Implications of Decarbonizing Canada's Electricity Grid

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Summary

- Canada's federal government has set an ambitious national target to achieve 100% carbon-free electricity by 2035. This goal presents Canada with the dual challenge of decarbonizing its existing electricity grid while expanding capacity to meet growing demands across transportation, industry, and buildings. This bulletin explores a critical aspect of this transition: expanding the production of clean electricity to replace current fossil fuel-based generation.
- The scale of replacing fossil fuel-based electricity generation is substantial. In 2023, clean energy sources—including hydro, nuclear, wind, and solar—produced 497.6 terawatt hours (TWh) of electricity, accounting for nearly 81% of Canada's total supply. However, fossil fuels still contributed 117.7 TWh, or 19.1% of total supply. Replacing this fossil fuel-based electricity with hydro power alone would require constructing approximately 23 large hydro projects like BC's Site C—or 24 similar to Newfoundland & Labrador's Muskrat Falls. If nuclear power were to assume this role, it would necessitate building 2.3 facilities equivalent to Ontario's Bruce Nuclear Generating Station or 4.3 similar to the Darlington Nuclear Generating Station. Alternatively, transitioning to wind energy would require the installation of around 11,000 large wind turbines within the next decade. Addressing the intermittency of wind energy would also demand substantial investments in energy storage solutions like lithium-ion batteries and/or backup power systems, further escalating costs to the electricity system.
- The process of planning and constructing electricity generation facilities in Canada is complex and time-consuming, often marked by delays, regulatory hurdles, and significant cost overruns. For example, the BC Site C project took approximately 43 years from the initial feasibility and planning studies in 1971 to receive environmental certification in 2014, with completion expected in 2025 at a cost of $16 billion. Similarly, developing the eight nuclear units at Ontario's Bruce Nuclear Generating Station spanned nearly two decades, hindered by safety concerns and public opposition.
- Canada's slow and cumbersome system for approving major projects is further complicated by the federal Impact Assessment Act introduced in 2019, which has added additional layers of uncertainty and complexity to the review process. Given the slow pace of regulatory approvals and extended construction timelines, achieving the necessary expansion of clean electricity generation and grid infrastructure by 2035 appears unrealistic.
- Beyond regulatory challenges and the high and steadily rising costs of building major energy projects, the land requirements for new electricity generation facilities also present significant obstacles. Replacing 117.7 TWh of fossil fuel-based electricity with wind power, for example, would require approximately 7,302 square kilometers of land—larger than Prince Edward Island and nearly nine times the size of Calgary. Hydropower projects would require even more land, about 26,345 square kilometers, nearly half the size of Nova Scotia.
- The expansion of renewable energy also brings complex challenges related to infrastructure siting and facility location. Although there is broad support for renewable energy sources, local communities often resist these projects. Overcoming public opposition to the siting of clean electricity facilities and their supporting infrastructure is another significant challenge that must be addressed.

Introduction

The federal government has set an ambitious national target to achieve 100% carbon-free electricity by 2035—just over a decade from now—and to reach net-zero greenhouse gas emissions economy-wide by 2050. The proposed Clean Electricity Regulations, the final version of which will be released in 2024, are intended to steer and enforce the transition to a net-zero electricity system by 2035. This transition involves not only replacing existing fossil fuel-based electricity generation but also expanding capacity to meet the expected dramatic rise in electricity demand in the coming years and decades. According to the federal government's 2024 budget, Canada's electricity demand is expected to double from 2022 to 2050 (Department of Finance Canada, 2024). Factors driving this increase include the expected widespread adoption of electric vehicles, population growth, the electrification of industrial processes, and the use of building heating pumps—all designed to reduce the use of fossil fuels as an energy source and an input into industrial production. To meet this increased demand for electricity, the federal government estimates that electricity system generation capacity must increase by up to 2.2 times from current levels (Department of Finance Canada, 2024). Some forecasts envisage that generation capacity must expand by as much as 3.4 times by 2050 (Dion et al., 2022). Such targets mean doubling or tripling the electricity output developed in Canada over the past century—and doing so in just a quarter of the time.

Canada faces the immense dual challenge of decarbonizing its existing electricity grid while simultaneously expanding electricity generation capacity to meet new demands across transport, industry, and buildings (Canadian Electricity Advisory Council, 2024). Currently, electricity accounts for less than 20% of Canada's total energy end-use consumption. The other major sources of energy consumed in Canada are refined petroleum products (about 40%) and natural gas (36%). Biofuels play a much smaller role, accounting for six to seven percent of energy consumption (Canadian Energy Regulator, 2024).

