Report

Comparative Analysis of Electricity Generation Costs by Source

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Executive Summary

WaterPower Canada (WPC) commissioned this white paper to present a comparative analysis of the current and future cost of various sources of electricity generation.

The purpose of this paper is to help inform policymakers of the cost comparison between different electricity sources when considering pathways to achieve a net-zero electricity infrastructure in Canada.

The overall objectives of this paper were to complete a literature review to support the comparison of current and future costs of various sources of generation and highlight the importance of hydropower on the path to new-zero electricity.

Based on this review, a summary of findings are as follows:

- The net-zero emissions goal for electricity in Canada will require replacement of approximately 36.5 GW of existing Greenhouse Gas (GHG) emitting electricity generation capacity by 2035.
- A comparative analysis of the Levelized Cost of Energy (LCOE) for various sources of electricity generation, based on available literature, shows that energy from wind and solar electricity is generally less expensive than hydropower and other technologies. This comparison, however, excludes integration costs of solar and wind to manage grid reliability.
- An alternate metric, Value Adjusted Levelized Cost of Energy (VALCOE), adjusts the LCOE of various generation alternatives such that they can be compared on a like-for-like basis related to the value that each generation alternative brings to the respective interconnected grid.
- The VALCOE for non-dispatchable renewables is higher than the LCOE because of their integration costs. The actual costs are grid-specific, but generally the more variable the generation source and the less correlated it is with power demand, the higher are the potential additional costs imposed on the system.
- Hydropower is a mature technology and can present a competitive LCOE compared to new wind and solar. Reservoir-based hydropower generation offers both dispatch flexibility and firm capacity.
- Incremental generation capacity through hydropower refurbishments (life extension) and upgrades presents a very competitive LCOE as compared to new installations.
- Hydropower has a wide range of LCOE and, in the future, is expected to remain competitive with other forms of renewable power, especially considering its benefits of ancillary services.

- As fossil fuel fired generation is retired, dispatchable and firm generation resources will be required to meet on-peak demands. Hydropower capacity expansions, through refurbishment and redevelopment, are options to provide this capacity and flexibility.
- Hydropower is a core source of electricity making up more than 90% or more of the generation in some provinces.
- Based on CER’s 2023 study, hydropower generation is projected to increase approximately 26% (approximately 21.2 GW) from 2021 to 2050. This increase will come from projects currently under construction and projected new developments as well as upgrades to existing hydropower units.
- Hydropower provides a host of essential grid services including dispatchability, which helps to maintain a balanced and reliable grid given its ability to store water then respond quickly to variable and peak power demand requirements. This will become even more important as more intermittent solar and wind power is added to the grid.
- Investments in hydropower generation through the development of new facilities and life extension/upgrades can help to achieve the net-zero emissions electricity goals in Canada.

1. Introduction

WaterPower Canada (WPC) commissioned this white paper to present a comparative analysis of the current and future cost of various sources of electricity generation.

The Canadian federal government has committed to achieving a net-zero emissions electricity supply by 2035 on Canada's path to achieve carbon neutrality by 2050.[1]

In 2020, Canada produced 636 TWh of electricity, with approximately 82.6% from non-emitting sources such as hydropower (60.2%), nuclear (14.6%), wind (5.5%), solar (0.7%) and biomass 1.6%) generation.[2] The total installed capacity in Canada in 2020 was 149 GW.[3] The distribution, reflected as a percentage of the total, of various sources of electricity (capacity and generation) are shown in Figure 1-1.

