Evaluating the True Value of Hydropower

Prepared for: WaterPower Canada
February 2026

Evaluating the True Value of Hydropower

Prepared for: WaterPower Canada
February 2026

Submitted by:
Power Advisory
55 University Ave, Suite 700, PO Box 32
Toronto, ON M5J 2H7
www.poweradvisoryllc.com

TABLE OF CONTENTS

1. EXECUTIVE SUMMARY 1
2. LITERATURE REVIEW AND CURRENT ESTIMATES OF LCOE 3
   2.1 High-level Overview of Different Sources of Supply 3
   2.2 Cost Comparison of Different Supply Resources 5
   2.3 Common LCOE Reports Utilized by the Electricity Industry 7
   2.4 Canadian IRPs that Provide Levelized Costs of Different Supply Options 9
   2.5 Common Concerns and Adjustments to the LCOE Approach 10
   2.6 Hydro-Specific Concerns Over the LCOE Approach 12
3. STAKEHOLDER COMMENTARY 14
   3.1 LCOE is simplified metric that can be used at an initial screening phase 14
   3.2 The LCOE does not account for the long-term value of hydropower 14
   3.2 The LCOE does not provide a system-wide approach to value 15
   3.3 Developing a long-term asset such as hydropower is difficult under most existing commercial arrangements 16
4. ALTERNATIVES AND ADJUSTMENTS TO THE LCOE 17
   4.1 Capacity Value Approach 17
   4.2 Residual Value Approach 20
   4.3 Real LCOE Approach 22
   4.4 Replacement Chain Approach 24
   4.5 Incorporating Multiple Adjustments to the LCOE 25
5. CONCLUSION AND NEXT STEPS 27

1. EXECUTIVE SUMMARY

The most common approach to comparing the economics of different supply options to meet future supply needs for the electricity grid does not truly represent the cost or value of long-term, reliable and capital-intensive resources such as hydropower. By not properly comparing the long-term costs and value of different supply options, decisions today that rely upon short-term or limited financial metrics may result in unnecessary and duplicative costs for both current and future ratepayers.

One of the most common tools to compare different supply options is a simplified metric known as the Levelized Cost of Energy (LCOE). The LCOE converts the up-front and ongoing costs of one supply option into a per-unit value, which can then be used to compare supply costs from different resource types. The LCOE is often used to rank the economics of various supply options. The LCOE has a number of known flaws, particularly as it relates to hydropower:

1. The LCOE does not account for what is known as the "Capacity Value" of different resource types, which is a key component for maintaining the reliability of the electricity grid. Hydropower can provide a large amount of firm supply in peak demand hours, which reduces the need to procure additional capacity to maintain reliability and lowers total system costs compared to alternative resources.

2. The LCOE does not properly account for the long-term nature of hydropower compared to other resource types, with many of the large-up front capital costs of a hydropower facility capable of lasting up to a century or longer. By not accounting for the long-term nature of the different components of a hydropower facility, the LCOE does not fully capture the value of an asset beyond typical accounting timelines, including the residual value.

3. A simplified LCOE does not account for the need to replace nearly all components of most resources over a 50 to 100-year period, which increases the costs of assets with a 20 to 30-year operational life.

To address the deficiencies of the LCOE metric, the following report provides a number of different methodological approaches that allow for a more apples-to-apples comparison between different resource types. The different approaches can be used on their own or in conjunction with one another. When incorporating the additional costs and values that are not currently captured in the LCOE metric, hydropower can become a more cost-effective option to meet future supply needs. The approaches include:

1. *Capacity Value* – Incorporating the cost of capacity required to account for the difference between installed capacity and forecasted output during peak demand hours.