Achieving the goal of decarbonizing Canada's electricity grid by 2035 and reaching net-zero emissions across all sectors by 2050 will require clean electricity to become the country's primary form of energy supply. Studies indicate that this will necessitate roughly tripling electricity's share of total energy consumption within a single generation (Natural Resources Canada, 2024). Failing to provide sufficient electricity to meet the growing demand could lead to price spikes or limited access to electricity.

This essay investigates one part of the broader challenge of decarbonizing the Canadian economy: namely, expanding the production of clean electricity to replace the existing electricity generated from fossil fuel sources. We do not explore the need to expand electricity generation to meet the demand associated with population growth or a policy-driven "big switch" from fossil fuel energy sources to clean electricity across the economy (Dion et al., 2022). Instead, we concentrate on the seemingly simple task of replacing current fossil fuel-based electricity with clean generation. To underscore the magnitude of the challenge confronting Canada in this endeavour, we provide illustrations of what it would entail to generate this new electricity utilizing existing electricity infrastructure, such as British Columbia's Site C or Ontario's nuclear power from Bruce Power.

We begin with an overview of Canada's electricity grid. In the second section, we examine what replacing fossil fuel electricity with clean energy in Canada would entail. Next, we discuss the challenges Canada will face in this transition. Finally, we offer concluding remarks.

Overview of Canada's Electricity Grids

We start by providing an overview of Canada's electric grid. Table 1 illustrates the Canadian electricity generation sector's installed capacity by energy source in 2020, the latest year of available data. Capacity is the maximum output of electricity a generator can produce under specific conditions. As of 2020, hydro/tidal generation capacity in Canada reached 81 GW, comprising 54.2% of the nation's total installed capacity. Meanwhile, natural gas contributed 16.1%, with wind and nuclear energy accounting for 9.4% and 8.7%, respectively. Coal and oil together account for 8.4% of Canada's capacity.

While generation capacity showcases the maximum electricity supply potential of a generator, actual electricity production varies. For example, hydroelectric power generation can fluctuate based on the water level in the reservoir behind the dam, which changes with the seasons, or from the flow of water in the case of run-of-rivers assets. Similarly, wind and solar energy are intermittent sources affected by weather conditions such as cloud cover and solar irradiance, as well as the time of day. The efficacy of a generator in delivering electricity is measured by its capacity factor (CF), which indicates the ratio of actual electricity generation to the maximum potential output over a specific time frame. According to data from the U.S. Department of Energy in 2021, nuclear energy boasted the highest capacity factor at nearly 93%, while natural gas, wind, and solar had capacity factors of 54.4%, 34.6%, and 24.6% respectively (U.S. Department of Energy, 2022).

