreciate the patience of our collaborators during the learning process entailed in such an ambitious project.



Review of global and Canadian decarbonization models and studies, highlighting 10 technically feasible strategies and actions to achieve zero emissions in Canada by 2050. **Report:** ***Zeroing in on Emissions: Canada's Clean Power Pathways*** ***(June 2019)***

Insights on clean electricity options form more than 150 energy stakeholders in Canada, and views on national polls and focus groups on the low-carbon transition. **Report:** ***Talking Transition: Canada's Clean Power Pathways*** ***(Sept 2020)***



Insights from more than 35 local leaders in Regina, Saskatchewan, to support the city's move to 100 per cent renewable energy at the municipal level. **Report:** ***Unleashing Regina's Renewable, Energy-efficiency Economy*** ***(Feb 2021)***

A discussion paper on the policy options for Canada to implement a Clean Electricity Standard in order to achieve 100% clean electricity across Canada by 2035 or sooner. **Report:** ***Policy Options for a Clean Electricity Standard in Canada*** ***(Aug 2021)***

Photo: Adobe Stock Images

MODELLING SCENARIOS: CANADA'S CLEAN POWER PATHWAYS

> To me, hope is not something that is given to you, it is something you have to earn, to create. It cannot be gained passively, through standing by and waiting for someone else to do something. Hope is taking action. It is stepping outside your comfort zone. And if a bunch of weird schoolkids were able to get millions of people to start changing their lives, just imagine what we could all do together if we really tried.
>
> *— Greta Thunberg*[27]

Two modelling scenarios that were strengthened through stakeholder input are explored. Both achieve zero-emissions across all electricity generation by the year 2035 and maintain zero-emissions as the electricity sector expands to accommodate growth from electrification and other factors through to the end of the study period in 2050. Both are compared to a business-as-usual (BAU) policy scenario.

There are different levels of electrification and load growth assumed in each scenario. The "Zero" scenario uses baseline load growth published from utility forecasts across Canada. The "Zero Plus" scenario uses modelling by Dave Sawyer and Navius Research to explore greater levels of electrification in buildings, transportation and industrial sectors, as well as giving greater priority to energy efficiency and building retrofit options. Together, these two scenarios are referred to as the "Clean Power Pathways scenarios" or simply "our scenarios" throughout this report.

These scenarios explore pathways that prioritize variable renewable energy expansion and integration and reliable power system operations to meet decarbonization goals. The scenarios also explore the role that expanded transmission connections between provincial electricity grids can play in supporting renewable integration and fossil fuel generation phase-out; the electrification of high-emitting sectors such as transportation and buildings; the role of energy storage, building retrofits and energy efficiency; and the implications of policies including carbon pricing and emissions regulations.

While we recognize that there are scenarios that could be modelled to explore significant capacity expansion for other non-emitting generation such as new large hydroelectric resources, small modular nuclear reactors, traditional nuclear reactors and biomass, or significant reliance of fossil generation with carbon capture and storage applications, we leave those scenarios for others to develop and model.

Technologies

We approached the decisions around which generation technologies to include in our scenarios with great care to try and provide a unique, useful contribution to these conversations around electricity transformation in Canada with the capacity and modelling resources available to us for this project.

The table below gives details around which technologies were included in the Clean Power Pathways scenarios and which were excluded for consideration from the model based on environmental, social and political factors, and values-based technology decisions.

As noted through this report, the design of these modelling scenarios was the responsibility of the Foundation alone, and they do not necessarily reflect the views of the SESIT modelling team or other collaborators.

Note that all technologies listed in both categories below are included in the business-as-usual modelling scenario as a point of comparison.

Table 1: Technologies selected for the Clean Power Pathways modelling scenarios

Technologies selected for the Clean Power Pathways scenarios	Technologies excluded from the Clean Power Pathways scenarios
Wind electricity	All unabated fossil fuel electricity including coal, oil and gas–fired generation
Solar electricity	Fossil fuel electricity with carbon capture and storage (CCUS)
Battery storage (represented as lithium-ion 4-hr)	New nuclear electricity at any scale, including small modular nuclear reactors (SMNRs)
Retrofits and refurbishments to existing hydroelectricity dams	New large-scale hydroelectricity dams (>100 MW)
Pumped hydro storage	New large-scale biomass electricity (>100 MW), including bioenergy with carbon capture and storage (BECCS)
Geothermal electricity	Direct-air capture technologies (DACs) or other negative-emissions technologies used to offset electricity sector emissions
Energy-efficiency programs and deep-energy retrofits of buildings	
Electrification of transportation, buildings and industry	

In both of the Clean Power Pathways scenarios, Canada's existing fleet of hydroelectric resources is maintained and refurbished and continues to play a foundational role in Canada's clean electricity system throughout the study period. Given that this report focuses on renewables, some readers might expect to find scenarios that include thermal generation based on bioenergy with carbon capture and storage, which in theory offers the potential of negative emissions. Our scenarios eschew BECCS, as it is both costly[28] and likely to have biodiversity and other impacts that may undermine climate benefits and overall sustainability.[29]

Our scenarios achieve 100 per cent zero-emissions electricity across Canada in 2035. Few other comparable Canadian studies achieve net-zero emissions in the electricity sector by the target date and no Canadian studies yet achieve zero emissions. Most research focuses on the goal of achieving net-zero emissions by 2050. Clean Power Pathways fills a gap in the needs around electricity decarbonization in Canada.

These scenarios lean heavily on new clean electricity resources like wind, solar, battery energy storage and new transmission connections between regions. The SESIT modelling suite is uniquely positioned to explore scenarios with very high shares of variable renewable energy generation like wind and solar and to evaluate what is possible, reliable and affordable over the study period.

The business-as-usual scenario is presented as a point of comparison between the Clean Power Pathways scenarios and the most ambitious federal policies and emissions forecasting. At the time the scenarios were being developed, the broad policy landscape presented in the December 2020 federal climate plan, "A Healthy Environment and a Healthy Economy," were selected for the BAU scenario.[30] The business-as-usual scenario is also presented as a point of comparison on the basis of technology adoption, as new natural gas generation, new large-scale hydroelectricity, new nuclear generation and large biomass are not constrained in this scenario.

The David Suzuki Foundation is solely responsible for deciding modelling scenario parameters, policies and constraints. Scenarios and the model outputs are not a prediction, but one possible future, and we acknowledge that future insights and learning would benefit from modelling more scenarios and conducting additional sensitivity analysis. Indeed, until the grid is fully decarbonized and the energy transition away from fossil fuels is complete, there will be ongoing need for iterative modelling, learning and recalibrating policies and investments.

Table 2: High-level Clean Power Pathways modelling scenario constraints

		"Zero Plus" Scenario	"Zero" Scenario	BAU Policy Scenario
SESIT Modelling Suite	Clean Electricity Standard	100% Clean Electricity by 2035	100% Clean Electricity by 2035	90% Non-emitting Electricity by 2030
	Emissions Constraints	0 Mt sector emissions by 2035	0 Mt sector emissions by 2035	As per 2020 climate plan (HEHE)
	Carbon Pricing	\$170/t in 2030 \$370/t in 2050	\$170/t in 2030 \$370/t in 2050	\$170/t in 2030 \$170/t in 2050
	Fossil Fuel Generation Phase-out Dates	Coal: 2030 Natural Gas: 2035	Coal: 2030 Natural Gas: 2035	Coal: 2030 Natural Gas: N/A
	Inter-Provincial Transmission	Partially Constrained	Partially Constrained	Unconstrained
	New Unabated Natural Gas	None	None	Unconstrained
	New Natural Gas + CCUS	None	None	Unconstrained
	New Large Hydro (>100 MW)	None	None	Unconstrained
	Existing Hydro Generation	Maintained	Maintained	Maintained
	New Nuclear Generation (Conventional or SMR)	None	None	Unconstrained
	Existing Nuclear Generation	Maintained, decomissioned at end-of-life	Maintained, decomissioned at end-of-life	Maintained, decomissioned at end-of-life
	Battery Storage & Pumped Hydro Storage	Unconstrained	Unconstrained	Unconstrained
EnviroEconomics Modelling	Electrification of Buildings and Transportation	Prioritized	Baseline	Baseline
	DSM, Building Retrofits	Prioritized	Baseline	Baseline

THE SCOPE OF MODELLING WORK

For a national electricity modelling report such as this, it is necessary to define the scope in order to address one set of problems, while leaving important additional work for future modeling studies.

This report is focused on the gird-scale transformation of Canada's electricity system. Our modelling work includes Canada's electricity sector south of 60º latitude — the bulk electricity systems in each of the 10 Canadian provinces. Off-grid and remote electricity systems, territorial grids or non-integrated electricity systems are beyond the scope of this report.

The main focus of this study — and the modelling — is on the generation and ***supply*** of clean electricity, yet we also investigated future electricity ***demand*** as we account for the fact that the electricity sector expands throughout the study period as other energy end uses are switched from fossil sources to electricity. To go beyond utility load forecast projections, we contracted demand-side energy and economic modelling to project how the transportation, buildings and industrial sector's electricity demand grows as they increasingly transition to meeting their needs for energy through the electricity system.

The models account for emissions from fossil fuel generation at the point of generation, which does not include upstream emissions.[31] We do not account for full life-cycle emissions; e.g., the emissions involved in manufacturing wind, solar, battery and transmission assets or the emissions in the mining sector associated with supplying the raw materials needed.[32] Likewise, emissions associated with land disturbance to develop projects are not included within the project's scope.

Technologies such as offshore wind, geothermal generation, distributed energy resources, demand response, green hydrogen and hybrid projects (e.g., a project where solar generation and battery storage are bundled) are likely additions to the clean electricity transition yet lay beyond the scope of this report. These technologies would add further options in the scenarios explored, and we look forward to other efforts to investigate their efficacy and to complement the present modelling.

We also do not account for electricity market structure, the regulatory environment facing utilities and private power producers or ownership structure (public, Indigenous, private, cooperative).[33] Likewise, while we recognize that it is critically important to build social buy-in to new energy infrastructure and to deliver community benefits, and that doing so can take time, this is not an issue resolved through modelling.

Table 3: Topics out of study scope and technologies excluded from DSF's scenarios

Topic	Reason for being out of scope
Offshore wind	Modelling resources unavailable at the time when the project scope was being defined.
Territorial and remote grids	Not connected with the 10 provincial electricity grids that were the central focus of this modelling work.
Behind-the-meter generation, including residential and commercial rooftop solar	Modelling resources unavailable at the time when the project scope was being defined.
Distributed energy resources	Modelling resources unavailable at the time when the project scope was being defined.
Demand response	Modelling resources unavailable at the time when the project scope was being defined.
Sensitivity for varying levels of import/export with the U.S. electricity system	Levels of electricity import and export were held constant at the base model year (2018). No sensitivity analysis was done on U.S.–Canada electricity trade benefits for renewable integration.[34]
Climate sensitivities and inter-annual variability in wind and solar resources	Sensitivities around how changing climate will impact the resource availability for wind, solar and hydro were not included in this modelling work. Furthermore, the modelling used a representative year of wind and solar data and therefore this study does not incorporate sensitivity analysis to explore the implications of inter-annual variability.[35]
Behavioural analysis	Specific analysis on behaviour change as a driver for electricity demand reduction was not included in this modelling work.
Green hydrogen	Modelling resources unavailable at the time when the project scope was being defined. Therefore, "green" hydrogen production using electrolysis powered with renewable electricity was not included in the demand forecasts for these scenarios, and could be assumed to dramatically increase the demand for clean electricity above and beyond what is shown in these scenarios. Similarly, hydrogen-powered electricity generation was not considered as a generation source or as a form of storage in these scenarios.
Emerging energy storage technologies	Beyond the energy storage provided by Canada's existing hydroelectric reservoirs, only battery storage and pumped hydro retrofits were included in our modelling scenarios. Other battery storage durations, battery chemistries and technologies such as compressed air energy storage and additional battery chemistries may yet play an important role, but were not included due to model limitations, technological immaturity and a limited confidence in price forecasts.
Electricity demand tied to negative emissions technologies (e.g., direct air capture).	There are many uncertainties around future deployments of negative emissions technologies and the electricity demand that may result.

UNDERSTANDING CLEAN ENERGY PREFERENCES THROUGH STAKEHOLDER ENGAGEMENT

Our scenarios were first developed following a survey of more than 150 energy experts across Canada on their views about how to best reach zero emissions and the role of the electricity sector in supporting climate goals. This survey and the insights it generated are summarized in "Talking Transition: Shaping Canada's Clean Power Pathways." This report also provided a review of recent polling and dialogues relevant to the energy transitions, to provide insights on the energy preferences of people living in Canada. Of particular relevance, this report helped shape the scenarios we modelled, and it supports our decision to exclude fossil generation, new large hydro and all new nuclear (see figure below).

Low-emissions power preferences

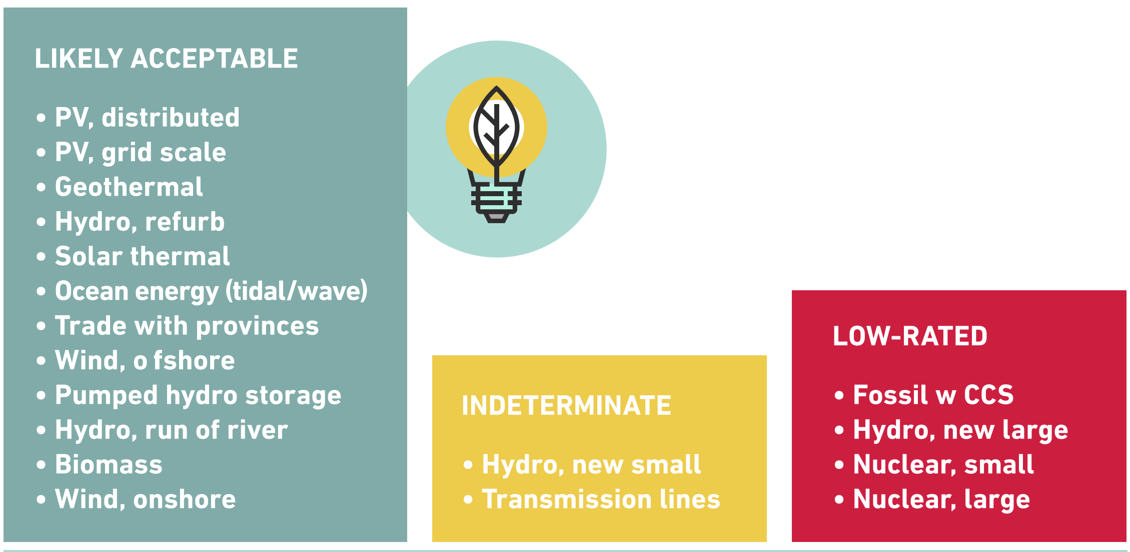


Figure 2: Preferences in Canada for various low-emissions technologies, from "Talking Transition: Shaping Canada's Clean Power Pathways" (September 2020)

Further iterations of our modelling scenarios were developed after focused stakeholder feedback on our preliminary results in Autumn 2021. Between October and December 2021, the Foundation invited stakeholders to provide feedback on our early modelling results and to provide insights on the most promising strategies for decarbonizing Canada's electricity system. There were multiple ways for stakeholders to engage with modelling parameters, insights and results, including two focused online workshops, bilateral meetings with stakeholders, an online survey and a detailed presentation and discussion at the Electricity Transformation Canada conference in Toronto in November 2021.

Of course, not all stakeholder preferences can be reflected in our modelling scenarios, and decarbonizing Canada's electricity system will take time, and many future iterations on the scenarios presented in this report.

THE MODELLING TOOLBOX: COPPER AND SILVER

Researchers in the Sustainable Energy Systems Integration and Transitions (SESIT) group at the University of Victoria, led by Madeleine McPherson, have been developing a set of integrated models that span the electricity, transport and building sectors as well as municipal, provincial and federal scales to explore the role of energy systems integration and electrification in Canada's energy transition.[36] The SESIT team's models are built specifically with the Canadian electricity system in mind. They're specialized to have fine spatial and temporal resolution for variable renewable energy generation across Canada and formulated to work with and integrate to Canada's 10 provincial electricity systems. They are also open-source models, meaning that other researchers can access, add to and use these models.

The David Suzuki Foundation is solely responsible for deciding modelling scenario parameters, policies and constraints. The SESIT team did not shape and does not necessarily endorse the scenarios or specific clean electricity goals presented as part of Clean Power Pathways.

To explore the future of the electricity system in Canada, including the growth of variable renewable electricity like wind and solar on the Canadian electricity system, one needs a capacity expansion model. The Canadian Opportunities for Planning and Production of Electricity Resources (COPPER) model is a capacity expansion model built by the SESIT team that charts the national generation and transmission capacity for the electricity system in each province based on chosen policy and technology constraints, technology price forecasts, demand forecasts and other the inputs.[37]

The Strategic Integration of Large-capacity Variable Energy Resources (SILVER) model is a production cost model built by the SESIT team that dispatches provincial electricity systems with temporal and spatial resolution for the electricity system configuration that is suggested by the outputs of the COPPER model.[38]

The COPPER model is a capacity expansion model that charts what generation, transmission and storage resources are built across Canada for a given scenario on a cost-optimal basis.

The SILVER model is a production cost model that adds validation by dispatching what COPPER has built at high temporal and spatial resolution.

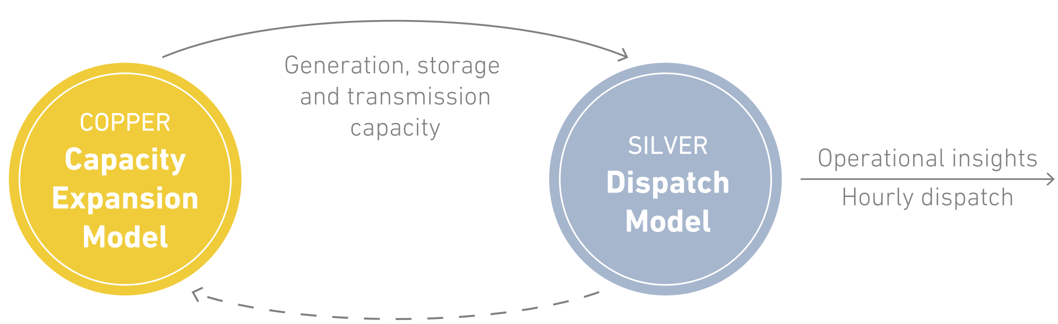


Figure 3: A diagram exploring the modelling suite used for Clean Power Pathways

Both COPPER and SILVER represent the wind and solar resource at high temporal and spatial resolution. COPPER represents the study area (Canada south of 60° latitude) as 2,278[39] grid cells with wind and solar resource characteristics tagged to each cell from relevant databases.[40] The cells vary in size from around 2,000 km^2 to 2,700 km^2 as one heads from north to south. The COPPER model decides what generation, transmission and storage resources are built and where they are built for a given scenario on a cost-optimal basis.[41] The SILVER model tests operational feasibility by dispatching what COPPER has built, running for every hour in the model year.[42] After running each scenario iteration, the modelling team then looked at the results to identify operational realities that suggest/require a modification to the system design. This allowed the Foundation to identify instances where adjustments to the scenarios would be advised (e.g., adjusting limits on the transmission capacity between interconnected provinces).