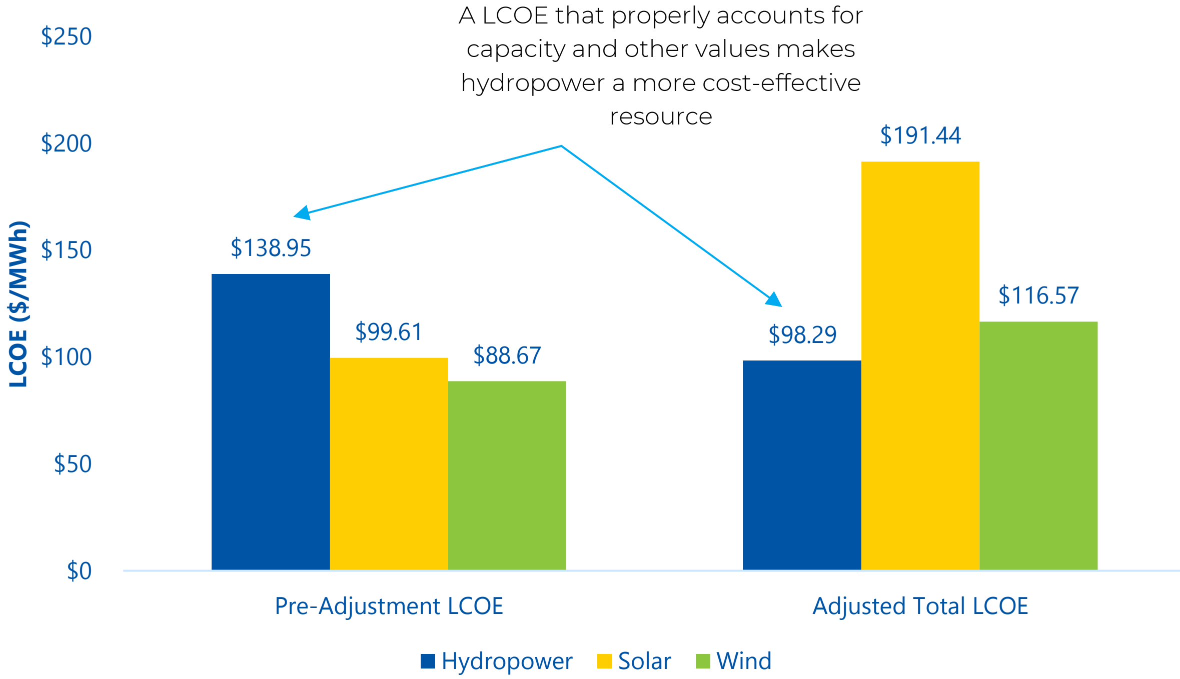
2. *Residual Value* – Offsetting the up-front capital cost with the remaining value of an asset – either from an accounting or market-value perspective – beyond its forecasted operational life.

3. *Real Value LCOE* – Converting the LCOE from a nominal to real value to account for the long-term nature of hydropower assets.

4. *Replacement Chain* – Accounting for the need to replace nearly the entirety of some assets multiple times over a 100-year time-period.

A number of these adjustments can be considered in tandem, which will often result in a hydropower asset becoming significantly more cost-competitive compared to other non-emitting resources that are currently being considered to meet future supply needs across the country.

Figure 1 LCOE With and Without Adjustments



2. LITERATURE REVIEW AND CURRENT ESTIMATES OF LCOE

Policy makers, grid operators, developers and other stakeholders in the electricity sector must continuously balance the need to maintain reliability while also cost-effectively supporting both existing and new supply options. Ensuring the right balance between reliability and the lowest total system costs requires grid operators and stakeholders to continuously compare the economics of physical characteristics of multiple types of supply resources. There are a range of different forums for how to value different supply options, but the most common approach is typically done through an Integrated Resource Plan (IRP) or similar analysis. An IRP provides a long-term view of supply needs and demand growth, while comparing different supply options to determine the most cost-effective option for grid.

How different resource types are evaluated from a cost perspective can impact the types of investment decisions either taken by participants in the electricity sector or supported by policymakers. For large, capital intensive projects such as hydropower, understanding how resources are evaluated from an economic or cost-effective perspective can highlight whether standard approaches are appropriate or under-value hydropower. The following chapter provides a high-level overview of the benefits and drawbacks of different resource types and, in particular, how this often does not account for the unique characteristics of hydropower and under-values using a long-term horizon.