Table 1: Installed Capacity and Share by Power Source in Canada in 2020

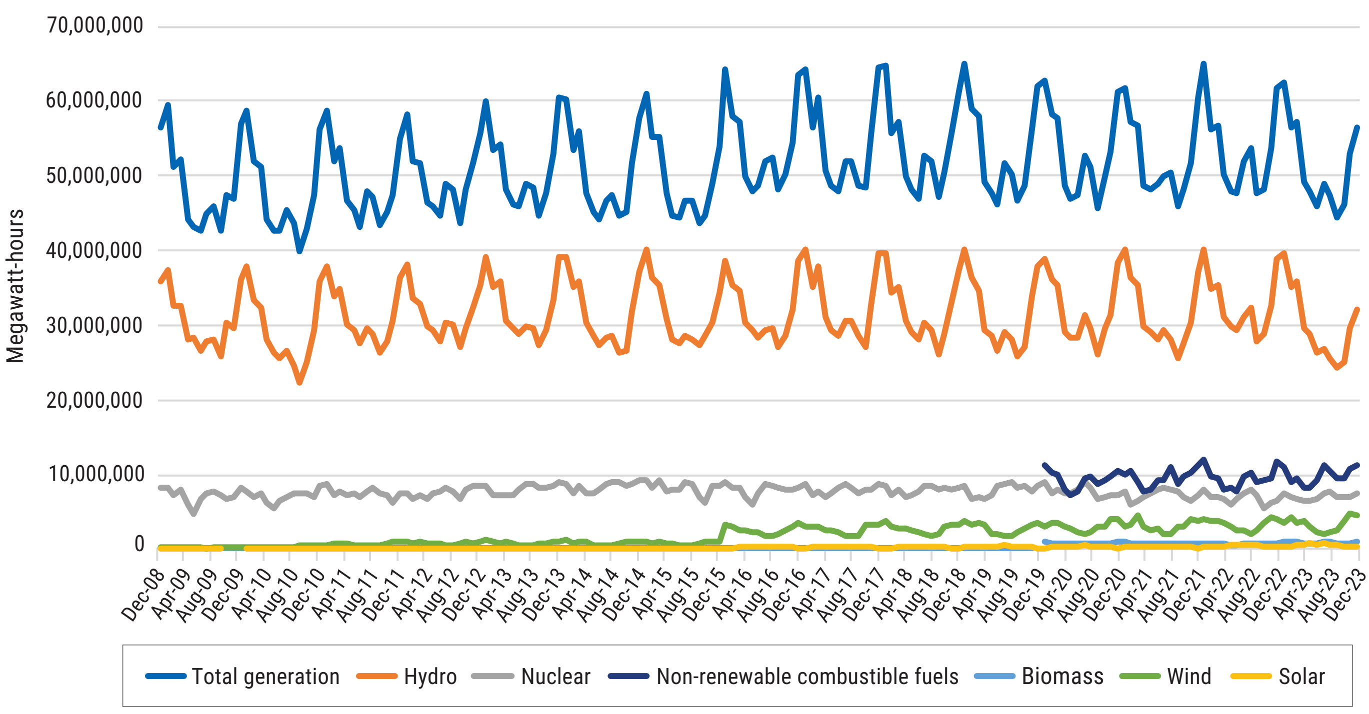
POWER SOURCE	CAPACITY (GW)	SHARE (%)
Biomass and geothermal	2	1.3
Solar	3	2.0
Wind	14	9.4
Nuclear	13	8.7
Hydro/tidal/wave	81	54.2
Natural gas	24	16.1
Oil	4	2.7
Coal and coke	8.5	5.7
Total	149.5	100

Source: Canada Energy Regulator, 2021.

Understanding a generator's ability to deliver electricity necessitates examining actual electricity generation rather than merely its installed capacity. Figure 1 illustrates monthly electricity generation in Canada by various sources from December 2008 to December 2023. Data on electricity production from fossil fuels (coal, natural gas, fuel oil, and diesel), referred to as non-renewable combustible fuels in figure 1, and data on electricity production from biomass, have only been reported by Statistics Canada since January 2020. As depicted in figure 1, hydro has consistently been the primary source of electricity generation in Canada. Following hydro, fossil fuels and nuclear are also significant contributors to electricity generation. Biomass and solar occupy minor roles, barely visible in figure 1. Despite producing more electricity since 2015, wind still plays a minor role in generating electricity, as evidenced in figure 1.

Table 2 presents electricity generation in Canada by source in 2023, including the share of each source. In 2023, total electricity generation in Canada reached 615.3 terawatt hours (TWh), with hydro accounting for 58.4% of that generation (359.3 TWh). Fossil fuels and nuclear accounted for 19.1% and 13.7% of generation, respectively. Wind generated 39.7 TWh of electricity, accounting for 6.4% of total generation. Biomass and solar accounted for 1.5% and less than one percent, respectively. Overall, clean (carbon-free) energy sources generated 497.6 TWh of electricity in 2023, representing almost 81% of Canada's total electricity supply. Fossil fuels

Figure 1. Monthly Electricity Generation in Canada by Source, Dec 2008–Dec 2023



Source: Statistics Canada, 2024.

Table 2: Electricity Generation in Canada in 2023, Categorized by Sources and Corresponding Shares

POWER SOURCE	GENERATION (TWH)	SHARE (PERCENT)
Total generation	615.33	100.0
Hydro	359.29	58.4
Nuclear	84.57	13.7
Fossil fuels (coal, gas and petroleum	117.70	19.1
Biomass	9.32	1.5
Wind	39.66	6.4
Solar	4.67	0.8
Other types of electricity generation	0.14	0.0

Source: Statistics Canada, 2024; calculations by authors.

generated 117.7 TWh of electricity, accounting for 19.1% of electricity generation in Canada.

For comparison, according to data from the United States Energy Information Administration (EIA), in 2023, fossil fuels (coal, natural gas, petroleum, and other gases) generated 2,505 billion kWh in the United States, accounting for 60% of the country's electricity generation. Clean energy sources (nuclear, hydro, wind, etc.) generated 1,669 billion kWh, accounting for 40% of total generation. More specifically, natural gas accounted for 43.1%, coal for 16.2%, nuclear for 18.6%, wind for 10.2%, and hydro for 5.7% (U.S. EIA, 2024). This comparison underscores the relative cleanliness of Canada's electricity grid.