The Clean Power Pathways modelling also makes extensive use the Canadian Open-Source Database for Energy Research (CODERS) to support this modelling work.[43] CODERS contains the data that have been collected by the SESIT group to populate the energy systems models. CODERS is currently hosted on a platform that is only available to SESIT collaborators, but will be made open-access when the licensing process and host portal are finalized. When complete, we hope that CODERS will close a significant gap in the Canadian energy systems modelling workflow and contribute to an ongoing national energy transitions dialogue.

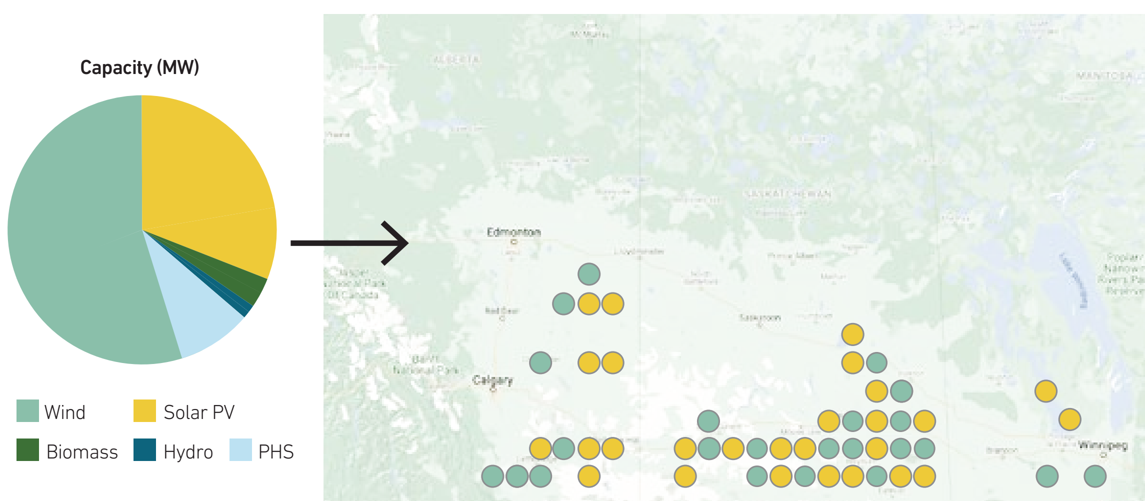


Figure 4: Illustrative example of how COPPER builds and models generation at the grid cell resolution

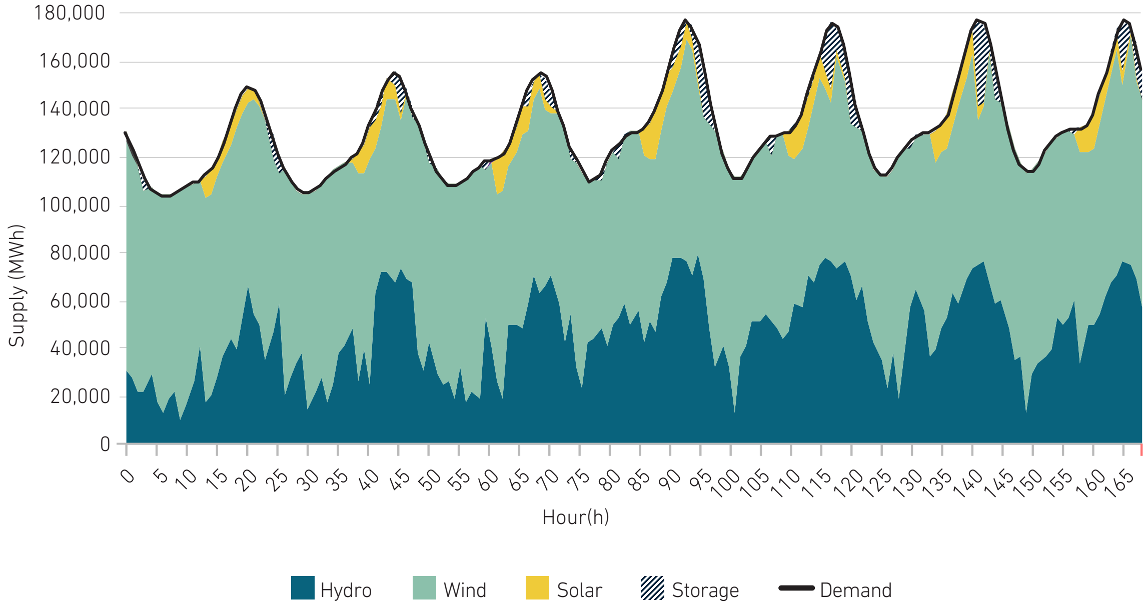


Figure 5: Representative example of the temporal resolution of the SILVER model

MODELLING DEMAND PROFILES FOR THE ZERO PLUS HIGH ELECTRIFICATION SCENARIO

Eliminating emissions from electricity generation is critical, yet a significant portion of the value of Canada's clean electricity transition comes from switching energy end uses that currently rely on burning fossil fuels to instead be powered with clean electricity. We must reduce the amount of fossil fuels we burn to meet our energy needs.

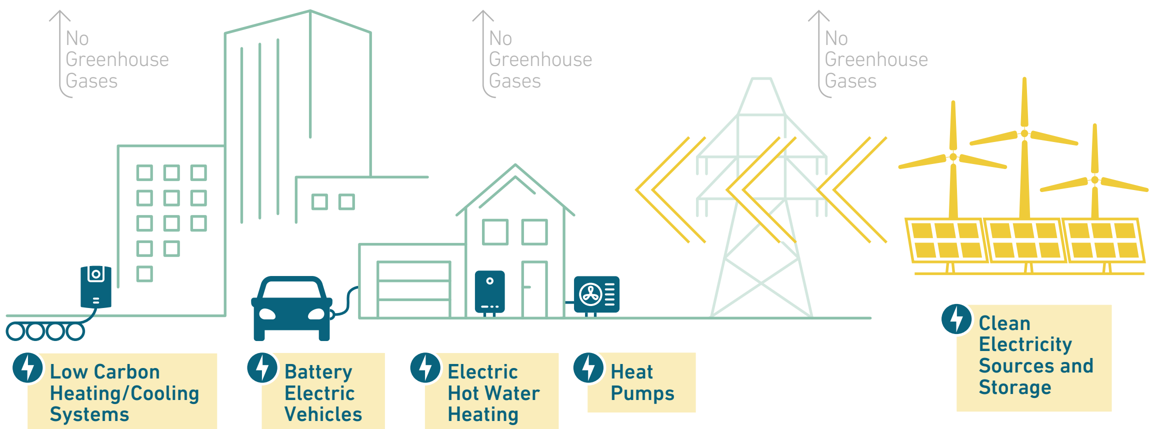


Figure 6: Illustrative graphic for the electrification of transportation and buildings

It was critical that our pathway prioritizes ambitious electrification of the transportation and buildings sectors and other energy uses. This approach required a modelling collaboration between two separate energy and economic modelling platforms. Dave Sawyer of EnviroEconomics was contracted to use the Navius gTech and IESD models to build demand-side modelling to produce hourly load profiles for each province and each model year between 2025 and 2050. These demand profiles were used as inputs into the SESIT modelling team's capacity expansion model COPPER for the Zero Plus scenario.[44] The Zero Plus scenario uses the EnviroEconomics modelling to explore greater levels of electrification in buildings, transportation and industrial sectors. It also gives greater priority to energy efficiency and building retrofit options.

The Zero and BAU scenarios use more modest electricity demand forecasts for each province. These are derived by the SESIT modelling team based on the latest available utility demand forecasts from each province. These demand forecasts only partially account for increasing economy-wide electrification as climate policy ratchets up and technologies improve. The level of electrification projected varies by utility across Canada. The three scenarios are compared below in terms of total electricity demand. While there is a small initial difference, the gap between the Zero Plus scenario and the others grows to more than 250 TWh annually by 2050.

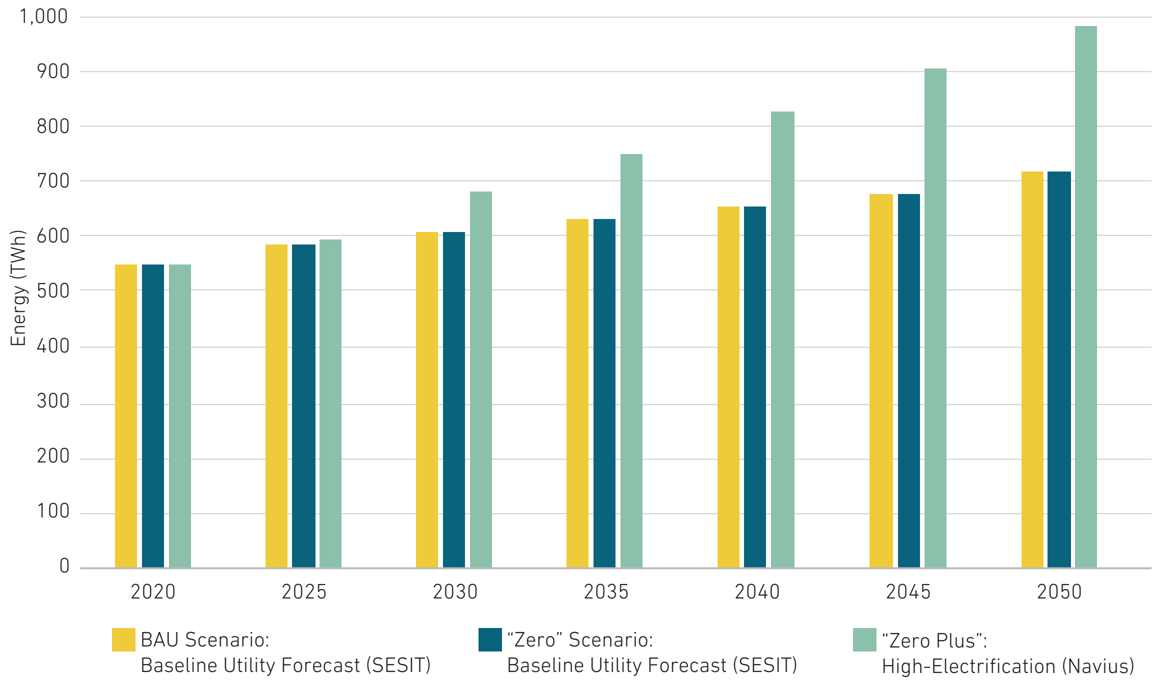


Figure 7: Comparison of national electricity demand by scenario reflecting differences due to economy-wide electrification

Photo: Adobe Stock Images

RESULTS AND DISCUSSION

This section presents the detailed results, modelling outputs and discussion for the Clean Power Pathways scenarios.

Unless otherwise noted, or presented in comparison across all three modeling scenarios, the detailed final results in this section are for the Zero Plus scenario, which the Foundation believes to contain the most useful and relevant insights for Canada's transition to 100 per cent zero-emissions electricity by 2035.

The Zero Plus scenario is focused on variable renewable energy penetration and overall growth of electricity capacity and generation to support economy-wide electrification and to maximize emissions reductions.

Table 4: High level comparison of key modelling outputs from the Clean Power Pathways scenarios

	2035			2050		
	BAU	"Zero"	"Zero Plus"	BAU	"Zero"	"Zero Plus"
Total Installed Capacity (GW)	**180**	**208**	**241**	**240**	**281**	**414**
Total Wind	66	110	135	102	168	252
Total Solar	3	6	8	34	20	47
Total Storage	0	3	8	5	13	35
Total Hydro	82	82	82	80	81	81
Share of Total Capacity (%)						
Wind	37%	53%	56%	43%	60%	61%
Solar	2%	3%	3%	14%	7%	11%
Storage	0%	1%	4%	2%	5%	8%
Wind + Solar + Storage	38%	57%	63%	59%	71%	81%
Wind + Solar + Storage + Hydro	84%	97%	97%	92%	100%	100%
Cumulative Inter-regional Transmission Additions (GW)	**13.1**	**25.0**	**25.9**	**24.6**	**26.4**	**28.9**
Total Capacity Increase over 2021	**1.2x**	**1.4x**	**1.6x**	**1.2x**	**1.9x**	**2.8x**
Total Wind	5x	8x	9x	7x	12x	18x
Total Solar	1x	3x	3x	14x	8x	20x
Total Storage	1x	18x	53x	32x	81x	219x
Total Wind + Solar	4x	7x	9x	8x	11x	18x
Total Hydro	1x	1x	1x	1x	1x	1x
Total NPV Cumulative Cost ($B 2018 CAD)	**$315**	**$362**	**$400**	**$430**	**$464**	**$560**
Generation Investment	$131	$193	$233	$160	$232	$311
Storage Investment	$0	$3	$8	$2	$7	$19
Transmission Investment	$10	$21	$24	$12	$22	$24
Operation & Maintenance	$174	$145	$135	$257	$202	$206
System-Weighted LCOE ($2018/MWh)	**$94**	**$91**	**$94**	**$83**	**$82**	**$82**

INSTALLED CAPACITY AND SUPPLY MIX

By 2050, the Zero Plus scenario results in a nationwide installed electricity capacity that comprises more than 80 per cent wind, solar and energy storage, with the remaining capacity coming from existing hydroelectric capacity.

As described above, all fossil fuel-fired electricity generation is phased out by 2035 in both of the Clean Power Pathways scenarios. Achieving this outcome is unique among contemporary Canadian studies. Because our scenario assumptions and constraints dictate that all major nuclear reactor refurbishments in Ontario and New Brunswick are constrained after 2026, all nuclear generation reaches the end of useful life by 2040.[45]

To meet rapidly rising electricity demand, and to accommodate increased carriable renewable energy generation, the total installed capacity in Canada's electricity system grows to 414,000 MW, which is an increase of about 2.8 times over the 2018 base year. The total electricity generation, however, grows to 983 TWh for the scope of generation within our models, which is an increase of about 1.8 times over the 2018 base year.

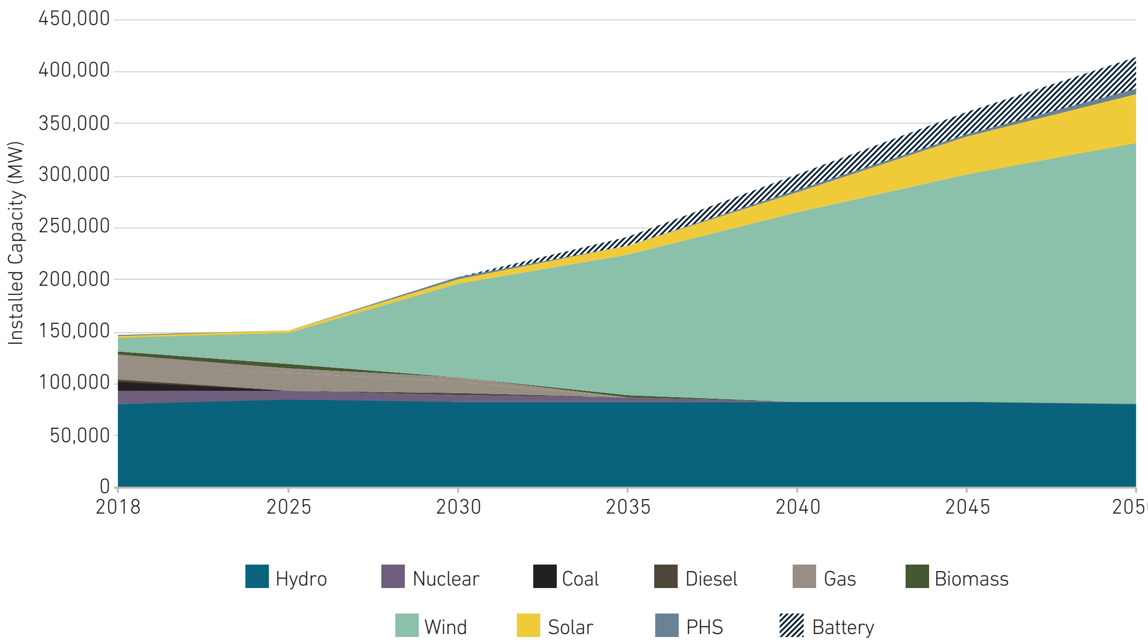


Figure 8: Canada's total installed capacity (MW) under the Zero Plus scenario

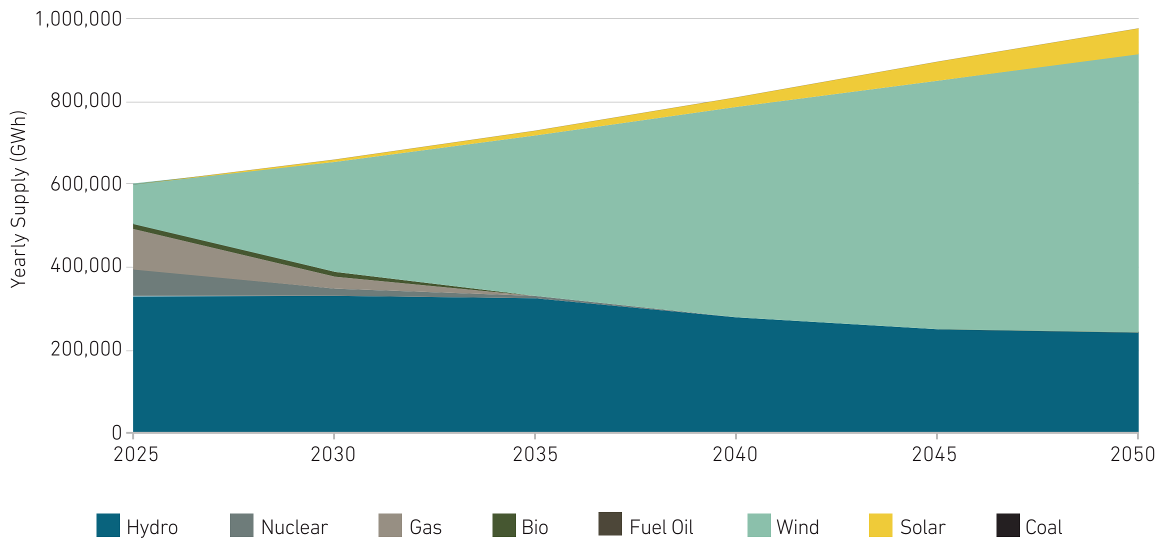


Figure 9: Annual electricity generation mix (GWh) for the Zero Plus scenario

The amount of grid-scale energy storage also grows dramatically in the Zero Plus scenario, with an additional five GW of pumped hydro storage and an additional 30 GW of battery storage installed in Canada by 2050. Although for modelling purposes, battery storage was represented by a four-hour lithium-ion battery, we note that storage technologies are rapidly evolving and what actually would be deployed will depend on the costs and technology characteristics when investment decisions must be made.[46] Thus, the energy storage requirements represented in these outputs will likely be served by a number of technologies, such as advanced compressed air storage, conversion to hydrogen, alternative battery chemistries, etc.