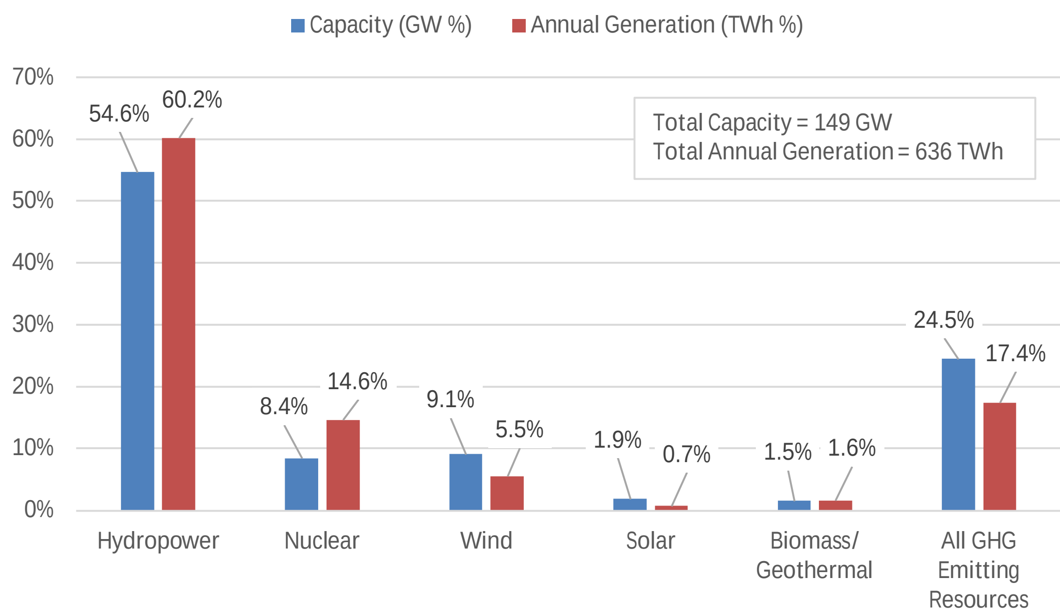


Figure 1-1: Electricity Generation Sources in Canada (2020)

Based on the various sources of electricity in Canada, to achieve the identified goal of net-zero electricity supply will require replacement of a large portion of approximately 36.5 GW of existing Greenhouse Gas (GHG) emitting generation capacity with new non-emitting hydropower, wind, solar, biomass, geothermal, hydrogen and nuclear generation sources. Economics will play a major role in selection of the replacement energy sources.

The purpose of this paper is to help inform policymakers of the cost comparison between different electricity sources when considering pathways to achieve a net-zero electricity infrastructure in Canada.

This paper presents the following:

- Cost metrics used to compare electricity generation prices
- Literature review to support the comparison of the levelized cost of electricity (LCOE) for various sources of generation
- LCOE comparison for the various sources of electricity
- Commentary on present and future costs
- Considerations for the role of hydropower on the path to net-zero electricity.

2. Generation Cost Metrics

Various metrics are used to compare costs of alternative electricity generation technologies when considering an investment in the expansion of generation capacity.

LCOE is a typical and common approach and refers to the estimated revenue required to construct and operate a power generation facility over a given recovery period, typically the estimated life of the asset. It represents the average revenue per unit of electricity. The calculation uses discounted cashflow to estimate the net present value of the overall generation costs divided by the discounted generation over the life of the asset to arrive at LCOE in $/MWh. LCOE is a commonly used metric to assess the overall competitiveness of different generating technologies.[4,5]

Provided each alternative being considered has similar operational characteristics, LCOE is a useful metric for comparison. For example, a natural gas fired plant has similar grid attributes to a hydroelectric plant – both provide firm capacity when called upon and provide load following services along with all ancillary grid services, so the LCOE comparison is a useful approach.

The LCOE metric is less useful when comparing resources that have different attributes and operating profiles. LCOE has its limitations and does not necessarily represent the economic value or potential indirect costs to the system due to the integration of variable renewable energy-based technology.

Value-adjusted levelized cost of electricity (VALCOE) is an alternate metric developed by the International Energy Agency (IEA) which adds additional elements to LCOE such as capacity and flexibility.[5,6]

VALCOE is a broader metric intended to complement LCOE; it takes into consideration other system costs, based on the system where the resource is located, such that it better represents both costs and the value provided to the system. This approach enables a better comparison of different power generation technologies and in particular helps to allow for comparisons between variable renewables (such as wind and solar) and dispatchable technologies (such as natural gas-fired combined cycle or reservoir-based hydropower).[7]

For example, a utility-scale solar plant is non-dispatchable and only provides output during daylight hours (with the solar irradiance intensity affecting the power output). The LCOE metric would only consider the cost of when energy is produced, not when it is needed. The VALCOE metric would consider the additional indirect costs to the system, for example, additional storage given the solar facility is non-dispatchable.

The more variable the generation source and the less correlated it is with power demand, the higher the additional costs imposed on the overall system are, based on where the resource is located. These additional system costs are dependent on the amount of variable renewable generation and the existing system in which the technology is deployed.[7]

As the deployment of non-dispatchable variable renewable generation resources increase on any given system, the value of dispatchable resources that are available on that system, such as hydropower, will increase, as greater flexibility and the provision of firm capacity will be a necessity to service customer requirements.

Based on the literature review and availability of published cost data, this white paper focuses on the LCOE approach. Given the limited availability of published VALCOE for Canada, a comparison of VALCOE is beyond the scope of this literature review.