The mix of electricity fuel sources varies markedly among the provinces. Most provinces—including Ontario, Quebec, British Columbia, Manitoba, and Newfoundland & Labrador—overwhelmingly produce and rely on carbon-free electricity. In fact, "approximately four in five Canadians live in provinces where electricity is already largely decarbonized (more than 90% non-emitting)" (Canadian Electricity Advisory Council, 2024: 9). Three provinces—Alberta, Saskatchewan, and Nova Scotia—are heavily dependent on fossil fuels to generate electricity. As of 2020, coal accounted for more than one-third of electricity generation in Alberta and natural gas for more than half. A few years earlier, in 2014, over half of all electricity generated in Alberta came from coal. In the last five years, coal power plants in the province have converted to natural gas, following the adoption of a coal phase-out policy by the provincial government (Weis, 2024). In Saskatchewan, approximately two-fifths of electricity generation in 2020 came from coal and a similar proportion from natural gas. In Nova Scotia, coal accounted for about half of electricity generation and natural gas and petroleum together for almost one-quarter (Canada Energy Regulator, 2024). These three provinces will face the greatest difficulties in abandoning fossil-fuel based electricity under the federal government's policy to fully decarbonize the electricity system by 2035.

Replacing Fossil Fuel Electricity with Clean Energy in Canada

To transition away from fossil fuel-based electricity in Canada, approximately 117.7 terawatt hours (TWh) of clean energy would need to be generated annually, assuming no growth in overall electricity supply. Below, we briefly explore what this could entail for different clean energy sources.

First, let us consider what would be required if all this new electricity generation were to be provided by hydropower. We can examine the construction of new hydropower facilities, such as the Site C project in British Columbia or Muskrat Falls in Newfoundland & Labrador. The Site C project will provide 1,100 megawatts (MW) of capacity and generate about 5,100 gigawatt hours of electricity (GWh) each year (British Columbia, 2018). Similarly, Newfoundland & Labrador's Muskrat Falls project will have a capacity of 824 megawatts and annual electricity production of 4,900 GWh (Newfoundland & Labrador, 2018). Generating 117.7 TWh of electricity, or more precisely 117,696 GWh, would require building and bringing into production approximately 23 mega hydro projects, equivalent in generation capacity to BC's Site C project, or 24 projects equivalent to Newfoundland & Labrador's Muskrat Falls. These numbers are determined by dividing 117,696 by 5,100 GWh and 4,900 GWh, which are the expected annual outputs of the Site C project and Muskrat Falls project, respectively.

Now, let us ask what would be required if all new electricity generation came from nuclear power—another carbon-free energy source. To do so, we can consider Bruce Power, the largest operating nuclear facility in Canada and globally, located in Ontario, and the Darlington Nuclear Generating Station, also in Ontario. The Bruce Power facility comprises eight nuclear reactors with a total capacity of 6,400 megawatts. Assuming Bruce Power operates 8,760 hours a year (that is, 365 × 24) at 90% capacity, this would mean the facility generates 50,458 GWh of electricity annually. To generate 117,696 GWh of electricity, it would require building and bringing into production an additional 2.3 facilities equivalent to Ontario's Bruce Power. Similarly, Ontario's Darlington Nuclear Generating Station has a total capacity of 3,512 MW (Ontario Power Generation, 2024). To generate 117,696 GWh of electricity, assuming a capacity factor of 90%, it would require building and bringing into production 4.3 facilities equivalent to Ontario's Darlington Nuclear Generating Station.

If this new clean electricity were to be generated by a mix of non-nuclear and non-hydro renewable energy sources, wind would be the most likely option. Assuming a capacity of 3.5 MW per turbine and a capacity factor of 35%, generating 117,696 GWh of electricity would require building approximately 11,000 large wind turbines in Canada over the next decade. To grasp the scale of these turbines, note that a typical 3.3 MW turbine has a rotor diameter averaging 114 meters, which exceeds the length of a Canadian Football League field (Canada Energy Regulator, 2019).