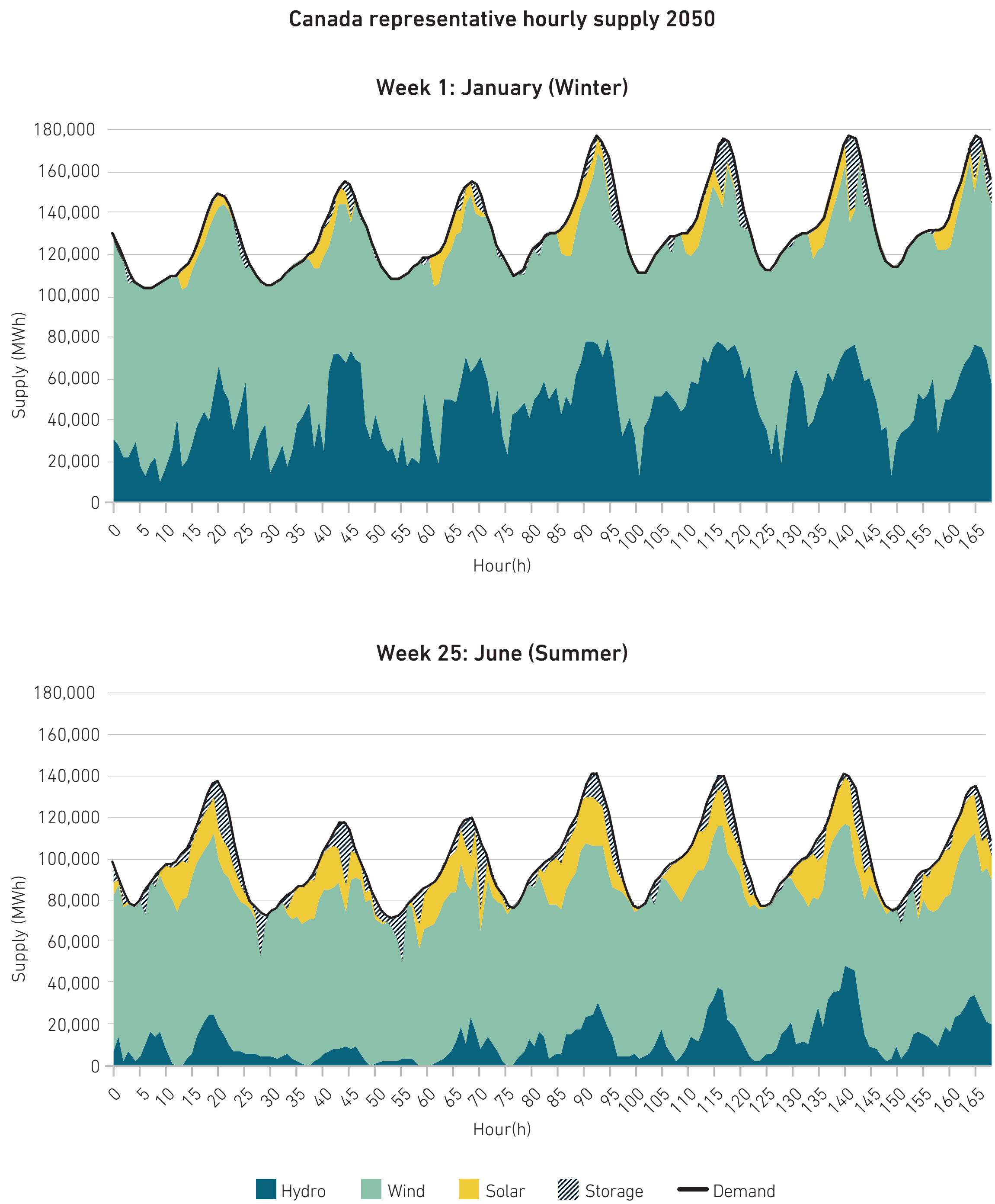


Figure 10: Hourly electricity supply comparison for two example weeks in Canada in 2050 for the Zero Plus scenario

INTERPROVINCIAL COLLABORATION AND TRANSMISSION

> The Canadian power market, by comparison [to Nordic countries], is highly balkanized. It features largely provincially owned, often vertically integrated corporations that dominate their home market but have no presence in other provinces. Politically, the success of "provincial champions" which provide high-paying jobs in communities all across a province is highly valued and can complicate the pursuit of low-cost, reliable, and environmentally sustainable power that greater integration offers.
>
> – *Shawn McCarthy*[47]

Confirming the findings of previous studies[48] and the federal government's Regional Electricity Cooperation and Strategic Infrastructure initiative, the Clean Power Pathways scenarios demonstrate how adding interprovincial and interregional transmission capacity helps enable a grid that is largely powered by renewables. Interprovincial and interregional transmission is proposed on a cost-optimized basis by our modelling to help balance and deliver the expanding amounts of variable renewable generation across and within provinces for both scenarios.

If unconstrained by political and social feasibility thresholds, the COPPER model builds levels of transmission capacity expansion that we deemed politically and socially unrealistic (>50 GW). For the scenarios evaluated in this study, total transmission capacity expansion was limited for many interprovincial lines.

For the Zero Plus scenario, nearly 29 GW of new transmission line capacity with more than 6,000 km of new or upgraded interregional transmission lines is built across Canada by 2050.[49] In terms of electricity-sharing capacity between provinces, this would be more than a three-fold increase on the current aggregate level of interprovincial transmission in Canada.[50] This would be added to Canada's existing 166,000 km of high voltage transmission lines that largely serve in-province electricity systems.[51]

This level of interprovincial and interregional transmission build-out and utilization would also require an unprecedented level of collaboration and coordination between provincial utilities and electricity system operators. Further, it would require extensive consultation with Indigenous rights holders to ensure free, prior and informed consent for any future transmission projects. Numerous landowner interests and land-use considerations, such as avoiding protected areas or areas with high biodiversity values, will also impact transmission line routing and viability (see *'Protecting nature, biodiversity and cultural values'* section).

It should also be noted that if electricity pathways prioritize other balancing measures, such as higher levels of energy storage, demand response and green hydrogen generation and utilization, high levels of renewable integration may be possible with a more modest build-out of interprovincial transmission.

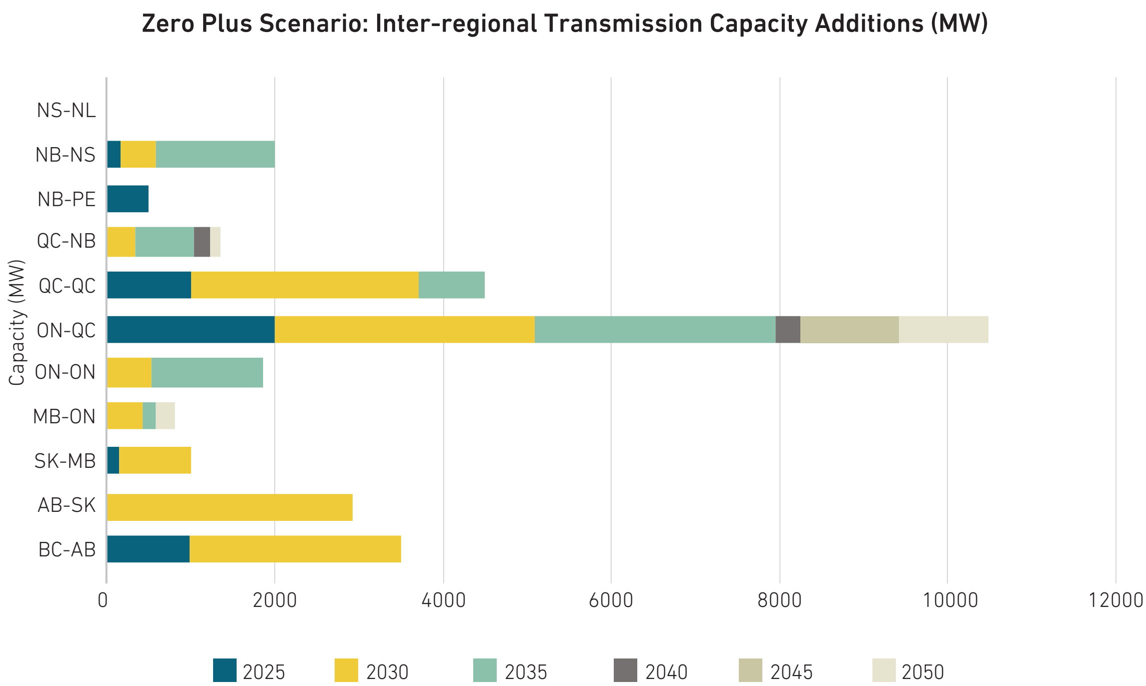


Figure 11: Inter-regional Transmission Capacity Additions (MW)

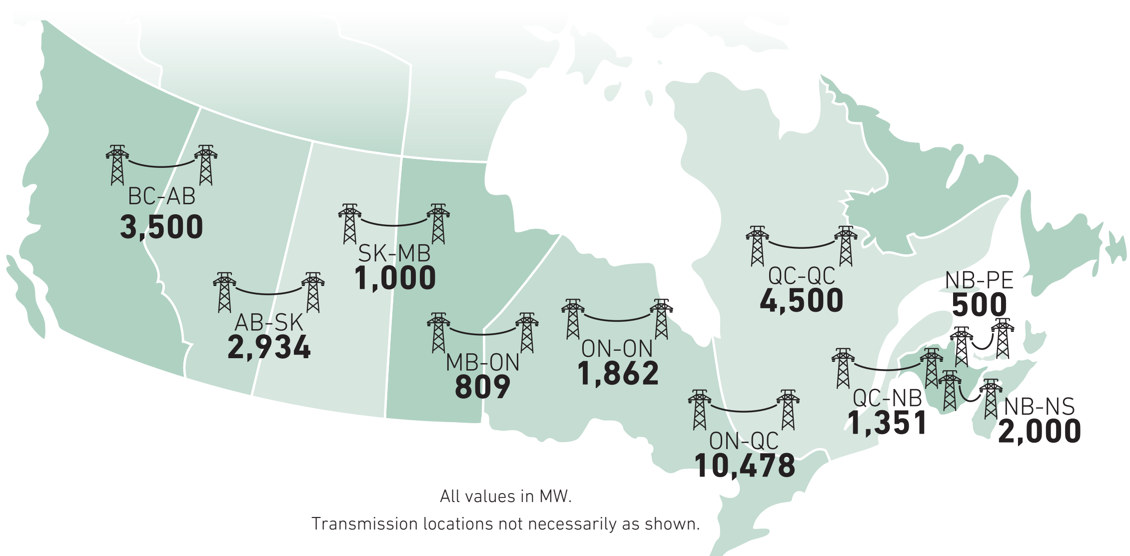


Figure 12: Transmission capacity expansion across Canada by 2050 for the Zero Plus scenario

SELECTED PROVINCIAL RESULTS

The Zero Plus scenario represents a significant transformation of the electricity system in every province, but the transition takes place at varying scales and from significantly different starting points across the 10 Canadian provinces.

The charts below show a snapshot of comparative provincial results for two example model years. The 2035 model year is the first year of interest, when all 10 provincial grids achieve zero-emissions electricity generation, and the 2050 model year being the end of the study period when significant new electricity demand has been added to each provincial system due in large part to the high electrification forecasted in the Zero Plus scenario.

Also shown are three examples of provincial results from the SILVER model showing the annual electricity demand and supply through the study period and two example weeks of hourly supply and demand results. These results are intended to provide an example of how the model balances hourly electricity demand with electricity generation from wind, solar and hydroelectricity, along with the capabilities of energy storage and interprovincial transmission between each balancing area. It is challenging to display all of the electricity flows that SILVER accounts for within each hour in terms of provincial imports and exports or charging of energy storage. Although exports and battery charging may also be taking place, these hourly graphs show the net electricity generation for in-province demand, the net discharging from energy storage and net imports from neighbouring provinces.

British Columbia, Alberta and Ontario were selected as large provincial grids that each have unique characteristics, insights and transformations through the study period.[52]