3. Literature Review

There are multiple organizations that provide LCOE data for different types of generation. For this study, the following key publications were considered:

- Natural Resources Canada, Energy Fact-book 2022-2023[2]
- International Energy Agency (IEA) - World Energy Outlook 2022[5]
- Lazard - Levelized Cost of Energy Comparison, v.16, 2023[8]
- National Renewable Energy Laboratory (NREL) - 2023 Annual Technology Baseline (ATB)[9]
- United States Energy Information Agency (EIA) - Annual Energy Outlook 2023[10]
- Fraunhofer Institute for Solar Energy Systems, Levelized Cost of Electricity Renewable Energy Technologies, 2021[11]
- NREL - Levelized Cost of Energy Calculator.[12]

For most publications, costs were available as a range (high and low) in 2020, 2021 or 2022 Canadian Dollar (CAD), United States Dollar (USD) or Euro (EUR). To allow for a relative comparison, costs were converted to 2022 CAD using appropriate escalation and currency exchange rates. In some publications, where future cost projections are available, we have also presented these costs in 2022 CAD for comparison.

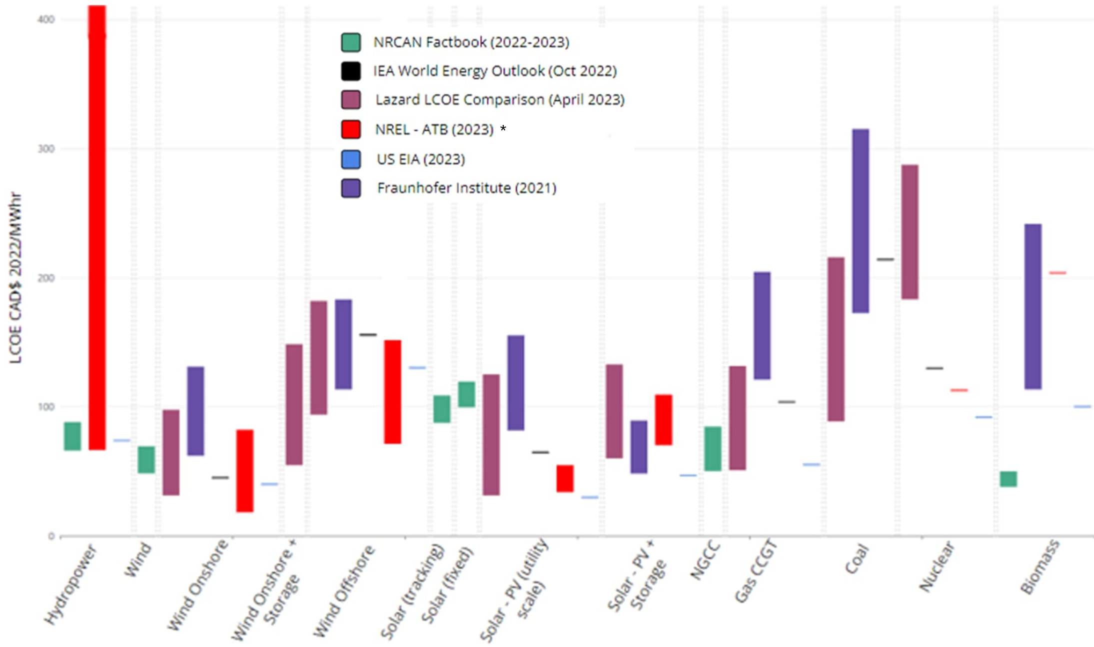
For comparison to greenfield hydropower, the LCOE for hydropower refurbishment (life extension) and upgrading was also estimated based on internal Hatch data. The NREL calculator was used to estimate the LCOE based on various capital and operating cost inputs. Based on the analysis, the estimated LCOE for hydropower life extension and upgrading (excluding major civil works) is $27/MWh to $40/MWh and $28/MWh to $48/MWh, respectively.

Hydroelectric facility operators should consider the value of additional capacity that can be obtained through refurbishment and redevelopment, particularly for facilities with storage flexibility. These may be cost effective means to additional capacity and storage.

4. Levelized Cost of Electricity Comparison

4.1 Current Costs

Based on the literature review, a summary of the comparison of the LCOE from the various organizations, escalated to 2022 CAD, is presented in Figure 4-1. As the LCOE values were found to have significant variation, Figure 4-1, presents the LCOE data by both generation technology and organization which highlights possible trends by generation technology and organization. Potential sources of variation include site location and technology type as well as life cycle durations and discount rates.