Given that renewable energy sources, including wind and solar, are intermittent, they are not always available to generate power. Their supply exhibits significant seasonal and daily fluctuations, which may not align with electricity demand. Consequently, addressing this intermittency issue requires building energy storage capacities, such as lithium-ion batteries, pumped hydro, and compressed air energy storage, and/or additional backup power capabilities in the form of dispatchable power to ensure the reliability of the overall power grid (Gerkšič et al., 2023). Despite natural gas being commonly used as a dispatchable backup source when electricity systems rely on intermittent renewables, natural gas generation directly produces greenhouse gas emissions—which conflicts with governments' carbon reduction goals, unless the resulting emissions are captured and stored. In the absence of zero-carbon dispatchable generation, managing the intermittency of renewable energy necessitates the development of extensive energy storage (Cosgrove, Roulstone, and Zachary, 2023), which significantly increases costs to the electric system. Moreover, backup power sources struggle to cover their direct costs since they do not deliver enough power consistently throughout the year, which leads to subsidies, adding more costs to the electric system (van Kooten, 2024).

Several studies have explored the feasibility and cost of using 100% renewable energy, primarily wind and solar, for electricity generation. These studies have shown that electricity demand cannot be reliably met at a low cost using only wind and solar energy sources. For example, a 2020 study assessed Alberta's potential to rely solely on wind and solar power for its electricity needs. The study found that addressing the intermittency issues of renewable energy sources would require an enormous amount of battery storage, making the transition prohibitively expensive and practically unfeasible (van Kooten, Withey, and Duan, 2020).

According to the study, if Alberta's electricity grid were to rely solely on renewable sources, it would need a battery storage system with a power capacity of 10,918 MW and an energy capacity of 10.92 GWh. To put this into perspective, the Tesla battery system in Australia has a power capacity of 100 MW and an energy capacity of 129 MWh, meaning Alberta would need a storage system more than 100 times larger (van Kooten, Withey, and Duan, 2020).

Moreover, the study estimates that eliminating fossil fuel-based generation in Alberta and relying entirely on wind and solar would incur costs exceeding $17.6 trillion, translating to nearly $364,000 per tonne of CO_2 reduction compared to the baseline. This is vastly higher than the current carbon tax of $80 per tonne of emissions. The study concludes that achieving a fully renewable grid using only wind and solar and batteries is virtually impossible.

Challenges Ahead

1. Regulatory hurdles and cost overruns in Canadian energy and related infrastructure projects

Planning and constructing electricity generation facilities and the related supporting infrastructure in Canada is a lengthy and intricate process, often plagued by numerous hurdles, delays, and significant cost overruns (DeLand and Gilmour, 2024; Canada Electricity Advisory Council, 2024).

Consider the case of BC's Site C project. Initially proposed in the late 1950s, the project began with engineering studies undertaken by BC Hydro in 1971. However, public hearings in 1983 led the British Columbia Utilities Commission to recommend postponing the project (Eagle, 2017; Canadian Press, 2021). Revived in 2010 under Premier Gordon Campbell's government, the project underwent extensive review, including an Environmental Impact Statement (EIS) and multiple amendments to address stakeholder feedback and regulatory requirements. In May 2014, provincial and federal environmental certificates were granted, with numerous recommendations for changes in the project (CBC, 2014; BC Hydro, 2014). Construction finally began in July 2015, but significant cost overruns soon emerged. By 2017, the project's cost had risen from $8.3 billion to $10.7 billion, and by 2021, it had increased to $16 billion. After more than five decades of public discussion, Site C is expected to be completed and electricity is finally set to flow in 2025 (Globe and Mail, 2021).

The Muskrat Falls Project, aimed at providing energy independence to Newfoundland & Labrador, also faced major challenges throughout its nearly two-decade journey. Originally projected to cost $6.2 billion, the project ended up billions of dollars over budget, years behind schedule, and under scrutiny by a commission of inquiry (CBC, 2018). Commencing its environmental process in 2006 and construction in 2013, the project encountered early cost overruns, with expenses steadily rising over subsequent years. Although the hydroelectric plant was commissioned in November 2021, by 2022 it was delivering only 30% of the expected electricity to Newfoundland due to issues with the Labrador Island Link, a high-voltage transmission line connecting Labrador to the island of Newfoundland (Hughes, 2023). These technical challenges delayed the full commissioning of the link until April 2023 Despite multiple delays and cost escalations, the project was completed in 2023 with total expenses increasing to $13.5 billion, more than double the initial budget.