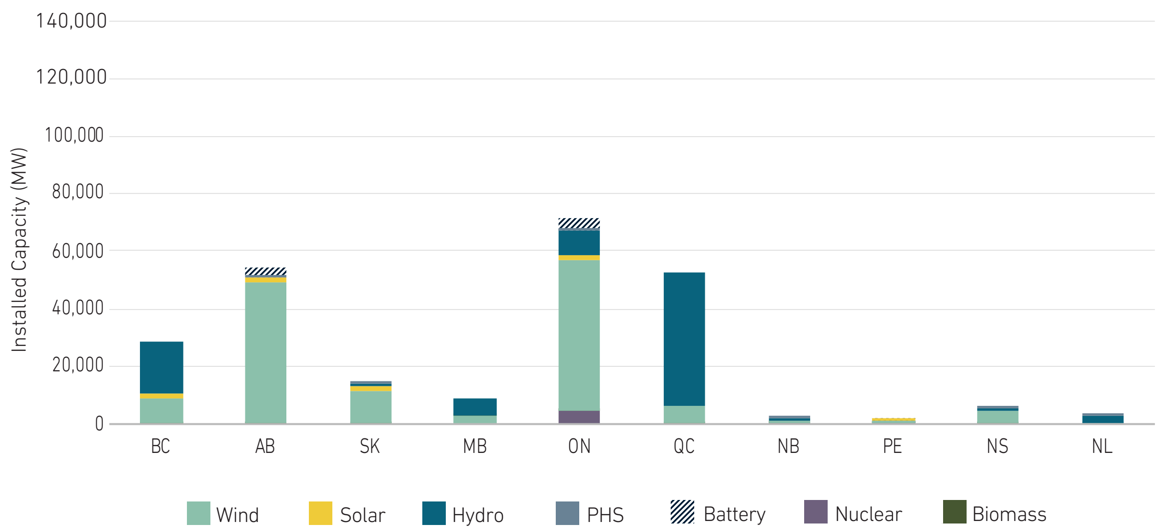


Figure 13: Zero Plus scenario: Provincial installed capacity (MW) for 2035

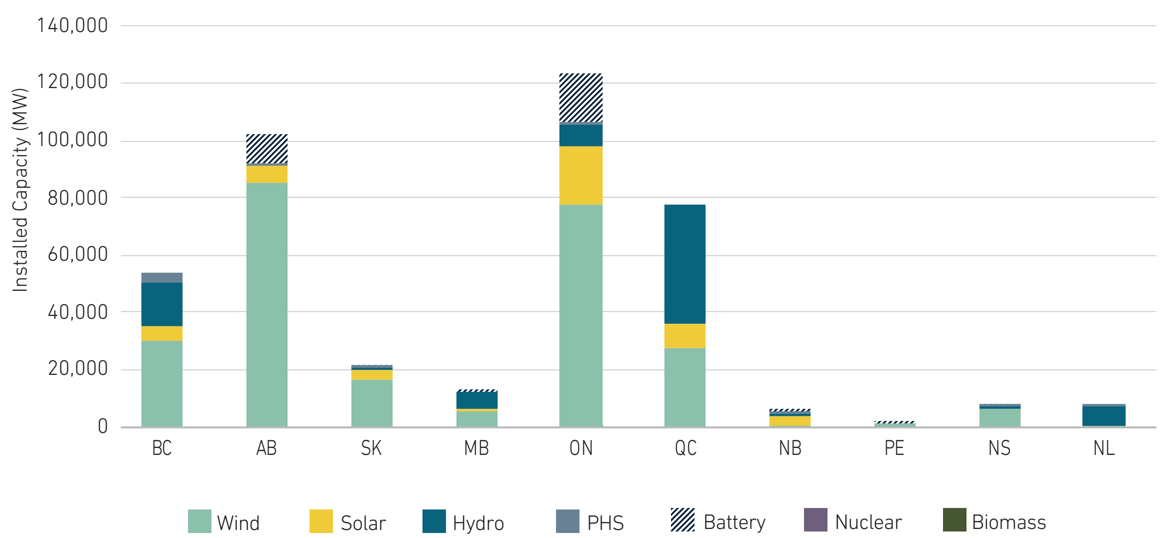


Figure 14: Zero Plus scenario: Provincial installed capacity (MW) for 2050

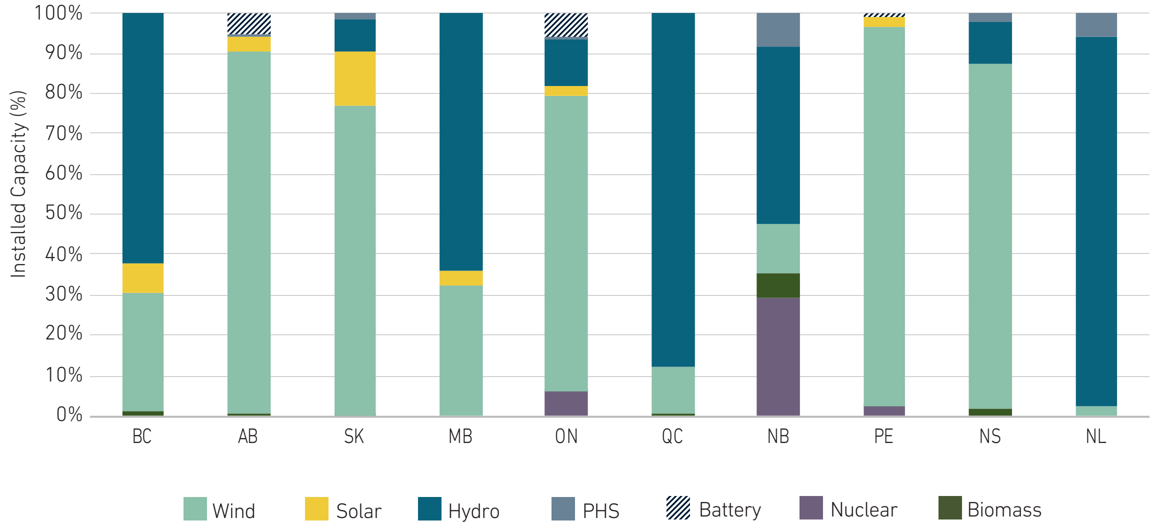


Figure 15: Zero Plus scenario: Provincial installed capacity (%) for 2035

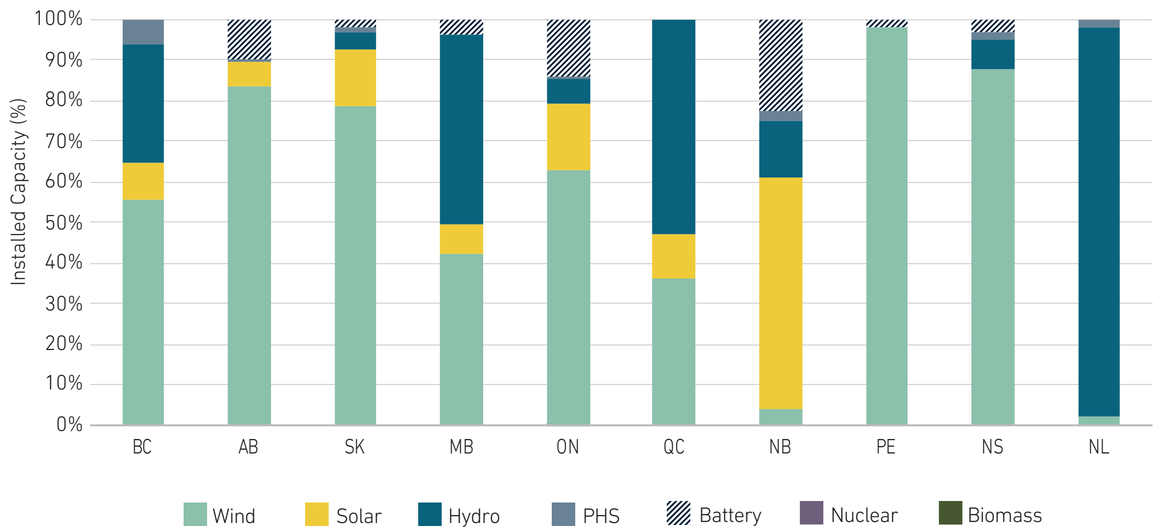


Figure 16: Zero Plus scenario: Provincial installed capacity (%) for 2050

Alberta

Although Alberta's electricity system does not have much hydroelectric capacity and is currently dominated by fossil fuel generation, it becomes a veritable renewable energy superpower in Canada, as does Saskatchewan, in its own right. Alberta's significant wind resource is utilized in this scenario, with the vast majority of new generation being wind electricity throughout the study period. Alberta benefits greatly from its interties to B.C.'s large hydro reservoirs and to Saskatchewan's grid, as each of these neighbouring provinces benefit from Alberta's excesses of low-cost wind electricity in hours of high production. A multitude of factors occur within and between neighbouring provinces each hour in terms of electricity demand and supply. As a high-level example, as a weather system with strong winds moves across the prairies, Alberta can export excess electricity generation to Saskatchewan or British Columbia when windy conditions prevail to the west and then import power from Saskatchewan as the storm moves east. When B.C. is importing wind power from Alberta, it can scale back hydroelectric generation, keeping its hydro reservoir capacity for later use. Significant energy storage capacity is also built in Alberta, helping to balance and follow variable wind and solar generation.

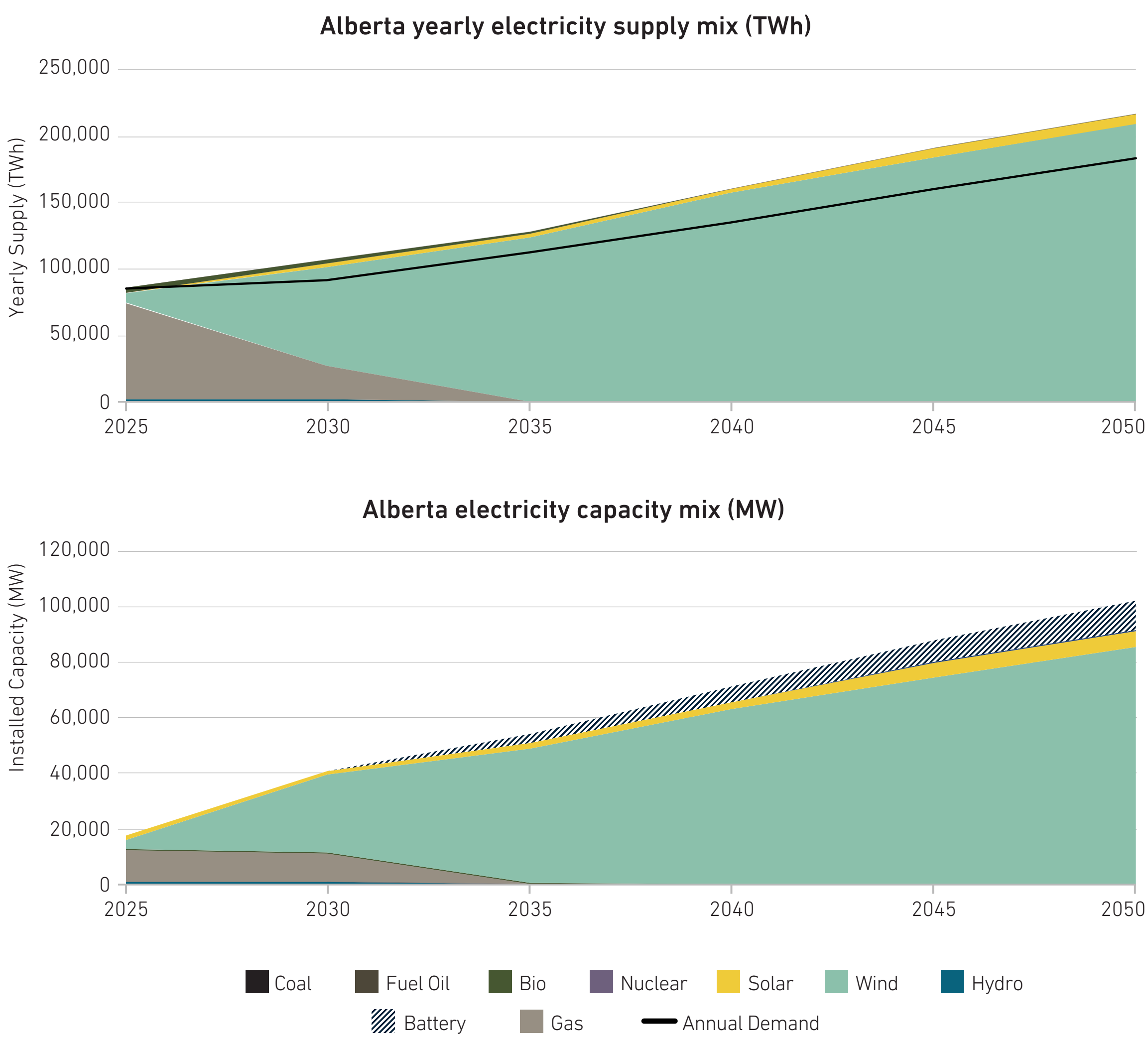


Figure 17: Total capacity and supply comparison for Alberta for the Zero Plus scenario

Alberta representative hourly supply 2050

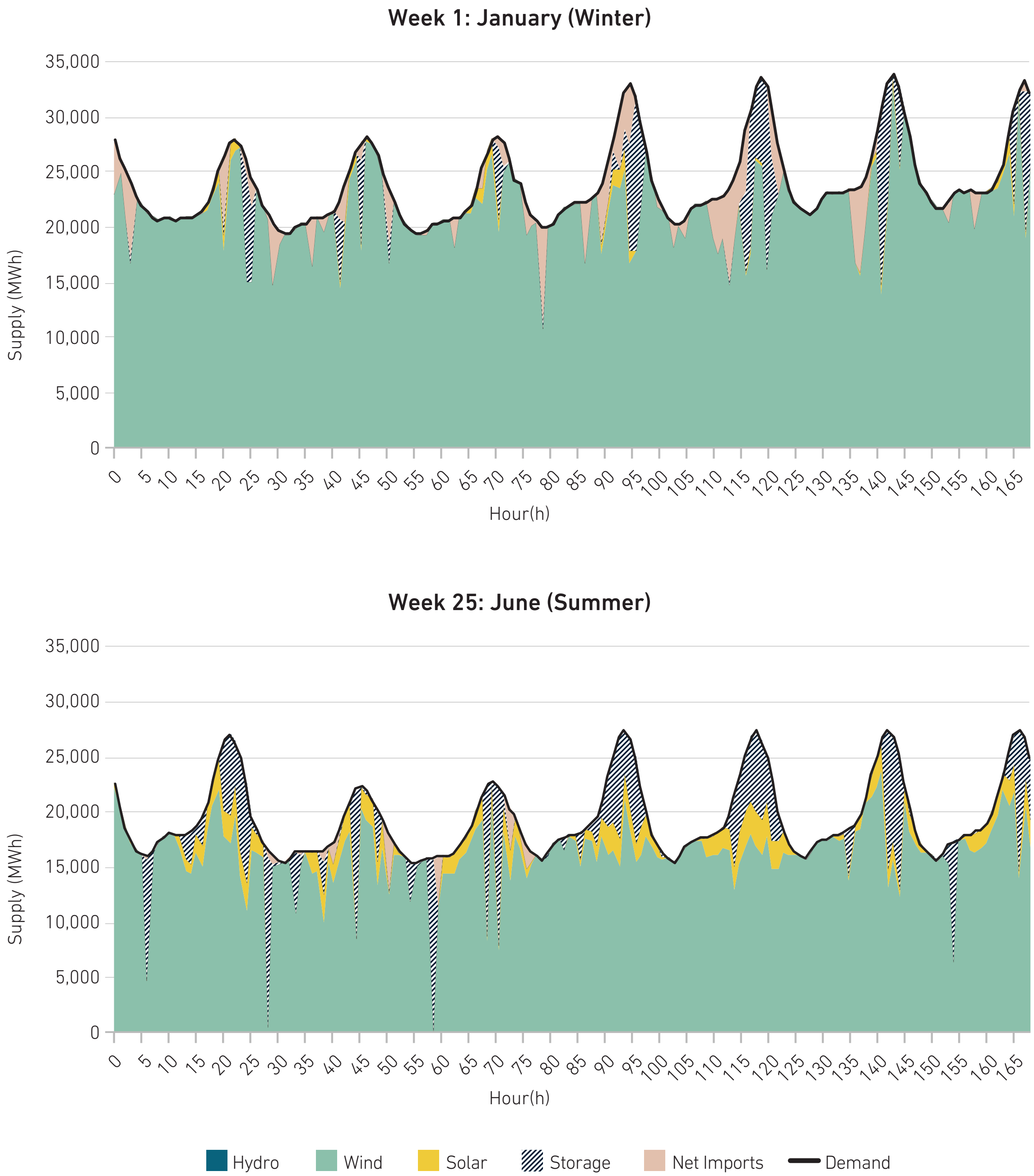


Figure 18: Hourly electricity supply comparison for two example weeks in Alberta for the Zero Plus scenario

British Columbia

In the Zero Plus scenario, British Columbia benefits from its existing large hydroelectric capacity, expanding wind and solar capacity, and new interties with Alberta. These new interties allow British Columbia's hydroelectricity to provide flexibility and reliability benefits to Alberta's grid, as well las its own growing wind and solar capacity. Similarly, when Alberta has excess wind and solar power, British Columbia is able to import low-cost wind and solar power and avoid drawing down its hydroelectric reservoirs for electricity generation.

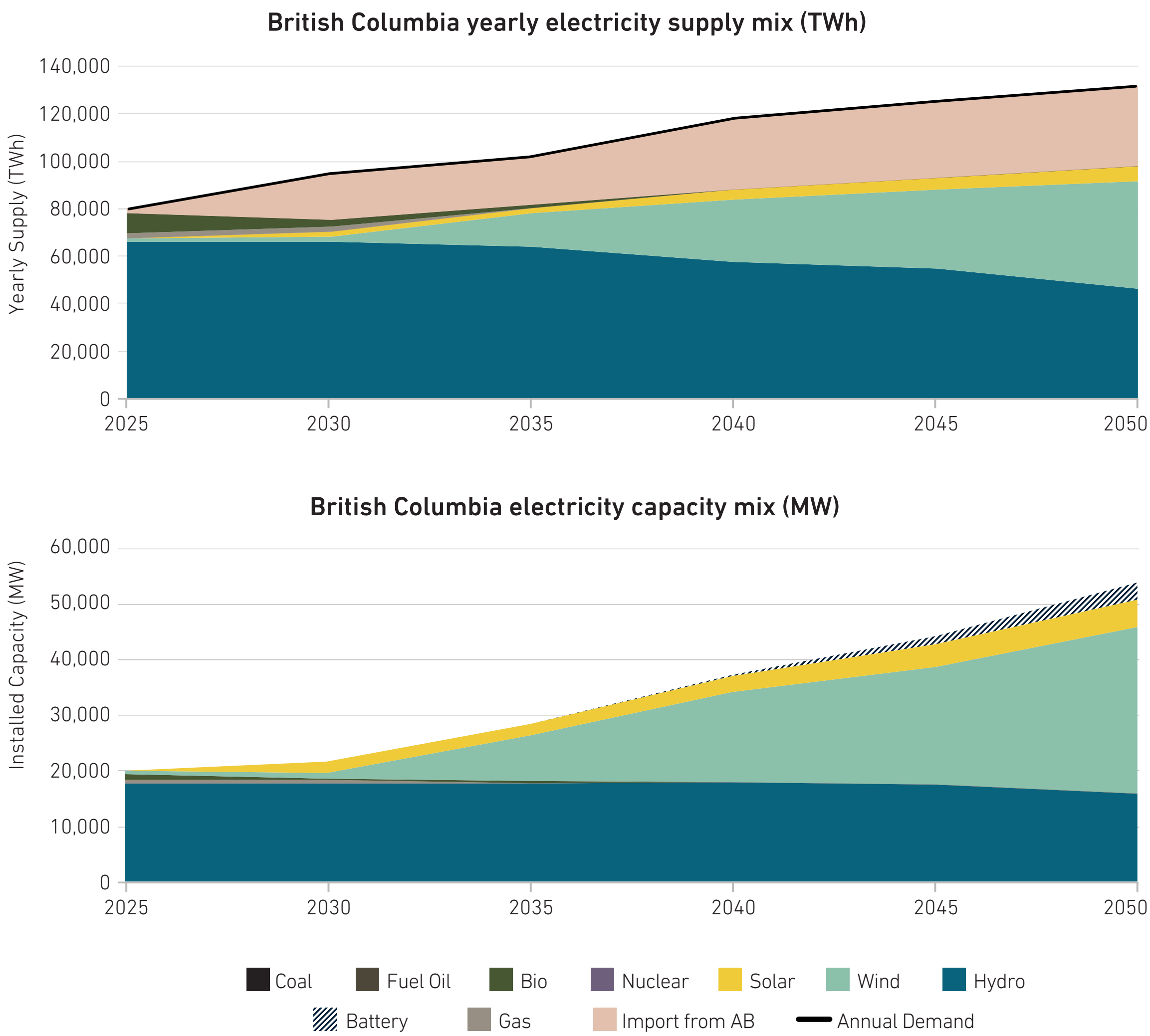


Figure 19: Total capacity and supply comparison for British Columbia for the Zero Plus scenario

British Columbia representative hourly supply 2050

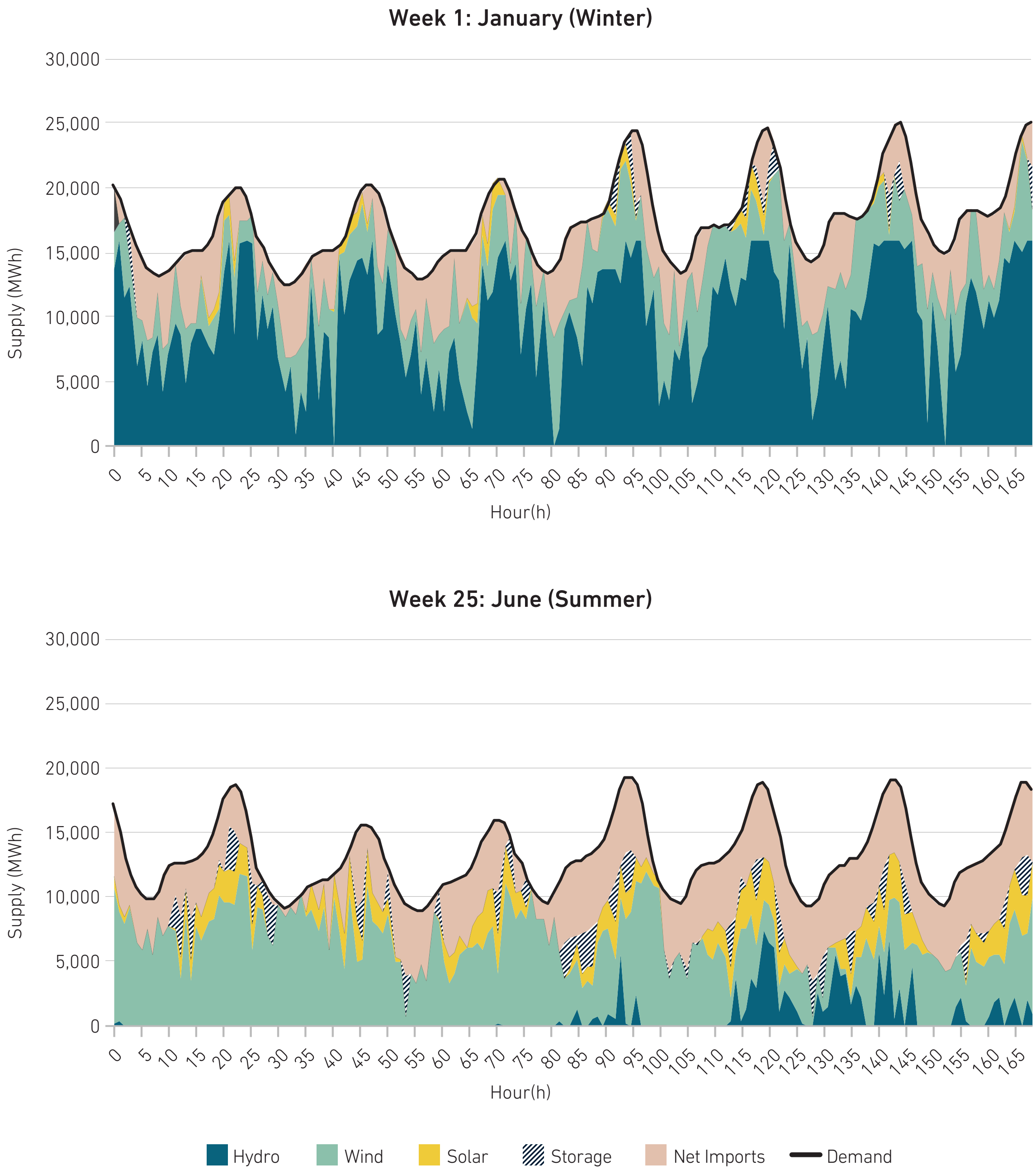


Figure 20: Hourly electricity supply comparison for two example weeks in B.C. for the Zero Plus scenario

Ontario

In the Zero Plus scenario in Ontario, wind generation grows steeply to support retirement of fossil natural gas generation capacity and later in the study period to replace nuclear capacity. Major retrofits and refurbishments of Ontario's nuclear reactors cease after 2027 in this scenario, and reactors are retired at end of life, with virtually all nuclear capacity being decommissioned by 2040. Thanks to considerable investments in interprovincial transmission, the province can benefit from Quebec's large hydroelectric capacity in periods when wind and solar production may be low. Importantly, Quebec also benefits greatly from the regular excess of low-cost wind and solar generated in Ontario. This high amount of shared electricity balancing of wind and existing hydroelectricity results in nearly even net import/export between the two provinces. Solar plays a modest role, but begins to be more prominent after 2040.