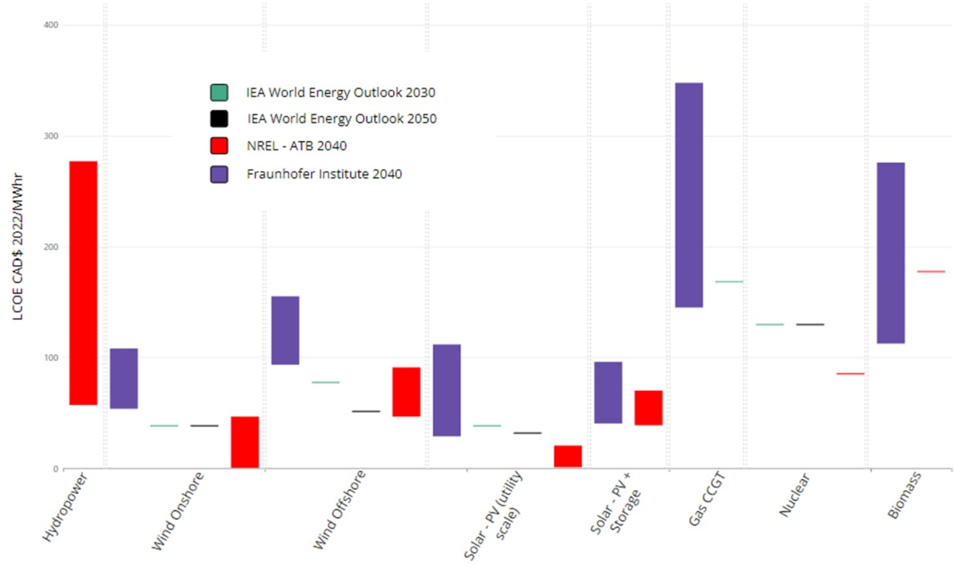


* NREL data offered a wide range of values, including what may appear to be outliers. This range of values reflects three site types in the data: Non-Powered Dams (Lakes), Non-Powered Dams (Locks) and New Greenfield Run-of-River Sites, of which the corresponding LCOE ranges are (in CAD 2022): 102 – 310, 91 – 417, and 78 – 122, respectively (assuming the moderate case). The higher costs of these ranges are associated with lower head, and lower capacity facilities (approximately 10 MW or less). The maximum-minimum values were included for consistency across data sources.

Figure 4-1: Levelized Cost of Electricity (2022 CAD)

4.2 Forecast Costs

Based on available data, Figure 4-2 compares the forecast LCOE for some of the same sources of electricity 10 to 30 years into the future (2030, 2040 and 2050). It is based on fewer available sources of published data.



* NREL data includes various financial assumptions that impact LCOE (see NREL financial cases and methods).

Figure 4-2: Projected Future Levelized Cost of Electricity (2022 CAD)

4.3 Commentary on Current and Forecast Costs

Based on the data from the various reference publications and generation technology, the following is noted:

- Solar – Different configurations of solar have the lowest LCOE. Since solar is non-dispatchable and the capacity factor in Canada is relatively low (10% to 25% depending on location), the addition of battery storage can enhance the value of solar. It is noted that NRCan data indicates that LCOE for solar can be higher than hydropower.
- Wind – Wind is a close competitor for solar, but it has the same drawback in that it is non-dispatchable, requiring support from other dispatchable sources of electricity. The LCOE generated by on-shore wind is lower than off-shore wind. The capacity factor for on-shore wind ranges from 28% to 35%, whereas for off-shore wind ranges from 40% to 44%. The LCOE of off-shore wind is higher than on-shore wind. Offshore wind is currently not commercially deployed in Canada.
- Hydropower – Hydropower is a mature technology and can present a competitive LCOE compared to new wind and solar. Facilities with reservoir storage are also dispatchable which integrates well with the non-dispatchable and variable nature of wind and solar. Hydropower facilities also provide additional ancillary services to support grid reliability. Refurbishment (life extension) of existing provides very competitive LCOE. If additional capacity can be achieved through equipment upgrades or constructing additional generating units, this could represent a cost-effective source of flexibility and firm capacity to enable deployment of additional variable renewable generation.