Similarly, the journey to establish full operations at Ontario's Bruce Nuclear Generating Station, the world's largest operating nuclear facility, was a prolonged and intricate process spanning nearly two decades from 1968 to 1987. It began with conceptual studies in 1968, followed by formal applications in 1969. Challenges, including safety concerns and public opposition, emerged, leading to additional cost pressures (Durand and Horton, 1974). Despite these hurdles, four reactors (Bruce A) were declared in service between 1977 and 1979, with Bruce B's four reactors operational by 1987. However, the plan for an additional nuclear plant, known as Bruce C, extended over several decades. Initially proposed in the 1970s, the idea was repeatedly postponed. In 2007, Bruce Power revisited the concept, but after extensive public consultations and regulatory processes, it was abandoned in 2009 in favour of refurbishing Bruce A and B (Canada, 2011; Saunders, 2009).

In October 2023, Bruce Power initiated an impact assessment for Bruce C, almost five decades after its initial conception. This marks the beginning of a new phase involving extensive consultation, public engagement, environmental studies, and permitting activities, illustrating the enduring complexity and lengthiness of such mega-infrastructure projects (Bruce Power, 2023).

Convincing the public of the safety of nuclear plants remains a challenge. A 2023 survey by the

Canadian Nuclear Association (CNA) found that more respondents associated "nuclear" with war and accidents, such as Fukushima and Chernobyl, rather than with innovation or the production of low-emission energy (CNA, 2023). While 47% of respondents supported nuclear energy, 71% of moderate supporters were extremely or definitely concerned about nuclear waste management, and 57% were worried about potential accidents. Safety concerns surpassed logistical issues like costs and construction times. Among the 38% who opposed nuclear power, 87% cited waste management as a major concern, and 77% were worried about environmental impacts on land and water (CNA, 2023).

Canadian infrastructure projects frequently exceed budgets and timelines. A 2017 Ernst & Young report revealed that Canadian mega-projects typicaly overrun budgets by 39% and fall 12 months behind schedule on average (Wall, 2017). If anything, the situation has worsened since 2017. Besides project size and complexity, according to the report, Canada's regulatory and environmental regimes across several jurisdictions are an important cause of delays in project delivery in Canada.

A 2018 study conducted by Drance, Cameron, and Hutton analyzed Canadian regulatory reviews of major projects, focusing on the environmental component. Analyzing projects completed between 2010 and 2016, the study revealed prolonged approval timelines, with federal approvals averaging 49 months. Table 3 illustrates the timeline for the federal regulatory review of major electricity infrastructure projects. As shown, the Darlington New Nuclear Project took 68 months to receive federal approval, Newfoundland & Labrador's Muskrat Falls took 64 months, BC's Site C took 41 months, Darlington Refurbishment took 36 months, and Keeyask Hydro in Manitoba took 35 months (Drance, Cameron, and Hutton, 2018). It is important to note that these timelines represent only the federal stage of the environmental review process for these projects and do not include the provincial processes, which can also be very time consuming.

Table 3: Timeline for the Federal Regulatory Review of Major Electricity Infrastructure Projects

PROJECT	TYPE	TIMELINE (MONTHS)
Darlington New Nuclear	Generation	68
Muskrat Falls	Generation	64
Site C	Generation	41
Darlington Refurbishment	Generation	36
Keeyask Hydro	Generation	35
Maritime Link	Transmission	19
Labrador-Island Link	Transmission	57

Source: Drance, Cameron, and Hutton, 2018.

According to a 2019 World Bank report, Canada ranked second worst among 38 Organisation for Economic Co-operation and Development countries for the time required to obtain permits for new construction projects (Golshan, 2024). It took an average of 250 days to get a permit in Canada, three times longer than in the United States, with Canada only performing better than the Slovak Republic on this metric (Gardner, 2020). Additionally, from 2006 to 2019, Canada fell from fourth place to 22nd place in the World Bank's ease of doing business rankings—another indicator of the growing difficulty of advancing projects in many Canadian industry sectors (Natural Resources Canada, 2024).

In response to these and other challenges, the federal government introduced the *Impact Assessment Act* (IAA), also known as Bill C-69, in 2019. This legislation was intended to replace the previous federal project approval process established under the *Canadian Environmental Assessment Act* of 2012 (CEAA). Bill C-69 aimed to overhaul the environmental assessment process for major projects in Canada, with one of the claimed goals being to streamline reviews and enhance the process's timelines and predictability. However, the bill also introduced broader project assessment scopes and several subjective criteria, such as the consideration of "social impacts" and "gender implications," which have made the regulatory system more subjective and less certain (Green, 2018).