2.1 High-level Overview of Different Sources of Supply

As discussed elsewhere in this report, supply options come with varying characteristics both from a financial and operational perspective. The following list provides a high-level overview of a number of trade-offs that policy makers and grid operators must consider when reviewing different supply options. The intent of this overview is to highlight the landscape of supply options that are commonly included in IRPs and other system planning documents. The following section will then compare how a number of these different resources are evaluated from a financial or economic perspective.

1. Nuclear Power

   a. *Pros*: Provides a significant amount of low marginal cost baseload power – i.e. plants that run on a near constant basis. Given that nuclear power plants are built to provide baseload power, they have a high capacity factor and a high Effective Load Carrying Capacity (ELCC), which measures the amount of capacity that is expected to be available during peak demand hours. Supply from nuclear power results in no carbon emissions and is unimpacted by decarbonization policies at a municipal, provincial or federal level. While nuclear plants may require large capital investment throughout their operational life, many components will have an operational life that will span multiple decades.

   b. *Cons*: Nuclear power typically has large up-front capital costs. Nuclear units periodically undergo planned refuelling and maintenance outages. These are scheduled well in advance and incorporated into system operations and capacity planning, similar to other large generating facilities. Finally, while Small Modular Reactors (SMRs) have many potential benefits, Ontario has just begun construction of Canada ' s first SMRs and it will be a few years before we can fully understand the economics of these facilities.

4. Large-Scale Hydropower

   a. *Pros*: Large-scale hydropower provides a significant amount of baseload, low marginal cost supply with zero carbon emissions. Once built, it typically has fairly low operating and maintenance costs compared to other baseload supply options. Most large-scale hydropower plants have an annual capacity factor greater than 50% to 60% and can typically provide a large amount of baseload supply through different seasons. The ELCC is also high, as it can provide a predictable amount of capacity during peak demand hours. Most hydropower plants are highly flexible and can quickly respond to dispatch to increase or decrease output. The ability to store water can allow plants to shape their supply to increase (decrease) during peak (off-peak) demand hours. Many of the primary structures of a large-scale hydropower plant will have an operating life spanning many decades.

b. *Cons*: The installed capital cost is higher than most other non-emitting sources of supply, particularly intermittent resources such as wind and solar. Many recent large hydropower projects have suffered from cost overruns and schedule delays – similar to many other mega projects. Large-scale hydro also has a negative environmental impact, given it requires flooding and disrupting natural river flows.

5. Run-of-river Hydropower

   a. *Pros:* Run-of-river hydro typically has much less of an environmental impact than large-scale hydropower dams with large reservoirs. Given the smaller scale of most projects, it carries significantly less schedule and financial risk than large-scale projects with large reservoirs. It is also a non-emitting source of supply, with fairly stable output and low marginal cost.

   b. *Cons:* Run-of-river hydro typically does not provide a significant amount of energy or capacity (i.e. it is smaller in size and has a lower capacity factor than large-scale hydro, although there are some large run-of-river facilities in Canada). Given the environmental restrictions on most river systems, there have been few new small-scale hydropower projects considered or constructed in recent years. Due to the lack of storage, the plants will mostly operate on a must-run basis and, as such, often provide energy and capacity in off-peak months (spring in particular).

6. Thermal Generation (Oil, Natural Gas or Coal)

   a. *Pros:* Thermal generators can provide both dispatchable or baseload source of supply. Thermal plants provide a very reliable source of capacity, with one of the highest ELCCs of any resources. They also provide flexibility to system operators as they can respond to real-time dispatch instructions to increase or decrease output. Many thermal plants can be located near major load centres given their limited land footprint.

   b. *Cons*: Thermal plants have a much higher marginal cost and must purchase fuel inputs on volatile global commodity markets – ensuring that the marginal cost of supply is more volatile than most other sources of supply. They are also an emitting source of supply that are increasingly being subject to more stringent decarbonization policies. Many thermal plants require significant up-front capital costs and face the risk of schedule and cost overruns in construction, as well as policy risk that may limit their dispatch and economic viability.