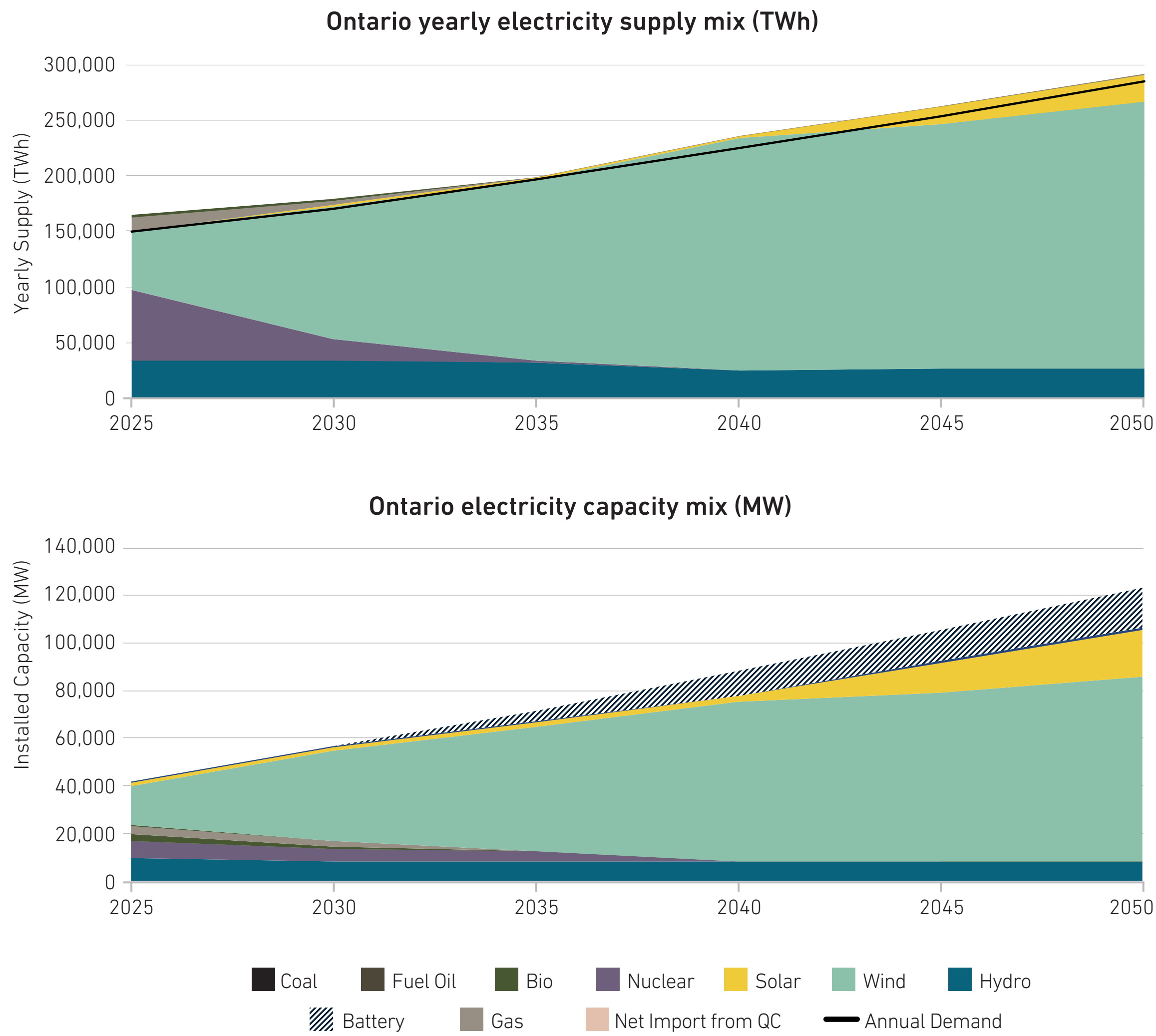


Figure 21: Total capacity and supply comparison for Ontario for the Zero Plus scenario

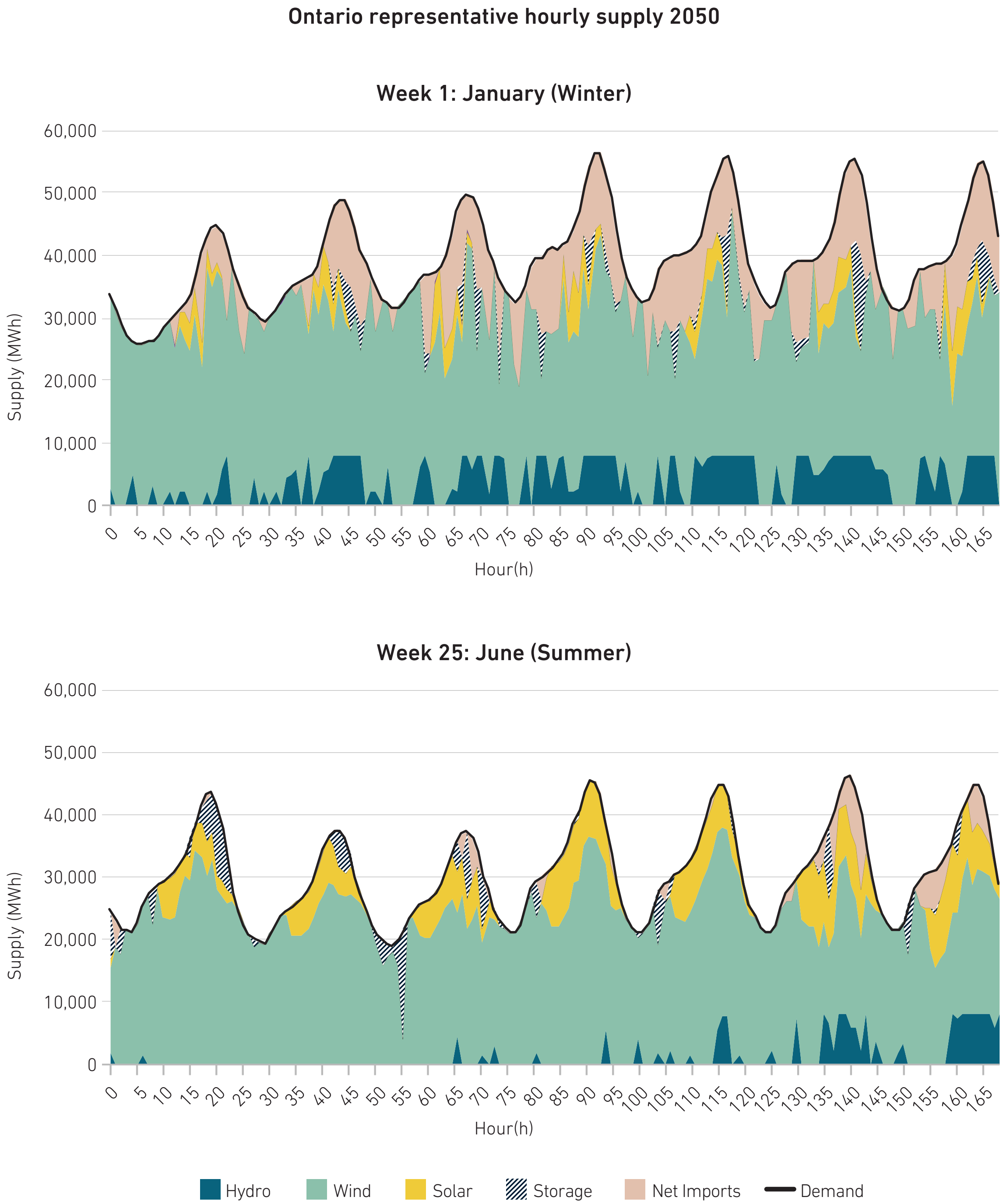


Figure 22: Hourly electricity supply comparison for two example weeks in Ontario for the Zero Plus scenario

RELIABILITY AND FLEXIBILITY

SILVER is a production cost dispatch model that tests the operational feasibility of the least-cost build-out that the COPPER model suggests by running the generation and transmission capacity and ensuring that, on an hourly basis for each of the six study years, the electricity generated in each provincial balancing area is adequate to supply the electricity demand.

One key reliability metric for SILVER's outputs is hourly load shedding,[53] which occurs when electricity supply does not meet electricity demand and electricity demand must be reduced to avoid a temporary blackout. A reliable electricity system is one with minimal periods when supply is unable to meet demand. Because these scenarios do not include demand response, they likely overstate the extent to which load shedding would occur. In real world conditions, when demand is close to exceeding supply, utilities can turn to their large electricity consumers and offer incentives to temporarily reduce demand. In addition, SILVER does not represent other mitigating measures such as how utilities can charge higher rates during peak demand to reduce load and ensure a more balanced system. The amount of load shedding reported out by SILVER is likely a conservative test of reliability.

In our Zero Plus scenario, the average annual occurrence of load shedding nationally is 0.007 per cent, or roughly 0.62 hours per year on average, but varies from year to year. In the highest occurrence, for the 2050 model year, load shedding occurs roughly 3.45 hours per year. This scenario achieves a total national installed capacity of nearly 72 per cent wind and solar in 2050.

Many factors contribute to overall grid flexibility and reliability in our scenarios

It should be noted that the scope of this study is limited and mainly focused on interprovincial electricity balancing for reliability. The development of in-province transmission and distribution upgrades is not in the scope of this study and their attributes are held steady based on the 2018 base model year. If the generation assets and transmission lines envisioned in the scenarios presented here were to be built, more in-depth analysis of reliability would need to be performed as part of provincial and regional utility integrated resource planning.

It's important to note that many factors contribute to overall grid flexibility and reliability in our scenarios, and the interactivity of these factors is what leads to reliable grid operation. The flexible operation of Canada's existing hydroelectric fleet; new energy storage capacity; new interprovincial and interregional transmission capacity; allocating wind and solar generation assets across diverse landscapes (lessening impacts of local weather conditions on system output); complementary energy efficiency; and electrification all contribute to achieving grid reliability.

Our report was not able to meaningfully consider the benefits of distributed energy resources, demand response, technological advances in wind and solar generation, high-resolution energy efficiency programming or other technologies and programs that could further increase overall grid flexibility and reliability.

CURTAILMENT

A common feature of electricity systems with high penetrations of variable renewable electricity like wind and solar is the so-called "over-build" of these generation sources in order to better ensure their availability throughout the year. There are times when large amounts of wind and solar resources are available, but demand is relatively low, storage capacity is full and there is nowhere else to deliver excess electricity. During these times it is necessary to curtail variable generation resources like wind and solar. Given the low cost of new wind and solar generation, the most economic option may be to invest in high levels of renewable generation and to accept that at certain times a fairly significant portion of the generated electricity will be curtailed. While it is relevant to examine the level of curtailment in a scenario, zero curtailment is not the goal as this would undercut system reliability.

If curtailment levels are high, that may suggest that there are other opportunities to optimize the system or to use the excess power for hydrogen production. However, it is most desirable to avoid excessive amounts of curtailment while maintaining reliability on the system to keep overall costs of wind and solar electricity low and limit the extent to which the system is "over-built."

The COPPER and SILVER models are designed to support evaluation of grids characterized by high penetrations of wind and solar generation. In our scenarios, the amount of interprovincial transmission, energy storage and cross-province electricity trade in times of high wind and solar generation also greatly reduces the impacts of curtailment in the Clean Power Pathways scenarios. More detailed evaluation of the economically and technically optimal level of curtailment under zero-emissions scenarios with high levels of variable renewables should be a priority for future analysis. The SESIT team is undertaking more detailed evaluation of curtailment for scenarios in the Canadian electricity system with high integration of variable renewables.[54]

Note also that in the long term, if modelling indicates high levels of curtailment will occur as increasing amounts of renewables are deployed, there may be economic opportunities to offtake this power, such as for hydrogen production.[55]

DEMAND-SIDE MODELLING RESULTS

Eliminating emissions from electricity generation is critical, yet a significant portion of the value of Canada's clean electricity transition comes from switching energy end uses that currently rely on burning fossil fuels to instead be powered with clean electricity. We must reduce the amount of fossil fuels we burn to meet our energy needs.

It was critical that our pathway prioritizes ambitious electrification of the transportation and buildings sectors and other energy uses. This approach required a modelling collaboration between two separate energy and economic modelling platforms. Dave Sawyer of EnviroEconomics was contracted to use the Navius gTech and IESD models to build demand-side modelling to produce hourly load profiles for each province and each model year between 2025 and 2050. These demand profiles were used as inputs into the SESIT modelling team's capacity expansion model COPPER for the Zero Plus scenario.[56] The Zero Plus scenario uses the EnviroEconomics modelling to explore greater levels of electrification in buildings, transportation and industrial sectors. It also gives greater priority to energy efficiency and building retrofit options.

Photo: dcbel, Unsplash

Demand-side modelling: Buildings

Energy use in buildings is a significant source of Canada's emissions. Despite our harsh climate, Canada has a long way to go to bring our buildings stock up to levels of energy efficiency compatible with net-zero futures. The average Canadian dwelling units and businesses are costly to heat and cool and most rely on natural gas for heating and cooking. Our demand-side scenarios were designed to improve energy efficiency and electrify commercial and residential building energy end uses such as heating and cooling as much as possible.

As shown in Figure 6, building energy use changes dramatically over the study period as end uses change to electricity. For the commercial sector, more than 90 per cent of the energy needed for space heating will be electric by 2050. The majority of that demand will be met with highly efficient air-source heat pumps. For the residential sector, more than 80 per cent of the energy needed for space heating will be electric by 2050. There will be an even mix of heat pumps and electric resistance heating, with wood heat and natural gas expected in small amounts.

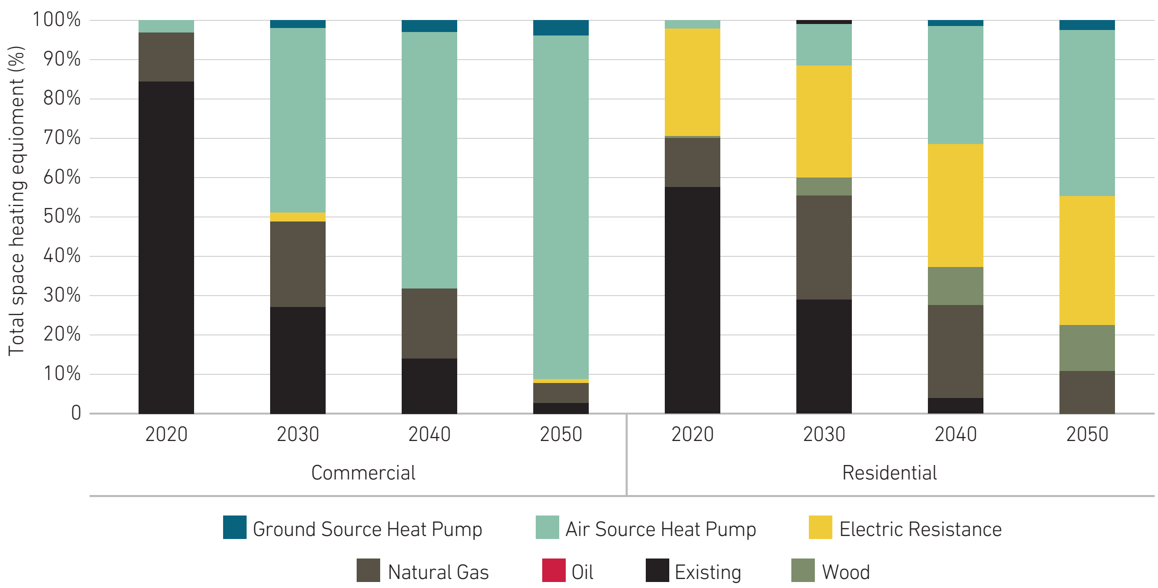


Figure 24: Space heating for buildings by heating source for the Zero Plus scenario

Energy efficiency and building retrofits greatly reduce energy demand while reducing energy costs. The Zero Plus scenario explored higher levels of energy efficiency, including deep-energy retrofits of buildings and building code updates for more efficient building envelopes and net-zero-ready buildings.[57] Switching a building's heating sources from fossil fuel–fired boilers and furnaces to high efficiency air-source heat pumps — which move rather than generate heat — also leads to dramatic efficiency savings. The HE scenario would require that nearly 65 per cent of commercial buildings and 60 per cent of residential buildings are either highly efficient or net-zero-ready by 2050.

As shown in Figure 20, the overall space heating energy consumption per unit area in commercial and residential buildings is reduced by about 40 per cent by 2050.