- Biomass – In general, biomass has a higher LCOE than other renewables. Biomass based generating plants are dispatchable and Canada has an abundance of biomass. Biomass combined with carbon dioxide capture and sequestration (at a higher LCOE) has the potential to be a net negative source of GHG emissions.
- Nuclear – Based on some of the data sources, the LCOE for nuclear can be lower than other sources of thermal generation, with refurbishment of existing facilities being generally attractive. Investment in the development of small modular nuclear reactors (SMR) is of key interest globally to help contribute to emissions reductions and power system reliability.[5]
- Gas Turbine – While combustion turbine generation (either simple or combined cycle) is mature and dispatchable, proposed restrictions on unabated generation will limit its use to peaking or emergency use only in Canada.[13] Long-term use of gas combined cycle generation will require carbon capture and sequestration (CCS) to offset GHG emissions, which will add significantly to the cost (at a higher LCOE) of this alternative. Non-emitting energy technologies available to replace existing GHG emitting electricity economically are solar, wind, nuclear, and hydropower.
- Future LCOE – Solar with and without battery storage followed by wind are forecast to continue to be the lowest cost renewable sources of electricity. Hydropower has a wide range of LCOE and is expected to remain competitive with other forms of renewable power, especially considering its benefits of ancillary services. Various LCOE publications are not including greenhouse gas emitting coal and gas turbine technologies in future net zero emissions scenarios.

5. Hydropower: The Role in Net-Zero Electricity

Hydropower, as renewable source of electricity, can play an important role in helping to achieve net-zero targets based on the following:

- In 2020, hydropower contributed to 72.8% of the electricity generated annually across Canada by renewable resources.
- Hydropower is a core source of electricity in many provinces making up more than 90% or more of the generation in BC, Manitoba, Quebec, and Newfoundland and Labrador.[14]
- Hydropower is emission-free and has inherent dispatch flexibility and firm capacity.[13]
- Based on CER’s 2023 study, hydropower generation is projected to increase approximately 26% (approximately 21.2 GW) from 2021 to 2050. This increase will come from projects currently under construction and projected new developments, upgrades to existing hydropower units, and expansions of existing facilities.[13]

- Historically, hydropower units have provided essential grid services (frequency stability and recovery, system ramping for contingency and net demand variability, voltage control, and black start capability) to support stable and reliable power grids.
- Additional firm capacity will be required to replace the firm capacity from retired fossil fuel generation and also to meet higher peak demands associated with electrification, as variable renewables without storage will be unable to provide needed dispatch flexibility.
- The majority of hydroelectric plants in Canada are 30 to 100 years old. Many of the plants are due for major refurbishment/life extension with potential for redevelopment or upgrade in the next 10 to 20 years. Older plants can benefit from advancements in turbine design with a potential increase in capacity and efficiency. New turbine/generators can be optimized for a combination of additional energy from improved efficiency or additional capacity through improved design. These projects compare to a significantly lower LCOE (for energy) or VALCOE (when capacity and flexibility are considered) compared to new installations.
- Hydropower provides essential grid services to help maintain a balanced and reliable grid given its ability to store water and respond quickly to variable and peak power demand requirements.
- Reinforcement, redevelopment, and installation of additional bulk transmission facilities across Canada between large hydropower-rich provinces (British Columbia, Manitoba, Quebec, and Newfoundland) and neighboring provinces with high penetration of variable solar and wind generation, should be considered as part of the long-term planning to achieve net-zero electricity.
- Hydropower can be dispatchable and support the daily and seasonal variations in electricity from solar and wind. This is essential to balance electricity demand and supply.
- Hydropower plants can have an expected life up to and in excess of 100 years.

6. Conclusions

The overall objectives of this paper were to complete a literature review to support the comparison of current and future costs of various sources of generation and highlight the importance of hydropower on the path to net-zero electricity.

Based on this review, a summary of findings are as follows:

- The net-zero emissions goal for electricity in Canada will require replacement of approximately 36.5 GW of existing GHG emitting electricity generation capacity by 2035.
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expensive than hydropower and other technologies. This comparison, however, excludes integration costs of solar and wind to manage grid reliability.

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- Hydropower has a wide range of LCOE and, in future, is expected to remain competitive with other forms of renewable power, especially considering its benefits of ancillary services.
- As fossil fuel-fired generation is retired, dispatchable and firm generation resources will be required to meet on-peak demands. Hydropower capacity expansions, through refurbishment and redevelopment, are options to provide this capacity and flexibility.
- Hydropower is a core source of electricity making up more than 90% or more of the generation in some provinces.
- Based on CER’s 2023 study, hydropower generation is projected to increase approximately 26% (approximately 21.2 GW) from 2021 to 2050. This increase will come from projects currently under construction and projected new developments as well as upgrades to existing hydropower units.
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- Investments in hydropower generation through the development of new facilities and life extension/upgrades can help to achieve the net-zero emissions electricity goals in Canada.

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