7. Wind

   a. *Pros*: Wind is a source of zero marginal cost supply with zero carbon emissions. It is not subject to stringent decarbonization policies being implemented in many jurisdictions. Wind development can typically be scaled up and down, depending on system needs and, as such, has a much lower schedule and financial risk that other large-scale sources of supply.

b. *Cons*: Wind provides intermittent supply and requires system operators to maintain other dispatchable resources when the wind is not blowing. The intermittent nature of its output also limits its capacity value, as it cannot be relied upon fully during peak demand hours. The more wind supply that is added, the lower its capacity value becomes. Increasingly, many communities have opposed existing or new wind turbines. Wind turbine also typically have a shorter operational lifespan compared to hydroelectric facilities.

8. Solar

a. *Pros*: Similar to wind, solar power is a source of zero marginal cost supply with zero carbon emissions and is not subject to stringent decarbonization policies. Developments can also be scaled up and down depending on system needs and has a much lower schedule and financial risk than other large-scale sources of supply. Unlike wind, it can be installed at a very small-scale, allowing it to be deployed in major urban centres.

b. *Cons*: Also like wind, solar provides intermittent supply, which requires system operators to maintain other dispatchable when the sun is not shining. The intermittent nature of its output also limits its capacity value, as cannot be relied upon fully during peak demand hours. Solar provides almost no capacity value in winter-peaking jurisdictions (which is most of Canada), as it often has no supply during peak demand hours in the evening.

9. Battery Energy Storage Systems (BESS)

a. *Pros:* Depending on their duration, storage systems can provide a firm source or capacity during peak demand hours. They are also highly flexible and can respond to dispatch instructions instantaneously. With their ability to charge and discharge, they allow system operators and asset owners to shift energy from low-value to high value hours – helping to avoid curtailment of baseload and intermittent resources. Many storage systems have a limited land footprint and can be installed in load centres.

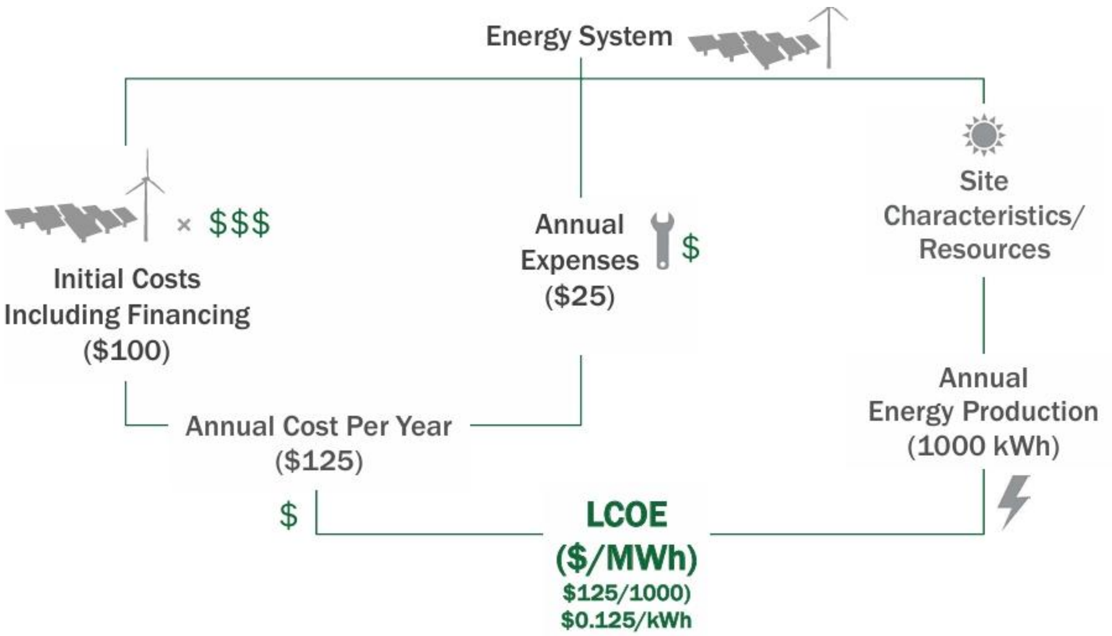
b. *Cons:* Short duration storage provides a very limited source of capacity, as many peak demand periods last multiple hours or days. Longer duration storage – which would provide a much higher capacity value – is significantly more expensive and can come with higher construction and schedule risk. Storage systems do not provide any new energy to a grid, given that the charge and discharge process results in an efficiency loss – instead, they act as a ”net-load” to the grid due to efficiency losses in charging.