A 2023 report evaluated the effectiveness of the *Impact Assessment Act*, by analyzing timelines of 25 projects under IAA review since its inception in August 2019. These projects range from infrastructure such as bridges and roads to energy projects—including pipelines, liquefied natural gas (LNG) facilities, and power plants. The report finds that almost all project submissions between August 28, 2019 (when the Act came into force), and mid-April 2023 (the cut-off date of the analysis) have remained in the early stages of the Impact Assessment process (Orenstein, 2023).

Specifically, under the IAA, a new phase called the planning phase was added to the review process, a component absent from the 2012 *Canadian Environmental Assessment Act*. This phase sets the stage for the assessment of projects by identifying the scope of the issues that need to be addressed. The Impact Assessment Agency has a legislated limit of 180 days to complete the planning phase. However, this limit does not include suspensions or occasions when the "clock stops," which can be requested by the Minister of the Environment or by the proponent (Orenstein, 2023).

Analyzing the actual time it has taken for the 25 projects to complete their planning phase, the report reveals that it took between 127 days to 693 days for projects to move through this phase, with an average of 332 days. Several factors contributed to the delays, including additional time for Indigenous consultation, requests for further details, and coordination with provincial processes. This inability to adhere to the 180-day objective indicates that the new review process is not functioning as initially envisioned. Overall, more than three and a half years after the IAA came into effect, all projects under its review were still in either Phase 1 or Phase 2 of the four-phase process.

The IAA was challenged in court by the province of Alberta and a number of other intervenors.

In October 2023, the Supreme Court of Canada ruled that the Act exceeded Parliament's authority under the Constitution and illegally encroached on provincial jurisdiction over natural resources and the management of Crown lands. As part of the 2024 budget, the federal government introduced amendments to the IAA to bring it into compliance with the Supreme Court's opinion. However, legal experts contend that the amendments are minor, likely to give rise to additional uncertainty with respect to future project reviews, and will have little effect on how the IAA regime operates (Bennett Jones LLP, 2024a; Langen, Lemmens, and Barrington, 2024; DeLand and Gilmour, 2024).

The provinces also have legislative and regulatory regimes in place to review proposed projects within their jurisdiction. In addition, the provinces maintain robust environmental permitting rules which apply to industrial facilities operating in the energy sector and other industries. The fact that both levels of government are active in assessing proposed projects and in regulating the environmental impacts of industrial activities adds to the complexity of the overall Canadian legal framework governing electricity generation and transmission. And this is true not just for energy projects, but for all types of land-based industrial development, including mining (Mansfield Consulting Inc., 2023).

In order to accelerate the development of clean energy projects, Ottawa and the provinces will need to better coordinate efforts to identify and reduce barriers to advancing such projects, including for permitting and Indigenous participation (DeLand and Gilmour, 2024). As the Canada Electricity Advisory Council noted, "Achieving Canada's net-zero goals will require adding an average of 10GW of new, clean electricity generation per year. Building that generating capacity, as well as the associated grid and storage infrastructure, will require a dramatic shift in the pace of electricity system expansion" (Canada Electricity Advisory Council, 2024: 93).

Canada's slow and burdensome system for approving major projects—and permitting them once approved—has affected investment levels in the country. According to Natural Resources Canada's Major Projects Inventory, the number of major projects completed in Canada fell by 36.4% from 2015 to 2023, decreasing from 88 in 2015 to 56 in 2023 (Natural Resources Canada, 2016, 2023). The real value of major projects (both planned and under construction) declined by 35.1 %, from $711 billion in 2015 to $461 billion in 2023, with values expressed in 2015 dollars. Not surprisingly, Canada has gained a reputation as a country where major projects cannot be built in a timely manner (Business Council of Alberta, 2023).

Overall, given the slow regulatory approval process and extended construction timelines, building the necessary clean electricity generation capacity and supporting grid infrastructure in the next decade to replace all remaining fossil fuel-based generation in Canada is impractical. This suggests the target to achieve 100% clean electricity by 2035 established by the federal government needs—at a minimum—to be extended.