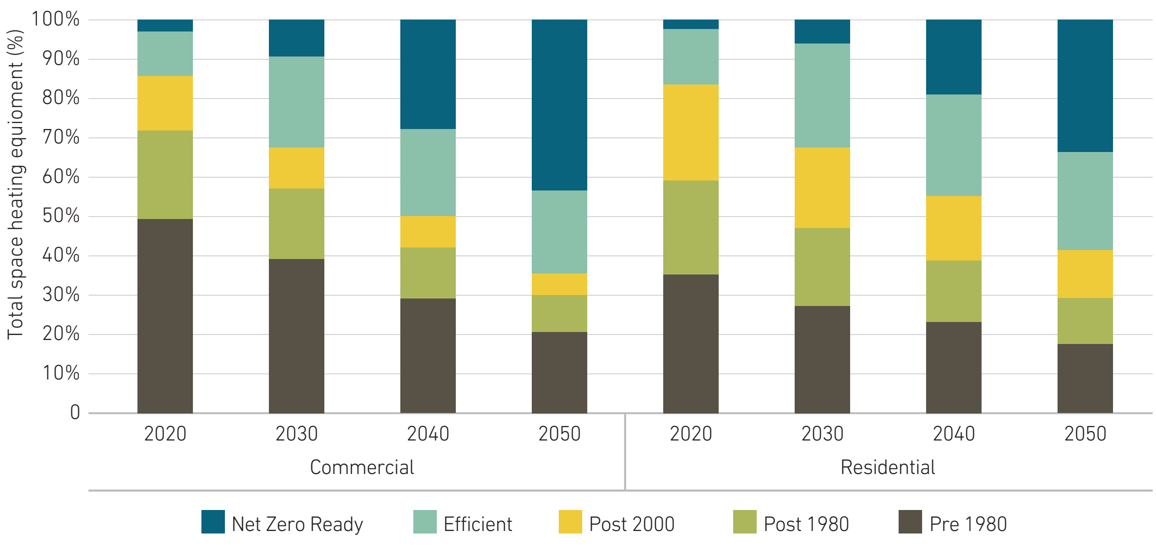


Figure 24: Building shells for commercial and residential buildings for the Zero Plus scenario

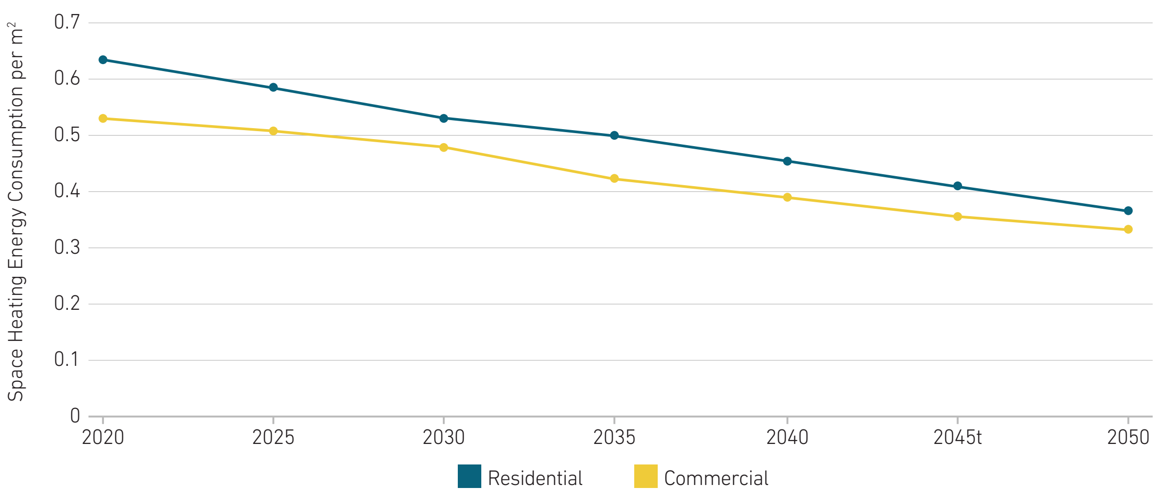


Figure 25: Space heating energy consumption per area for the Zero Plus scenario

Demand-side modelling: transportation

Transportation sector emissions are the second-highest source of greenhouse gas emissions in Canada. This is primarily due to the transportation sector's reliance on refined petroleum products such as gasoline and diesel.

A key strategy for eliminating transportation sector emissions is through the transition to battery-electric vehicles (BEVs) and other zero-emissions vehicles (ZEVs).[58] The demand-side modelling for the Zero Plus scenario involves increasing levels of electrification of light-, medium- and heavy-duty vehicles during the study period. However, it should be noted that the proposed federal ZEV sales mandate would require 60 per cent ZEV light-duty vehicle sales by 2030 and 100 per cent by 2035, which is somewhat more ambitious than the level modelled by Sawyer and Navius, where nearly 10 per cent of new vehicles sold in 2040 and 2050 could still be powered by combustion of liquid fuels. Because medium- and heavy-duty trucks are more challenging applications for battery-electric technologies, a smaller proportion of these fleets will be electrified by 2050 in our scenarios. It should be noted that we believe higher levels of transportation electrification are possible and should be pursued, and other modelling efforts are underway to explore the role renewables can play in supporting aggressive electrification of the transportation sector.[59]

Higher levels of transportation electrification are possible and should be pursued

Although out of scope of this report, reducing emissions in the urban transportation sector requires reduced reliance on passenger vehicles and increasing alternatives such as affordable and electrified public transit, active transportation and work-from-home options.[60]

In the charts below, "EV" means a fully battery-electric vehicle. "PHEV" means a plug-in hybrid electric vehicle, "FCEV" means a hydrogen fuel cell electric vehicle and the "other" category of vehicles is not necessarily only fossil fuel–powered internal combustion vehicles, but could include a variety of other vehicle types such as hydrogen internal combustion engines, biofuels or other zero-emissions vehicles.

A switch from fossil fuel–burning internal combustion engines to electric drivetrains in our vehicles also brings dramatic overall energy savings, leading to significant reduction in overall emissions and overall energy demand for the transportation sector.

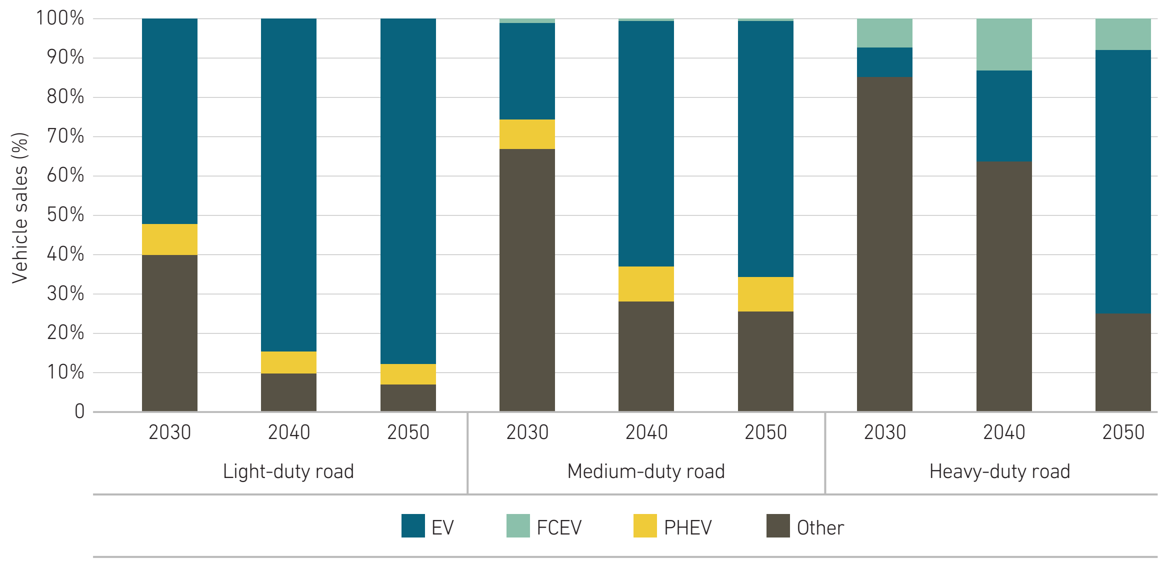


Figure 26: Annual vehicle sales for the Zero Plus scenario

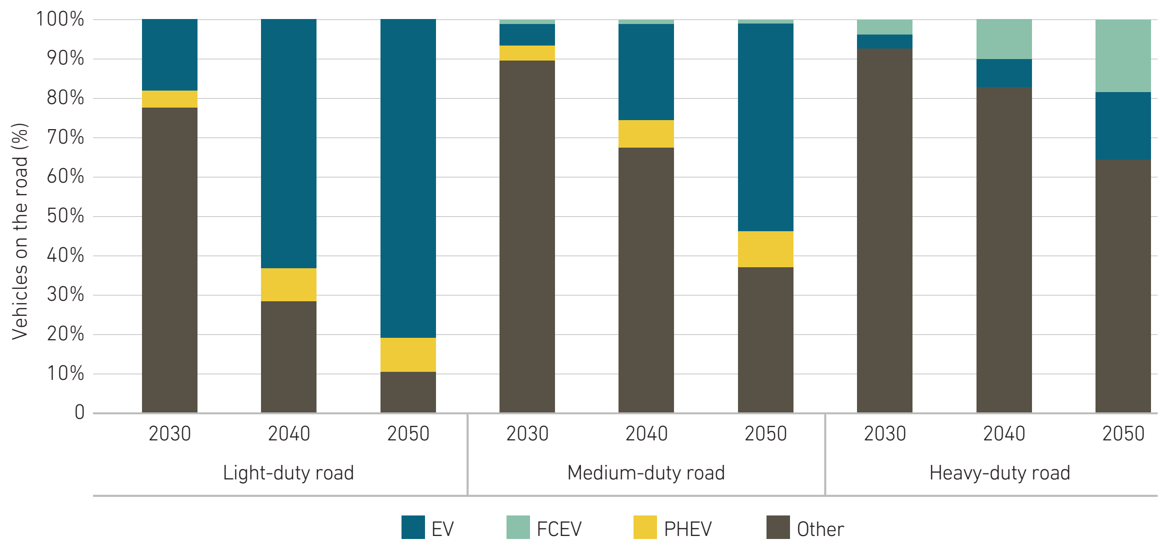


Figure 27: Share of vehicles on the road for the Zero Plus scenario

Demand-side modelling: industrial

With fewer opportunities for electrification in the industrial sector using currently available technologies, decarbonization is more challenging,[61] especially when it comes to high-temperature process heat. Industrial-scale heat pumps powered by electricity can help supply low- and medium-temperature process heat. A small proportion of high-temperature process heat can be readily supplied with electricity, such as for steel production. In other industrial applications, the gTech and IESD models assume as a default that fossil gas combined with CCS will be used and therefore this does not increase total electricity demand from the industrial sector.[62]

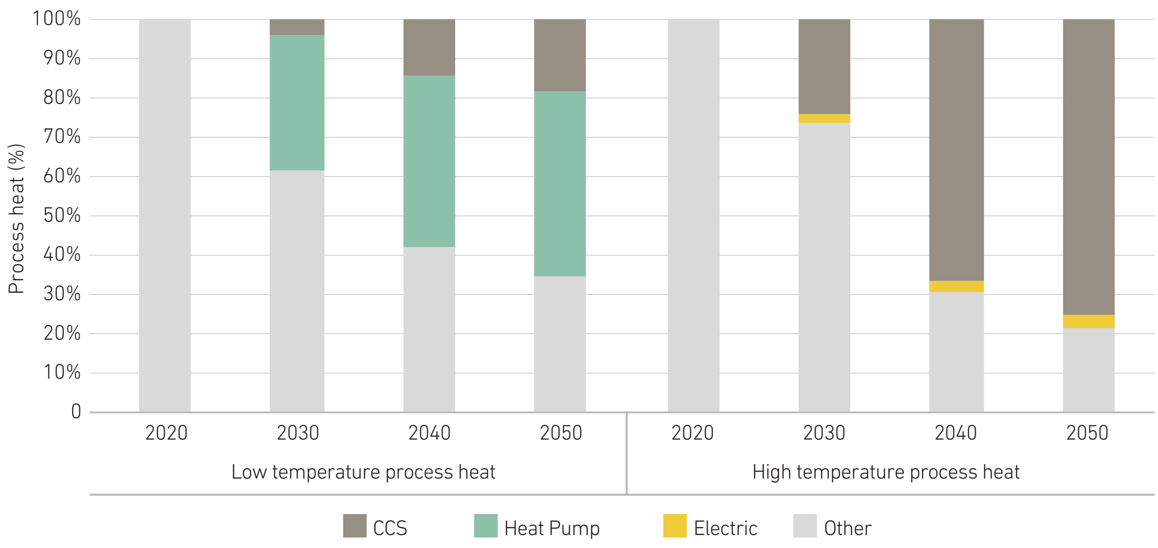


Figure 28: Share of process heat end-use by energy type for the Zero Plus scenario

FINANCIAL RESULTS

Maintaining and growing Canada's electricity system will be a significant financial undertaking in the decades to come no matter which pathways we choose. Energy affordability and keeping overall energy costs low for people living in Canada must continue to be a priority as we transition our energy systems. The financial results from the Clean Power Pathways scenarios were provided by the SESIT modelling team from the COPPER and SILVER models, and these results underwent further analysis by Bradford Griffin of Simon Fraser University's Canadian and Emissions Data Centre for the synthesized results presented in this report.

On point of comparison between scenarios is the total investment and operations cost of each scenario. The net present value (NPV) of total new construction, operation and maintenance costs of all electricity generation and new interprovincial transmission infrastructure between 2018 and 2050 is presented in the figure below. While the NPV of costs is highest in the Zero Plus scenario, this cost covers a much larger electrification of the economy than either of the other scenarios.

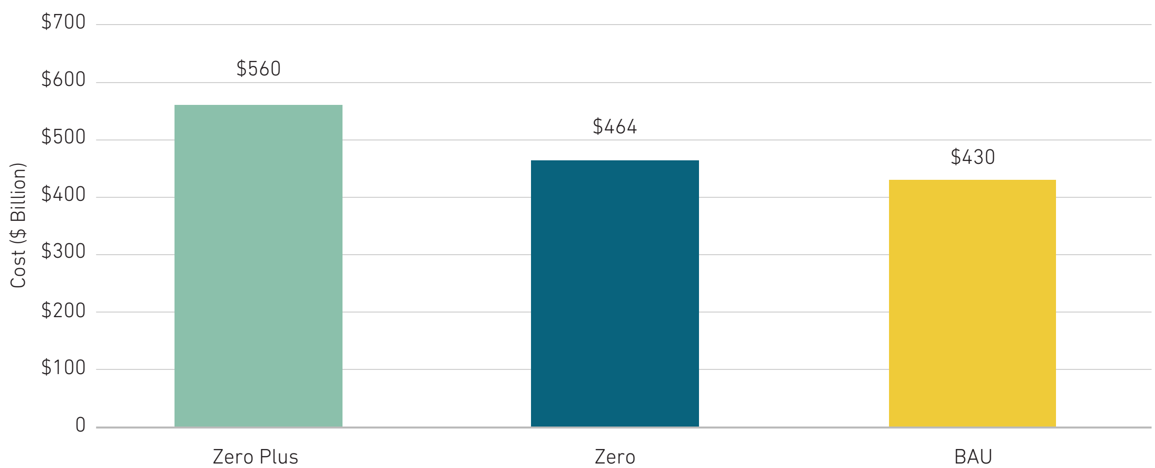


Figure 29: Comparison of total cumulative capital and operations costs from 2025-2050 per scenario

Considering the average cost of electricity provides another metric to compare scenarios, especially given the substantial differences in the demand for electricity across these scenarios. A system-wide-weighted levelized cost of electricity summarizes the differences between scenarios on a per unit of electricity basis. Levelized cost of electricity (LCOE) represents the average revenue per unit of energy production that would be required by a project owner to recover all investment and operating costs. Normally, LCOE is calculated for individual technologies in a given year as a measure to compare disparate technologies (for example, those that are capital-intensive versus fuel-intensive).

To calculate a system-weighted value, we divide all capital and operating costs (including carbon pricing) by total generation within a year. This value is used as a point of comparison between scenarios only and does not represent the marginal electricity costs or real delivered electricity costs to ratepayers for a given electricity system. In the figure below, the scenario costs are all remarkably similar. In the Zero Plus scenario, more capital-intensive, but cheaper to operate, wind and solar replace fuel-intensive natural gas generation. Despite the need for additional storage technologies and greater electrification of the economy, the average cost of supplied electricity decreases in line with the BAU and "Zero" scenarios.

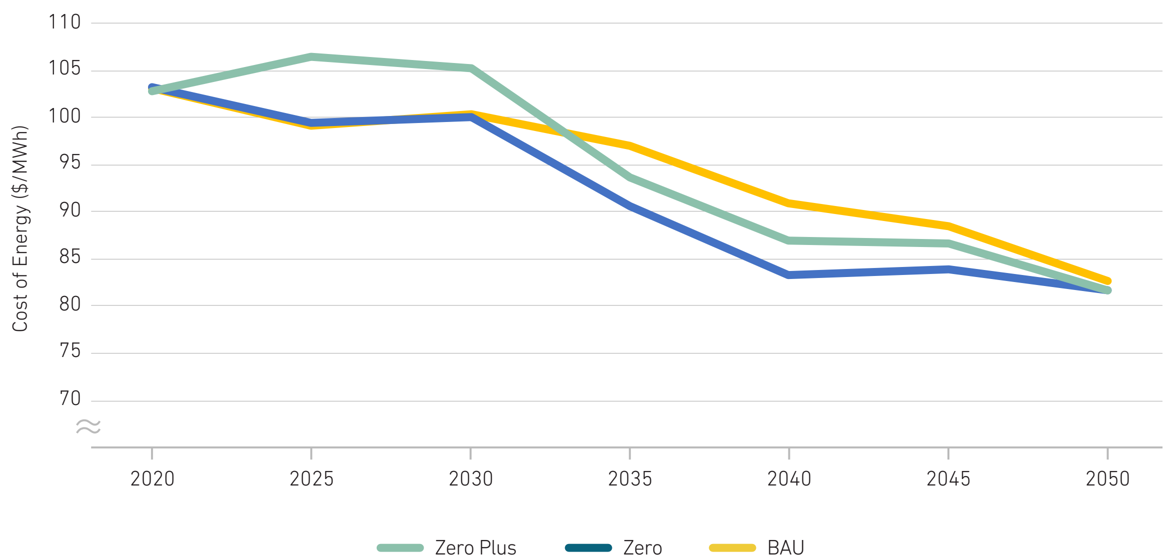


Figure 30: Scenario comparison weighted system LCOE over the study period

It is important to keep in mind the factors that an LCOE value includes and does not include. While this LCOE value captures the capital costs of new construction, it does not include any financing charges related to generation capacity existing before the start of our simulations in 2018. Operation and maintenance values represent the technical costs for each technology, but do not include any tax credits that might be received to incentivize particular technologies. Additionally, costs related to early decommissioning are not considered.

Perhaps most importantly, an LCOE value does not include representation of a technology's contributions to system flexibility, capacity-to-reserve margin or potential value attributions of the mismatch between the timing of generation and demand. However, these factors are considered in the capacity expansion model and dispatch model simulations provided by SESIT.

Cost estimates of technologies are continually evolving, especially for variable renewables like wind and solar, as well as storage options like batteries. While cost estimates sometimes trend upward, for the technologies mentioned, costs have decreased rapidly over the past several decades. We believe the cost estimates for wind, solar and renewables were quite conservative for these scenarios. Including alternative estimates for wind, solar and batteries could significantly lower the cost of our Zero Plus scenario. For example, using even the moderate price forecasts from the National Renewable Energy Laboratory's most recent Annual Technology Baseline from 2021 could have reduced the NPV (2018-2050) of the total cost of our high electrification scenario by as much as 28 per cent, and placed the comparative LCOE markedly below the BAU.

EMISSIONS PATHWAYS

Canada needs to move ahead without delay to achieve a zero-emissions electricity sector and meet climate commitments. By zeroing out the electricity sector's emissions by 2035 while ramping up generation to meet increasing demand, clean electricity becomes an even more valuable tool for decarbonizing Canada's economy. With 61 million tonnes of CO_2e emissions in 2019,[63] the electricity sector remains an important sector to decarbonize in the near term.