2.2 Cost Comparison of Different Supply Resources

While different supply options provide different physical benefits and drawbacks to system operators, they also have a wide range of costs that will need to be recovered from ratepayers. During the planning process, grid operators will evaluate both the short and long-term needs of the grid from a physical standpoint and then compare the costs of different resource mixes that will most cost-effectively maintain reliability. To compare the different supply options from a financial or economic perspective, grid operators often rely on a range of metrics that attempt to provide an apples-to-apples comparison.

The most commonly used metric for comparing the cost of different resources is known as the Levelized Cost of Energy (LCOE). The LCOE compares the lifetime costs of different resources to their total energy production. At its most basic level, the LCOE provides a present value of different supply types on a $/MWh basis in order to better inform policy makers and system operators on the most cost-effective supply option, but it does not specifically address reliability concerns. Given the simplified nature of the output – a $/MWh value – the LCOE is both easy to understand and calculate. The following graphic provides a simplified version of the LCOE approach and the output it provides.

Figure 2 Simplified Example of LCOE[1]



From a more technical perspective (shown below), the LCOE discounts all of the lifetime costs and energy production to calculate a present value metric for the cost of energy from a particular supplier on a per unit basis. Different supply options will have a range of varying inputs – including up-front and annual capital costs, ongoing operating and maintenance (O&M), operating life and financing costs. All of these values are then incorporated in the total cost of each supply resource. The costs are then compared to the total energy supply that the resource. LCOE's can be done on the total operational lifespan of an asset or in any given year based on the carrying costs of the initial capital investment. The basic calculation that for an LCOE is shown in the graphic below.

[1] Levelized Cost of Energy (LCOE)

Figure 3 Detailed LCOE Calculation[2]

$$LCOE\left(\frac{\$}{MWh}\right)=\frac{\sum_{t=0}^{T}\frac{CapEx_t\ +\ O\&M_t\ +F_t}{(1+\text{Discount Rate})^t}}{\sum_{t=1}^{T}\frac{AEP_t}{(1+\text{Discount Rate})^t}}$$

Average revenue per unit of electricity that would be required to recover the costs of constructing and operating a generating plant during an assumed financial life

2.3 Common LCOE Reports Utilized by the Electricity Industry

While the LCOE approach is utilized across the industry, there are a few known shortcomings of this approach. Most notably, the LCOE is simply a cost-based metric that does not provide any insight into the value that different resource types provide to the broader grid, particularly for reliability needs. The following section provides an overview on the key aspects of a few of the most prominent publicly available LCOE approaches. Afterwards, the report provides commentary on adjustments to the LCOE that have been incorporated into a number of reports to account for its shortcomings.