2. Land requirements

In addition to regulatory issues and the high and steadily rising cost of building major energy projects, land requirements for new electricity generation facilities and related infrastructure present additional challenges. These projects inevitably entail trade-offs as they compete with land that is or could otherwise be used for agriculture, residential purposes, or wildlife habitat. The extent of land usage varies across different sources of electricity generation. A critical metric for evaluating the land use of different energy sources is power density, which indicates the rate of energy generation per unit of ground area in a given period of time (Miller and Keith, 2018; Smil, 1984). Renewable energy sources, such as wind and solar, generally exhibit lower power densities compared to non-renewable sources like natural gas and coal. This implies that these types of facilities require more surface area to produce an equivalent amount of power.

van Zalk and Behrens (2018) examined 54 peer-reviewed studies to assess the power density of electricity generation by power source in the United States. According to their analysis, natural gas boasts the highest power density, with a median power density of 482.1 W/m², followed by nuclear (240.81 W/m²), oil (194.61 W/m²), and coal (135.1 W/m²). Large hydroelectric projects with reservoirs have a median power density of 0.51 W/m², while wind power has a median power density of 1.84 W/m², and solar energy has 6.63 W/m².

Assuming a wind power density of around 1.84 watts per square meter, generating 117.7 TWh (or 13.4 GW) of electricity with wind turbines would necessitate approximately 7,302 square kilometers of land. To provide context, this is larger than the size of Prince Edward Island (5,620 square kilometers) and is nearly nine times the size of the city of Calgary (825 square kilometers).

Similarly, generating 117.7 TWh of electricity from hydropower (mega hydro projects with reservoirs) would require 26,345 square kilometers of land, almost half the size of Nova Scotia. This significant land consumption by renewable energy sources (and the concomitant vista degradation) has already caused public concern and opposition to many new projects involving these low-density power sources (Green, 2024).

The expansion of renewable energy also brings complex issues related to infrastructure siting and facility location (Finlayson and Mullen, 2021). While there is broad support for renewable energy sources, people and local communities often prefer that the impacts of these projects be concentrated elsewhere. This attitude is not unique to Canada. In the United States, approximately one-quarter of all county governments have imposed restrictions on using local lands for renewable energy projects (Campenella and Lawrence, 2024). Overcoming public opposition based on the location of clean electricity facilities and the supporting infrastructure is another significant challenge that will need to be addressed if Canada intends to move expeditiously to eliminate existing fossil fuel-based generation.

Concluding Remarks

Canada's goal of achieving 100% carbon-free electricity by 2035, alongside the broader aim of reaching net-zero greenhouse gas emissions by 2050, presents a significant challenge. This transition requires not only replacing remaining fossil fuel-based electricity generation but also expanding capacity to meet the growing demand for power from electric vehicles, population growth, and industrial electrification.

Although clean energy sources already supply the majority of Canada's electricity, replacing the remaining 19.1% generated by fossil fuels—amounting to 117.7 TWh—is no small task. The infrastructure required to achieve this transformation is immense. Replacing existing fossil fuel-based electricity with hydropower alone would necessitate the construction of approximately 23 large hydro projects similar to BC's Site C, or 24 similar to Newfoundland & Labrador's Muskrat Falls. If nuclear power were to replace fossil fuel-based electricity, Canada would need to build 2.3 facilities equivalent to Ontario's Bruce Power or 4.3 similar to the Darlington Nuclear Generating Station.

The experience with past projects, such as BC's Site C, Muskrat Falls, and Ontario's Bruce Nuclear Generating Station, underscores the difficulties in planning, regulatory approval, and execution. These projects often face delays, cost overruns, and public opposition, all of which contribute to Canada's reputation as a country where major infrastructure projects are notoriously difficult to complete in a timely manner. The introduction of the federal *Impact Assessment Act* in 2019, intended to streamline project approvals, has instead added more complexity and uncertainty to the review process.

Furthermore, the significant land requirements to build out the clean energy economy present additional hurdles. Replacing fossil fuel-based electricity with wind power, for instance, would require land areas larger than some Canadian provinces, and the associated environmental and social impacts have already sparked public resistance. Similarly, large hydropower projects demand extensive land use, further complicating the path to achieving Canada's decarbonization goals. And this is before we consider the implications of building new transmission infrastructure to allow clean energy generation to reach end-use markets.

Overall, the slow pace of regulatory approvals, the high and escalating costs of building major energy projects, the significant land requirements for clean energy projects such as hydro and wind, and public opposition to project siting all cast doubt on the feasibility of building the necessary clean electricity generation capacity and supporting grid infrastructure within the next decade to replace remaining fossil fuel-based generation in Canada.

Given these formidable challenges, it is evident that the federal government's target of achieving 100% clean electricity by 2035 should be reassessed to ensure it is both realistic and achievable. At the very least, the timeline should be significantly extended to avoid the likely wasteful failures of deploying clean technology too hastily.

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