The emissions pathways of the "Zero" and "Zero Plus" scenarios are nearly identical and each achieve zero emissions in the electricity sector by 2035. These emissions pathways were among the key constraints given to the modelling team for each of the Clean Power Pathways scenarios. Each of these two scenarios has a cumulative greenhouse gas emissions savings for the electricity sector of **380 million tonnes of CO_2e over the 2025 to 2050 period**.

Like each of the Clean Power Pathways scenarios, the Business as Usual scenario[64] also achieves near-zero emissions by 2050, but because emissions remain relatively high until that date, the electricity sector's cumulative emissions over time are significantly higher.

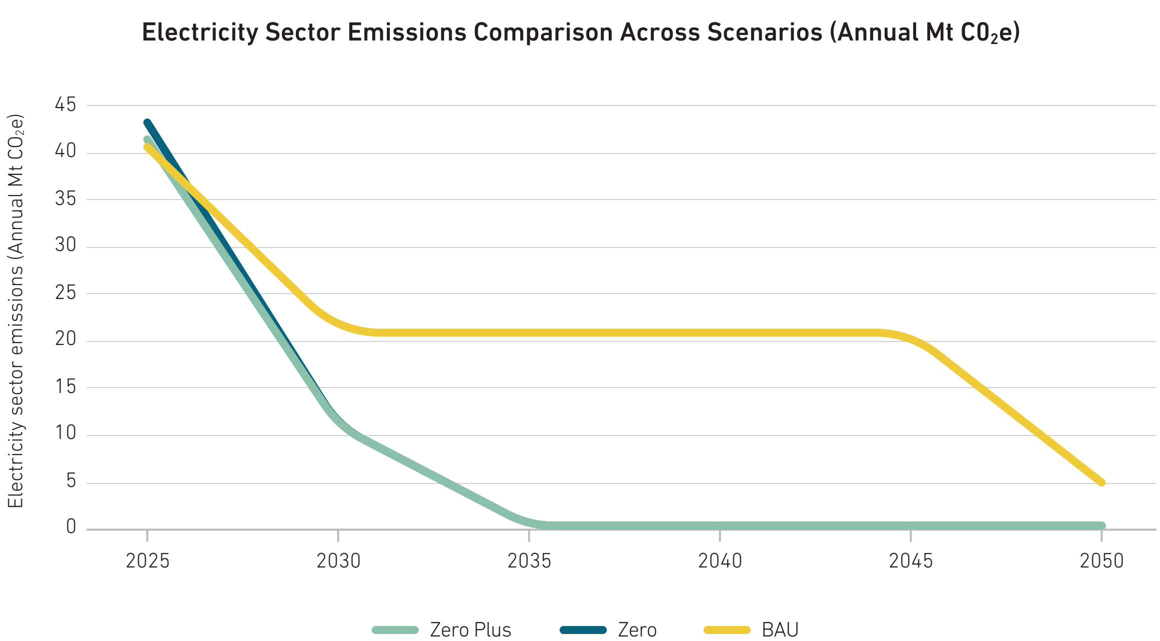


Figure 31: Electricity sector emissions across modelling scenarios

Although emissions avoided in the electricity sector are significant, the most substantial climate and health benefits of the Clean Power Pathways scenarios lie in switching energy end uses that currently rely on burning polluting fossil fuels to instead be powered with clean electricity. Our demand-side analysis shows this effect for the transportation, buildings and industrial sectors. Electrification also leads to marked improvements in energy efficiency in many applications (e.g., most of the energy in gasoline burned in a car is lost as heat).

When these emissions savings from electrification are also accounted for, the benefit of clean electricity grows significantly. For the Zero Plus scenario, the cumulative greenhouse gas emissions savings for Canada's electricity, transportation, industrial and buildings sectors grow to **3,200 million tonnes of CO_2e over the 2025-2050 period**.

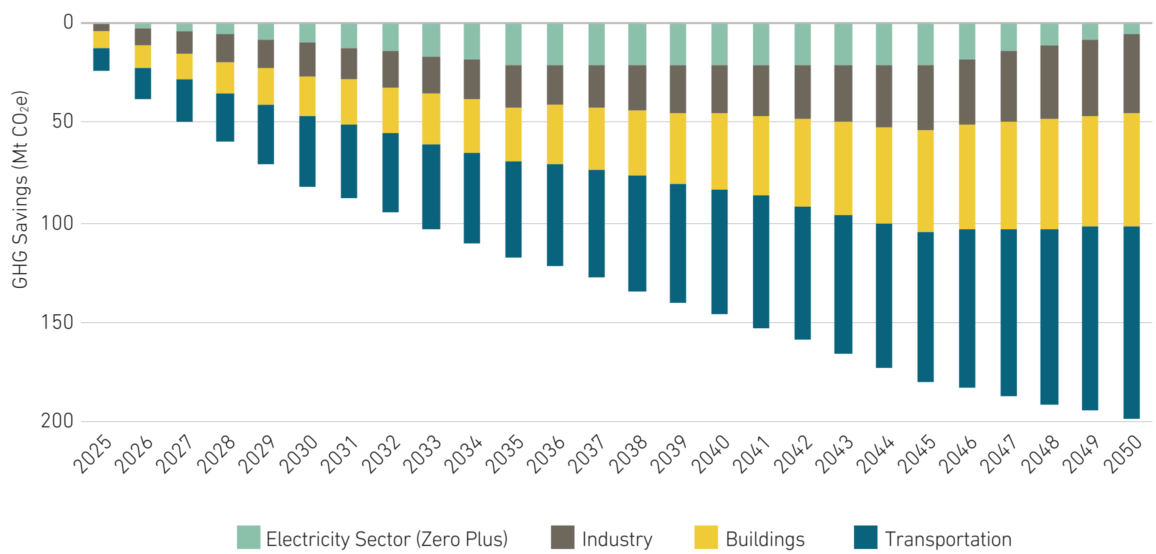


Figure 32: Total GHG savings from clean electricity and electrification by sector for the Zero Plus scenario

Photo: Adobe Stock Images

WHO BENEFITS? WHY IT MATTERS *HOW* WE ACHIEVE THESE PATHWAYS

The modelling we relied upon simplifies the real world, seeking only least-cost solutions to building out future generation, storage and transmission capacity to meet future energy demand within scenario settings and constraints. We recognize that a range of other factors and considerations will need to influence the grid of the future, including local preference for what renewable generation is built where, how provincial grid interties are strengthened and how electricity markets are structured.[65] These pathways need to be technically feasible as well as socially acceptable and to deliver benefits widely and equitably. These scenarios will also require significant capital investment to unlock climate and other benefits, and the models we used do not account for whether this investment will be from the public sector, Indigenous enterprises, the private sector, community co-operatives or hybrids of the these.

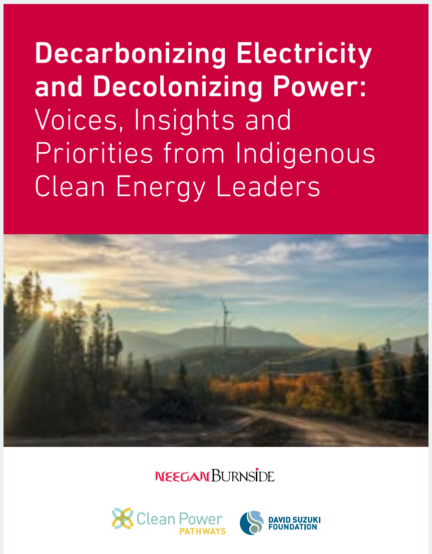
The version of the capacity expansion model we used for this study does not account for the role distributed renewable technologies, such as rooftop solar, or behind-the-meter battery storage, might play in reaching a zero-emissions grid. Recent studies suggest that adding distributed renewables can lower the system costs and help improve affordability for individual households or businesses.[66] Building out the grid in a way that also draws on scalable, distributed, low-impact renewable technologies will likely include local resilience and have a higher potential for community benefits and participation.

Alleviating energy poverty and improving access to reliable, affordable electricity are also crucial elements of consideration in this transition. In a later report, DSF will explore how to ensure people of all income levels benefit from the energy transition and no one is left having to choose between heating or cooling their home and affording other necessities of life.

INDIGENOUS RIGHTS AND OPPORTUNITIES FOR INDIGENOUS COMMUNITIES

As part of the Clean Power Pathways project, the David Suzuki Foundation contracted Neegan Burnside and Dean Jacobs to explore key priorities and opportunities for Indigenous communities in this transition. Drawing on a synthesis of insightful interviews with Indigenous clean energy leaders,[67] Neegan Burnside and Dean Jacobs identified six broad themes that need to guide planning and development of achieving 100 per cent zero-emissions electricity across Canada by 2035:

1. Indigenous world views and knowledge need to be incorporated and respected within broader societal and economic value systems;
2. Meaningful, rights-based and consent-based consultation needs to become common practice for all clean energy projects;
3. Existing Indigenous leadership needs to be honoured and advanced through support for capacity, ownership opportunities and jobs;
4. Indigenous leaders require a seat at decision-making tables, as decarbonizing electricity must also mean decolonizing power structures;
5. Solving systemic infrastructure gaps for Indigenous communities through focused just transition measures must be prioritized as part of the clean energy transition; and
6. Economic reconciliation must be central to the clean energy transition by removing barriers to accessing financial capital, ownership and other project benefits.



The full report from Dean Jacobs and Neegan Burnside, "Decarbonizing Electricity and Decolonizing Power: Voices, Insights and Priorities from Indigenous Clean Energy Leaders," is on the David Suzuki Foundation website.[68]

EMPLOYMENT AND ECONOMIC BENEFITS

> "Increasing employment under the transition to zero carbon is driven by the requirement for more labor in manufacturing, installation, and maintenance of renewables than their counterpart fossil fuel technologies. It takes more people to install and keep a wind farm running than it does to drill a well and keep it pumping for the same amount of energy over time. Renewables get their fuels for free, whereas fossil fuels cost money. It takes more labor and maintenance to access those free renewable fuels. This is a very desirable trade-off..."
>
> —*Job Analysis, Rewiring America*[69]

The David Suzuki Foundation performed high-level analysis on the potential for labour requirements resulting from the infrastructure build-out in the Zero Plus scenario. This analysis uses jobs factors retrieved from the National Renewable Energy Laboratory's Jobs and Economic Development Impacts (JEDI)[70] models, and a recent report from the Pembina Institute.[71] This analysis is intended to be insightful about the magnitude of the direct labour requirements for this level of build-out of infrastructure but is not meant to replace more detailed macroeconomic analysis for the overall transition in this sector.

The values presented below only account for the direct construction, operation and maintenance labour requirement for wind, solar, pumped-hydro storage and high-voltage transmission. We were unable to identify reliable jobs factors for deploying battery storage, so jobs resulting from that technology's build-out were conservatively assumed to be zero. Note also that this high-level analysis excludes any indirect or induced jobs, or any attributions for manufacturing jobs that could be created in Canada as the demand for wind, solar, energy storage and high-voltage transmission grows, or the overall growth of the electricity sector. Similarly, the labour requirement from related electrification activities in transportation, buildings and industry are not included in this analysis.

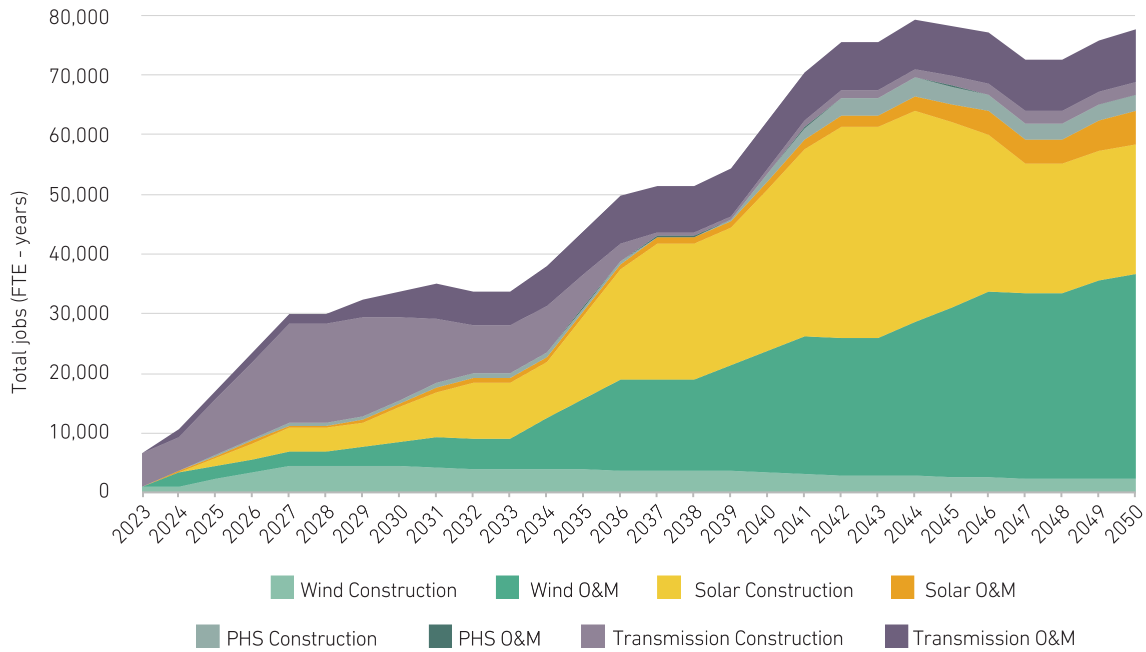


Figure 33: Annual employment requirement for the Zero Plus scenario

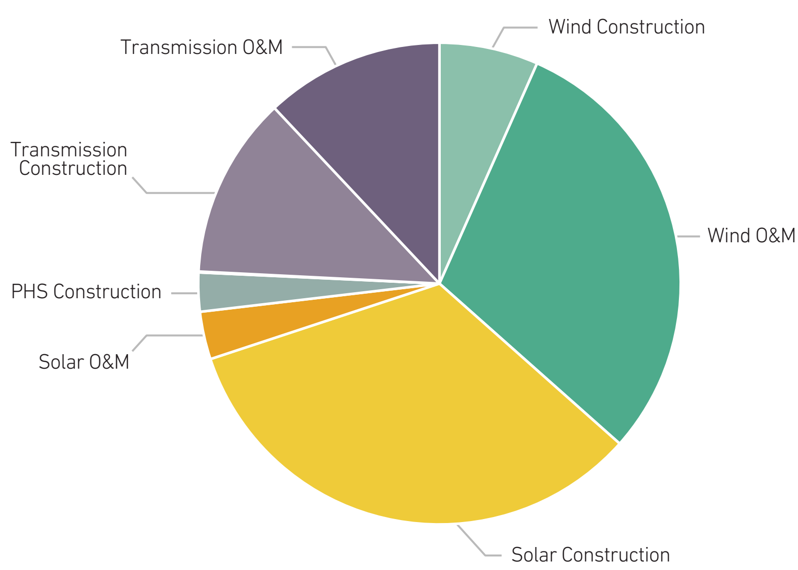


Figure 34: Share of total FTE-years of employment requirement by technology type for the Zero Plus scenario

Photo: Green Energy Futures

The Employment Dividends of Renewables and Electrification

By Jim Stanford

The global energy transition continues to build momentum, despite (or perhaps because of) the disruptions in the world economy experienced over the past three years — including the COVID pandemic, shattered supply chains and now Russia's invasion of Ukraine. If anything, the vulnerability that nations face from sky-high petroleum prices and supply disruptions only reinforces the business case for rapid transitions to renewable, self-sufficient energy.

That's why the rollout of alternative energy systems is accelerating, and this will continue as the economy recovers from the pandemic. Key features of this real-time energy revolution include:

- Major expansion in renewable sources of electricity generation.
- Electrification of all sectors in the economy (including transportation).
- A growing emphasis by financial investors on decarbonizing portfolios — and positioning to capturing future profits from renewable energy.

As the energy transition picks up speed, fears about potential negative employment effects from renewable energy have become less compelling, with good reason. Jurisdictions around the world (including Canadian provinces) have proven that successful transitions from fossil fuels to sustainable, electrified power systems can be accomplished without negative impacts on employment and labour markets.

The new Clean Power Pathways report provides important new evidence regarding the net employment benefits from the coming electrification of Canada's economy. Far from undermining job prospects, even in petroleum-producing regions of Canada, accelerated electrification would open up very attractive new opportunities in a range of industries and occupations.

Several streams of employment benefits would be unleashed by an ambitious, accelerated electrification strategy. Jobs would be created up and down the entire energy supply chain:

- Jobs in developing and operating renewable generation systems (including solar, wind, geothermal and hydroelectric power). Construction of these projects will create hundreds of thousands of person-years, with thousands more ongoing jobs in operation and maintenance.
- New work in expanding and upgrading the electric grid. Major investments will be required to upgrade transmission facilities, install modern control and regulating equipment and prepare the grid for the more complex and variable power distribution requirements associated with dispersed renewable generation.
- Manufacturing of capital equipment and other material inputs to renewable generation projects. With appropriate value-added industrial strategies to enhance Canada's industrial footprint in these growing industries, thousands of permanent jobs would be created manufacturing wind turbines, solar power equipment, transmission equipment and materials, and other capital inputs to electrification.
- Installation and maintenance of new equipment that uses electricity in various industrial and consumer applications — everything from residential heating systems to electric vehicles to large industrial power systems.
- Jobs in new industries attracted to Canada by the availability of clean, reliable and competitive electricity. Canada's abundance of primary renewable electricity resources would position us at the forefront of the global transition to sustainable electric energy. That will stimulate interest and investment by industrial firms and financial investors around the world.

The "Clean Power Pathways" report presents a rigorous and credible roadmap, showing accelerated electrification of Canada's energy system is technically feasible and economically appealing. Investments in both generation capacity and transmission facilities ensure that a fossil-fuel-free electric network can reliably supply all of Canada, in all seasons. The Clean Power Pathways simulations indicate that 75,000 new jobs would be created by the rapid decarbonization of Canada's electricity grid over a roughly 15-year period — in wind and solar generation, new transmission facilities and storage. Thousands of other jobs will be spurred in installation, electrical upgrades and building retrofits. The biggest beneficiaries of this jobs boom are current fossil-fuel-producing regions (like Alberta and Saskatchewan), where the GDP and employment gains from electrification are even larger.

These positive employment forecasts have been verified by other Canadian research (including Clean Energy Canada, IRENA, Navius, the Ecology Action Centre and C40). This is no longer a hypothetical scenario: thousands of these jobs are already being created each year, as renewable power generation and applications expand throughout Canada's economy. An accelerated electrification strategy, however, would ensure those gains are captured more rapidly and fully.