Lazard – While the investment firm Lazard provides one of the most publicly cited LCOE reports, it does not provide a value for large-scale hydro projects. Instead, the report focuses on the cost of supply from a suite of resources that are being actively developed across North America, particularly wind, solar, energy storage (and hybrids), gas-fired plants and nuclear power. Lazard's LCOE approach is fairly standard and measures total lifetime costs divided by total lifetime energy output, with costs broken down into technology-specific capital costs, variable O&M, fixed O&M and fuel costs. As discussed in more detail later in this report, Lazard has also started to incorporate the cost of "firming" supply from intermittent resources, such as wind and solar. Essentially, Lazard incorporates the cost of firm capacity to make up the difference between the installed capacity and the amount of capacity that is used for reliability metrics – with this approach attempting to address a known shortcoming of LCOE values. See the following example for the standard inputs that are used for the LCOE calculation.

[2] LCOE Alternatives: System Value and Other Profitability Metrics

Figure 4 Lazard LCOE Calculation[3]

Year [1]		0	1	2	3	4	5	30
Capacity (MW)	(A)		300	300	300	300	300	300
Capacity Factor	(B)		55%	55%	55%	55%	55%	55%
Total Generation ('000 MWh)	(C)* = (A) x (B)		1,445	1,445	1,445	1,445	1,445	1,445
Levelized Energy Cost ($/MWh)	***(D)***		***$36.7***	***$36.7***	***$36.7***	***$36.7***	***$36.7***	***$36.7***
Total Revenues	**(E)* = (C) x (D)**		**$53.0**	**$53.0**	**$53.0**	**$53.0**	**$53.0**	**$53.0**
Total Fuel Cost	(F)		--	--	--	--	--	--
Total O&M	(G)*		7.4	7.5	7.7	7.9	8.0	14.0
Total Operating Costs	**(H) = (F) + (G)**		**$7.4**	**$7.5**	**$7.7**	**$7.9**	**$8.0**	**$14.0**
EBITDA	**(I) = (E) - (H)**		**$45.7**	**$45.5**	**$45.3**	**$45.1**	**$45.0**	**$39.0**
Debt Outstanding - Beginning of Period	(J)		$342.0 [2]	$339.0	$335.7	$332.2	$328.4	$28.1
Debt - Interest Expense	(K)		(27.4)	(27.1)	(26.9)	(26.6)	(26.3)	(2.3)
Debt - Principal Payment	(L)		(3.0)	(3.3)	(3.5)	(3.8)	(4.1)	(28.1)
Levelized Debt Service	**(M) = (K) + (L)**		**($30.4)**	**($30.4)**	**($30.4)**	**($30.4)**	**($30.4)**	**($30.4)**
EBITDA	(I)		$45.7	$45.5	$45.3	$45.1	$45.0	$39.0
Depreciation (MACRS)	(N)		(114.0)	(182.4)	(109.4)	(65.7)	(65.7)	0.0
Interest Expense	(K)		(27.4)	(27.1)	(26.9)	(26.6)	(26.3)	39.0
Taxable Income	**(O) = (I) + (N) + (K)**		**($95.7)**	**($164.0)**	**($91.0)**	**($47.1)**	**($47.0)**	**($2.3)**
Tax Benefit (Liability) [3]	**(P) = (O) x (tax rate)**		**$38.5**	**$65.9**	**$36.6**	**$18.9**	**$18.9**	**($14.8)**
After-Tax Net Equity Cash Flow	**(Q) = (I) + (M) + (P)**	**($228.0)** [4]	**$53.7**	**$81.0**	**$51.5**	**$33.7**	**$33.5**	**($6.2)**
IRR For Equity Investors		**12%**						

Key Assumptions [5]	
Capacity (MW)	300
Capacity Factor	55%
Fuel Cost ($/MMBtu)	$0.00
Heat Rate (Btu/kWh)	0
Fixed O&M ($/kW-year)	$24.5
Variable O&M ($/MWh)	$0.0
O&M Escalation Rate	2.25%
Capital Structure	
Debt	60.0%
Cost of Debt	8.0%
Equity	40.0%
Cost of Equity	12.0%
Taxes and Tax Incentives:	
Combined Tax Rate	40%
Economic Life (years) [6]	30
MACRS Depreciation (Year Schedule)	5
Capex	
EPC Costs ($/kW)	$1,900
Additional Owner's Costs ($/kW)	$0
Transmission Costs ($/kW)	$0
Total Capital Costs ($/kW)	$1,900
Total Capex ($m)	$570

U.S. Energy Information Agency (EIA) – The federal EIA provides a widely used LCOE report. While the report does include a value for hydropower, the LCOE calculation is based on many of the same financial and economic parameters used for other resource types. The most recent report provides a single year annual value (2030 in the most recent report) for the LCOE. Notably, the EIA approach assumes a standard 30-year cost recovery period for all resources and does not recognize that this is significantly shorter than the operating life of a typical hydropower facility. As noted, the EIA's LCOE calculation is similar in design to the Lazard values, as shown below. The "fixed charge factor" annualizes the capital cost based on a Weighted Average Cost of Capital (WACC). If the total capital cost is $1 million and the WACC is 10%, the fixed charge factor would be $100K.

Figure 5 EIA LCOE Calculation[4]

$$\text{LCOE} = \frac{(\text{fixed charge factor} \times \text{capital cost}) + \text{fixed O\&M}}{\text{generating hours}} + \text{variable O\&M} + \text{fuel}$$

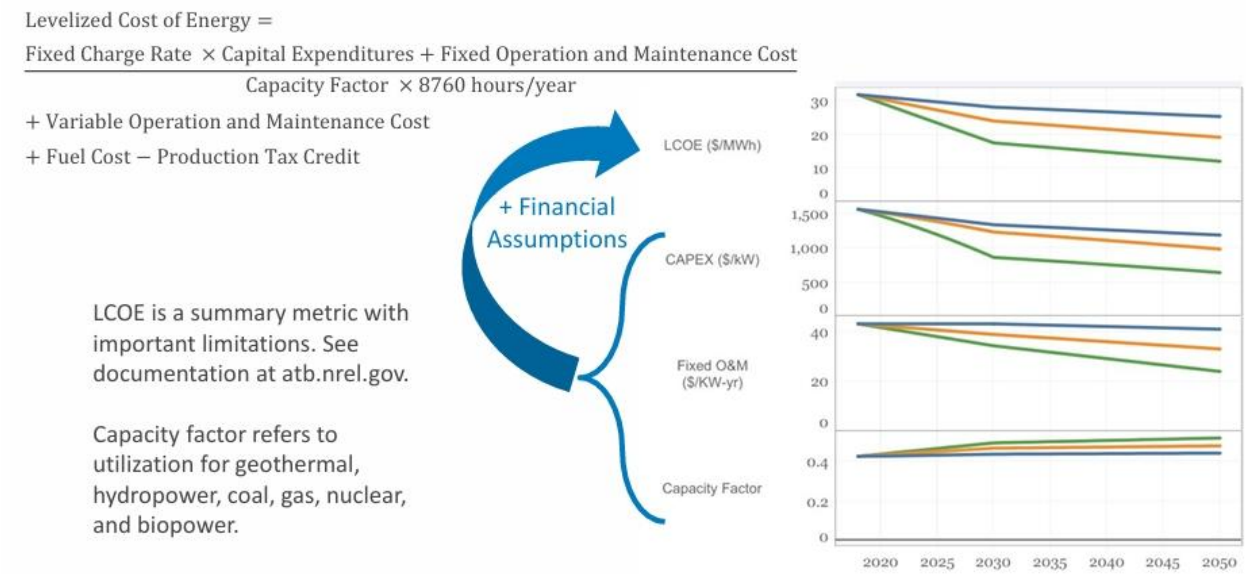
National Renewable Energy Laboratory (NREL) – The NREL LCOE approach largely aligns with that of the EIA. The capital recovery period typically used in its LCOE calculation is 30 years and it assumes no value beyond that point, which would potentially lower the LCOE. In short, like many of the other commonly used LCOE approaches, the value of a particular asset at the end of its operational life is not considered in

[3] lazards-lcoeplus-june-2025.pdf

[4] Levelized Costs of New Generation Resources in the Annual Energy Outlook

its LCOE. As discussed elsewhere in this report, this undervalues hydropower compared to nearly all other resource types. The description for the LCOE is shown in the graphic below.