Of course, the transition to a sustainable electrified power system is a complex, multi-faceted process. Some industries will shrink as this transition continues, and some jobs in those industries will disappear. It is important that this transition is managed proactively and fairly. But given the small number of jobs in Canadian fossil-fuel electricity production and distribution (less than 20,000 at present), lost jobs will certainly be more than offset by new jobs created.

In fact, this transition is *already occurring* without undue job loss or disruption. Canada's electricity system has already reduced its reliance on fossil fuel primary energy by one-third over the past two decades: from over 25 per cent at the turn of the century to 17 per cent by 2020. During that time, employment in the electricity generation and distribution sector *increased* — adding over 10,000 new jobs. Changing the primary source of power for electricity generation has no inherent negative impact on employment in this activity. Indeed, since renewable power sources are more labour-intensive than fossil fuel extraction, this transition will increase overall employment. Jobs in remediation and cleanup of previous fossil fuel facilities will further strengthen the net employment balance.

Concerns about job loss have been weaponized for years by vested corporate interests trying to deny or delay the transition to renewable energy sources. Their frightening predictions of job loss were never credible. But now the empirical evidence is clear: tens of thousands of new jobs are already being created as the energy revolution rolls on. The sooner and more fully we embrace it and accelerate electrification of Canada's economy, the faster those jobs will arrive.

Jim Stanford is economist and director of the Centre for Future Work in Vancouver. His report, "Employment Transitions and the Phase-Out of Fossil Fuels," described how fossil fuels could be phased out of Canada's economy without unemployment.

PROTECTING NATURE, BIODIVERSITY AND CULTURAL VALUES

Building out the grid with renewables as projected in our scenarios would affect large areas across each of the provinces. Beyond addressing Indigenous rights, land uses and other priorities, careful analysis and planning is needed to ensure that renewable infrastructure and transmission lines are located in landscapes in ways that minimize deleterious impacts on biodiversity or connectivity. Where possible, all infrastructure projects should be evaluated for their potential to support biodiversity recovery and incorporate elements of natural infrastructure.

In some regions, wind farms can be located with relatively little impact, such as in certain agricultural landscapes. Areas that supply critical habitat for migratory birds would likely be poor candidates for a wind farm location. Likewise, prime agricultural lands are better suited for food production and would be poor choices, in most instances, for locating solar farms (though solar PV on farm buildings makes good sense and they can reduce farmers' energy costs). Research suggests there are instances where electricity generation via solar PV farms and food production can be compatible with land uses.[72] Where possible, existing linear infrastructure, such as railway rights-of-way or highway corridors, should be considered for transmission lines to avoid additional habitat fragmentation and impacts on local communities, and potentially to speed up the pace of deployment.[73]

The capacity expansion model COPPER represents the study area (Canada south of 60º latitude) as 2,278 cells. Future analysis is needed to explore how constraining the model from selecting certain grid cells with high biodiversity value or other land-use constraints (such as lands excluded

Photo: Adobe Stock Images

by Indigenous title holders, critical habitat for SARA-listed species or key recreational or cultural areas) as potential sites to locate incremental renewable energy generation would impact model outputs. For instance, WWF-Canada has a tool to help renewable energy planners and developers locate projects to avoid key habitats,[74] and this could be overlaid to limit or zero out renewable potential in given cells. Likewise, in future scenario modelling, those cells that overlay areas of high population density could be partially or fully constrained, to ensure that COPPER avoids selecting regions that are poorly suited for renewable deployment because of existing infrastructure or conflicts with pre-existing land uses, or deploys suitably lower densities of renewable generation. For instance, wind farms and grid-scale solar farms are unlikely to be built in greater Montreal or Vancouver,[75] while modest levels of wind and solar generation might be acceptable near smaller communities. However, it was beyond the scope of this study to incorporate such constraints.

These limitations imply that the present study may somewhat understate the costs of powering Canada's grid with renewables, as some cells selected by the capacity expansion model for wind and solar deployment in the scenarios presented here would need to be replaced with others at greater distances from the existing grid or where the solar and/or wind resources are not as high quality. However, because the cells are fairly large, such constraints might only apply to a portion of the cell and there were relatively few cells where COPPER fully exploited the available renewable resource. Finally, adding distributed renewables like rooftop solar to the modelling suite would provide for generation that is likely to have little impact on biodiversity values while tempering the need for larger projects.

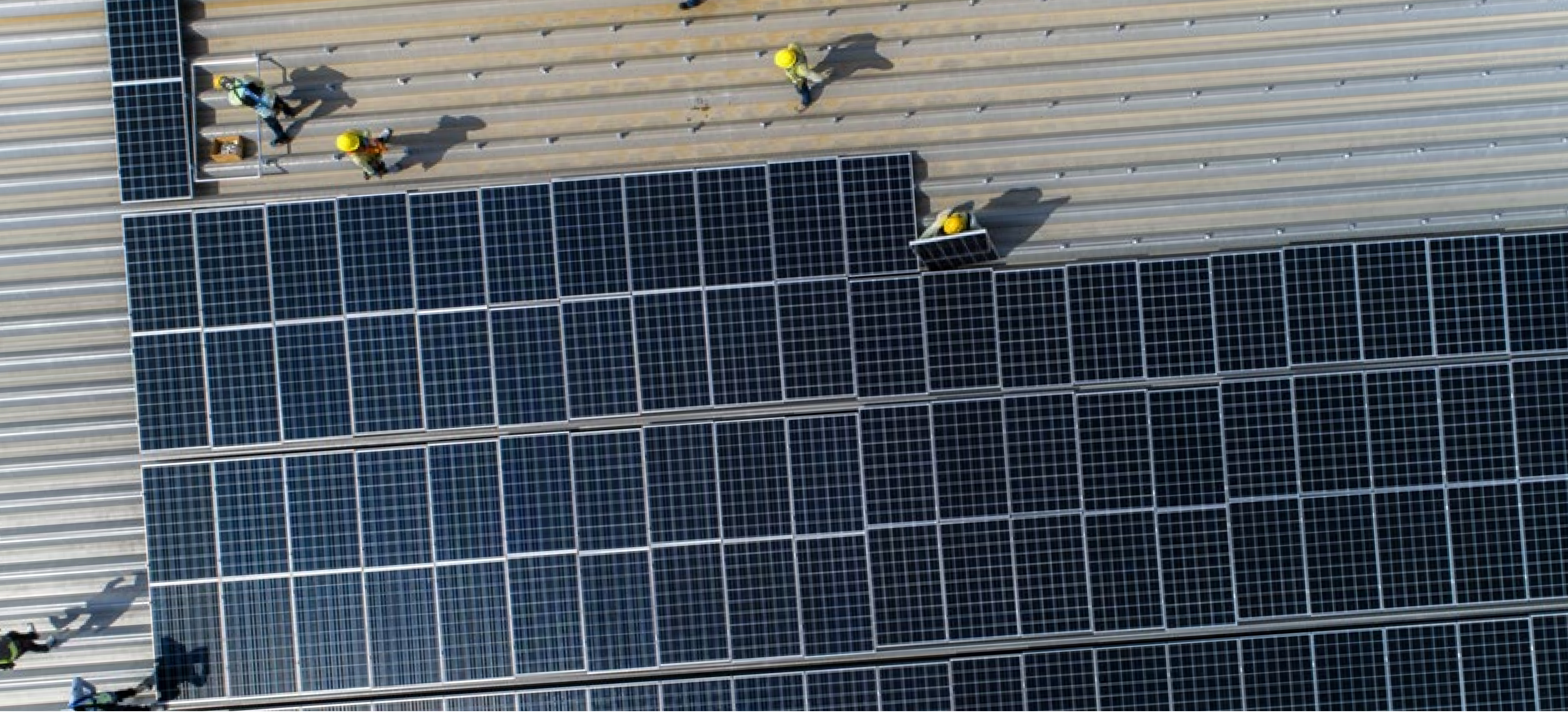


Photo: Adobe Stock Images

DISCUSSION AND RECOMMENDATIONS

> When you have a climate and energy emergency, like now, you need to invest judiciously, not indiscriminately, to buy the most efficient solution. Far better to deploy fast, inexpensive and sure technologies like wind or solar than one that is slow to build, speculative and very costly. Anything else makes climate change worse than it needs to be.
>
> — *Amory Lovins*[76]

The modelling presented in this report demonstrates that Canada's electricity system can achieve zero emissions by 2035 primarily through investments in wind, solar, energy storage and interprovincial transmission, complemented by investments in energy efficiency. To further drive down emissions, economy-wide electrification must be prioritized, offering further efficiency gains and improved local air quality.

To recap, our report finds:

- Expanding wind and solar electricity should be the foundation of achieving 100 per cent zero-emissions electricity across Canada by 2035 and meeting growing electricity demand to 2050.
- Energy efficiency, energy storage, existing hydroelectricity and grid connections between provinces work together to deliver reliability and flexibility for pathways with high levels of wind and solar generation.

- A zero-emissions electricity system powered by renewables is a cost-effective and affordable way to meet the growing demand for electricity.
- Cleaning up and expanding the grid by investing in renewables and transmission will lead to high numbers of new careers in clean energy across Canada.
- By cleaning up the electricity sector and switching out fossil fuels for clean electricity, these pathways deliver emissions reductions that support Canada's climate targets and net-zero goals
- The companion report by Neegan Burnside and Dean Jacobs describes how Indigenous clean energy thought leaders emphasize that decarbonizing electricity requires decolonizing power and ensuring benefits flow to Indigenous communities.

Investments in clean electricity will need to be scaled up rapidly to meet our stated climate and electricity goals in Canada. However, Canada starts from an enviable position when it comes to zero emissions electricity, thanks in large part to existing hydroelectric capacity, mature renewable electricity industries and a wealth of wind and solar resources.

Over the past two decades, governments have been taking measures to clean up the national electricity grid. From 2003 to 2014, Ontario went from relying on coal for 25 per cent of its generation capacity to zero.[77] The federal government has mandated that unabated coal generation be phased out nationwide by 2030. The federal government is currently developing regulations for a Clean Electricity Standard that will chart the path to 100 per cent net-zero electricity by 2035.[78] Over the past couple of years, despite a provincial government that has failed to prioritize climate action, Alberta has witnessed a surge in private sector investments in grid-scale wind and solar installations. This includes the Travers project, which will be Canada's largest solar farm at 465 MW when completed, eclipsing the previous record of 100 MW in Ontario.[79] Such developments have helped accelerate the timeline for phasing out coal generation in Alberta from 2030 to 2023,[80] though climate challenges remain as some coal generation is being converted to gas and new gas generation stations are still being commissioned. Though Saskatchewan lags behind its neighbour to the west, it too is emerging as a preferred location for renewable investment: from a baseline of 244 MW of wind in late 2021, more than 600 MW of wind and solar will be added to the grid in the near term, with First Nations leading a number of projects.[81] To the east, the effort to link the four Atlantic Canadian provinces and Quebec through a high-voltage transmission network called the "Atlantic Loop" is gathering momentum. If successful, this would facilitate adding more wind and solar to the grid in maritime provinces as coal and gas are phased out.

A notable outcome of the capacity expansion modelling was that even when allowed to do so, COPPER does not select large nuclear or new small modular nuclear reactors as cost-effective options. This should not be too surprising, as the costs for renewables have continued to plummet as more and more wind and solar generation capacity is installed globally,[82] while the costs of nuclear have continued to rise as safety requirements are updated. Indeed, new nuclear is generally uneconomic without subsidies[83] and federal guarantees or legislation that let operators off the hook for any costly nuclear accidents.[84] Furthermore, unlike off-the-shelf renewable technologies, SMNRs remain at the conceptual stage. The strategic plan for the deployment of SMNRs put forward in March 2022 by the four supportive provinces only envisions the first SMNR being commissioned in 2035, implying they will have limited relevance during the time frame when decarbonization and expansion of the grid is most urgent.[85] Even so, both at the federal and provincial level, there is enthusiasm for further investments in nuclear that are likely to be needlessly expensive approaches to supplying more zero-emission electricity, with attendant problems in nuclear waste disposal and proliferation risk. The modelling presented here shows this is unnecessary. Likewise, the pathways presented here show reliable and affordable electricity can be delivered by 2035 without depending on continued unabated fossil fuel generation, or on fossil gas generation with carbon capture, utilization and storage, reducing the need to turn to expensive direct air capture or bioenergy with carbon capture and storage to net out remaining electricity sector emissions. Finally, recognizing the impacts building large hydro reservoirs can have on landscapes and Indigenous land uses, the scenarios evaluated excluded large new hydroelectric projects, while taking full advantage of the energy storage capacity offered by existing dams.

Photo : Adobe Stock Images

POLICY RECOMMENDATIONS

The following recommendations are proposed to support cleaning up Canada's electricity system and expanding its ability to decarbonize the broader economy in Canada at a pace and scale commensurate to the climate emergency, all the while delivering affordable and reliable power and community benefits:

1. Prioritize proven, affordable, scalable and zero-emissions technologies like **wind and solar generation, energy storage, energy efficiency and improved transmission**.

    a. Renewable electricity sources are technically mature and the cheapest form of new electricity available. They, along with enabling technologies and policies, should be prioritized as the primary source of new electricity generation.
    b. Governments, utilities, businesses and households need to prioritize energy efficiency and conservation since in many cases the cheapest source of energy is the energy saved through efficiency.[86]
    c. To deliver early emissions reductions and to avoid new fossil generation assets being locked in or stranded, the federal government should put in place a stringent clean electricity standard and ensure that the electricity sector is fully exposed to carbon pricing.
    d. Terminate federal and provincial public financing of fossil fuel generation with carbon capture, utilization and storage and new small modular nuclear reactors and redirect public funds toward renewable electricity and the technologies that enable it.

2. **Maximize the value that can be delivered by the electricity system by taking a whole-system approach**, recognizing how the flexible operation of Canada's existing hydroelectric fleet; new energy storage capacity; new interprovincial and interregional transmission capacity; complementary energy efficiency and diversity of wind and solar resources can all contribute to achieving grid flexibility and reliability.

3. **There is no time for delay.** The build-out of renewable generation must start immediately if we are to achieved 100 per cent zero-emissions electricity by 2035 throughout Canada. Concurrently, electrification across the economy must be accelerated to wean society off of fossil fuels and to reach climate targets.

4. **Collaboration is key and reforms are needed in utility regulation.**

    a. Mandates are needed for electric utilities and system operators that give clear direction for electricity sector decarbonization by 2035, to promote interprovincial collaboration and connections and to harness the electricity sector's role in economy-wide decarbonization by 2050.
    b. Electricity system governance (from utility commissions to electricity markets) must evolve quickly to support the deployment of renewable and enabling technologies.
    c. Higher levels of interprovincial transmission are beneficial, and collaboration between system operators and provincial governments will be necessary to update policies and mandates that allow for mutually beneficial, cross-jurisdiction electricity planning and operation.
    d. The new Pan-Canadian Grid Council should support interprovincial electricity trade, regulatory reform and knowledge sharing toward high levels of renewable electricity.

5. **Prepare the workforce.** Canada must develop and properly fund training and retraining programs for the significant labour requirement needed in renewable electricity generation, energy efficiency and clean electrification.

6. **A national energy poverty strategy** and federal support for regulatory solutions to energy poverty are required. As end uses increasingly switch to the electricity sector, more energy poverty considerations will fall under the electricity sector's umbrella. Focused programming for low- and moderate-income and equity-seeking households must be a priority.

7. **Mobilize money and unlock opportunities.** Building out renewables, expanding interprovincial transmission, modernizing the grid, incorporating new storage technologies and electrifying the economy will require redirecting investment flows from carbon-intensive sectors **to markedly increase the level of investment** in the electricity sector and in economy-wide electrification. Governments can play a role in de-risking investments, correcting market failures and enabling Indigenous ownership and community-owned renewables.

The above policy recommendations should be read in conjunction with the companion study by Neegan Burnside and Dean Jacobs, which found that Indigenous rights and title must be forefront in the planning, development and deployment of renewable generation, transmission and storage in support of a 100 per cent clean electricity grid:

- Indigenous world views and knowledge need to be incorporated and respected within broader societal and economic value systems.
- Meaningful, rights-based and consent-based consultation needs to become common practice for all clean energy projects.
- Existing Indigenous leadership needs to be honoured and advanced through support for capacity, ownership opportunities and jobs.
- Indigenous leaders require a seat at decision-making tables, as decarbonizing electricity must also mean decolonizing power structures.
- Solving systemic infrastructure gaps for Indigenous communities through focused just transition measures must be prioritized as part of the clean energy transition.
- Economic reconciliation must be central to the clean energy transition by removing barriers to accessing financial capital, ownership and other project benefits.

While this report offers insights on prospects for cleaning up and expanding Canada's grid by turning to renewables, we offer the modelling as a tool to generate insights, not a prediction or a blueprint of the future. We acknowledge that we had to limit the project's scope and that additional scenarios could have been modelled that included other technologies that can play a role in the clean electricity transition, such as offshore wind, geothermal generation, distributed energy resources, demand response, green hydrogen and emerging energy storage technologies. These technologies are also evolving at a dizzying pace, confronting modellers and analysts with the need to frequently update technology characteristics and costs. More in-depth economic analysis of the costs and implications of different pathways would also be helpful to support deliberations about Canada's electricity future. We also believe that useful insights could be derived by harnessing the geographic resolution of the capacity expansion model to evaluate how incorporating biodiversity, critical habitat and other land-use constraints would influence the likely deployment of renewable generation and transmission across regions. Further analysis into optimal density of wind and solar deployment over large areas within different regions would be useful. Furthermore, it would be highly relevant to explore the implications of year-to-year variability in weather and the implications of climate change for renewable generation and electricity demand over time.

Fossil fuels are putting the future of humanity and the planet in peril. Clean electricity grids are widely recognized as having a lead role to play in eliminating fossil fuel use and emissions across the economy. The transition to zero-emissions electricity requires ongoing learning, experimentation, piloting, testing, critiquing and adaptation to changing circumstances. We welcome and encourage future efforts that build on the modelling presented in our report. Nonetheless, we are confident in the core findings of our report: zero emissions is possible in the electricity sector across Canada by 2035, and renewables can and should play a foundational role in Canada's future electricity grid. Done right, we can all benefit from cleaner air, better health, good jobs and a safer future.

ENDNOTES

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31 For instance, for a gas-powered generating station, the model accounts for the emissions from burning the fuel to generate electricity, but does not account for any methane that may be vented or that leaks upstream from the generating station).

32 As climate policy ramps up, technologies improve and the economy is increasingly electrified, an increasing proportion of these activities would become non-emitting.

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39 Each grid cell is ½ degree by 2/3 of a degree. They vary in east-west width from 48.6 km at the 49th parallel to 37 km at the 60th parallel and they have a north-south height of roughly 55.5 km. Wind generation built by COPPER in each cell is constrained to 2 MW per km2 while solar generation is constrained to a maximum of 31.3 MW per km2

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Clean Power PATHWAYS

DAVID SUZUKI FOUNDATION