Figure 6 NREL LCOE Approach[5]



2.4 Canadian IRPs that Provide Levelized Costs of Different Supply Options

A number of system operators in various Canadian jurisdictions have also released LCOE or similar metrics as part of their IRP processes. This list is not exhaustive and does not include analysis that system operators undertake internally, as they are not publicly available. Nearly all of these values are similar in design and approach to the LCOE metrics discussed above.

Independent Electricity System Operator (Ontario) – The IESO provided costs estimates as part of its Pathways to Decarbonization report for a number of different supply options.[6] The cost estimates included overnight capital costs, ongoing O&M and the annual revenue requirement to determine the total system cost of various supply alternatives. The economic life for large-scale hydro was assumed to be 75 years, which is significantly longer than nearly all of the assumptions in the LCOE models reviewed above. The report did not provide any estimates on the LCOE for different resource types and does not appear to have incorporated any terminal or residual value of hydro projects.

[5] Annual Technology Baseline: The 2024 Electricity Update

[6] https://www.ieso.ca/-/media/Files/IESO/Document-Library/gas-phase-out/Pathways-to-Decarbonization-Appendix-A.xlsx

Manitoba Hydro – As part of its 2023 IRP, Manitoba Hydro provided both capital costs and the LCOE for a range of different resource options.[7] Regarding hydropower, the IRP assumed an asset life of 72 years, which is (as noted above) longer than that considered in industry-standard LCOE reports. Similar to other IRPs, the analysis does not appear to include any terminal value of the hydro plant beyond the asset life.

NB Power (New Brunswick) – NB Power's 2023 IRP laid out the cost of a range of different supply options, but did not include the cost of large-scale hydropower, as that is not included in their expansion plans to meet future demand growth or supply needs.[8]

Nova Scotia Power – Nova Scotia Power provided cost estimates for different supply options as part of its Evergreen IRP. Similar to NB Power, the IRP does not include costs for large-scale (or small-scale) hydropower, as this is not included in its expansion plans.[9]

BC Hydro (British Columbia) – BC Hydro considered a number of different resources as part of future options in its last IRP. Notably, the asset list did not include large-scale hydropower, but did consider run-of-river and pumped storage.[10]

2.5 Common Concerns and Adjustments to the LCOE Approach

Many of the organizations and government bodies that release LCOE studies recognize that it has limitations and does not provide a holistic view of the value of different resource types to the grid. The following provides an overview of a few of the high-level concerns with the LCOE before looking at hydro-specific concerns with the LCOE approach.

The EIA in 2013 developed what it refers to as the Levelized Avoided Cost of Energy (LACE) to " improve comparisons of economic competitiveness between generation technologies" and provide a more "intuitive indication of economic competitiveness for each technology."[11] The LACE is used to determine what marginal unit of supply a typical resource will displace when it is added to the grid. The LACE metric is intended to show that simply calculating the cost of building and operating a new asset – as is done with the LCOE – does not show the value that certain assets provide to the grid and grid operators from a marginal cost perspective (i.e. does it displace higher marginal cost units and provide system-wide value). The LACE is determined by summing the expected market revenues of each asset and its total annual generation – ultimately calculating a dollar per MWh value for each resource type. The calculation is shown below:

Figure 7 Levelized Avoided Cost of Energy (LACE) Metric from EIA

$$\text{LACE} = \frac{\text{energy revenue} + \text{spinning reserve revenue} + \text{capacity revenue} - \text{intermittent limit cost}}{\text{generating hours}}$$

---

[7] irp-2023-a2-new-resource-options.pdf

[8] 2023_irp.pdf

[9] IRP Evergreen - Updated Assumptions

[10] 2021 Integrated Resource Plan

[11] Levelized Costs of New Generation Resources in the Annual Energy Outlook

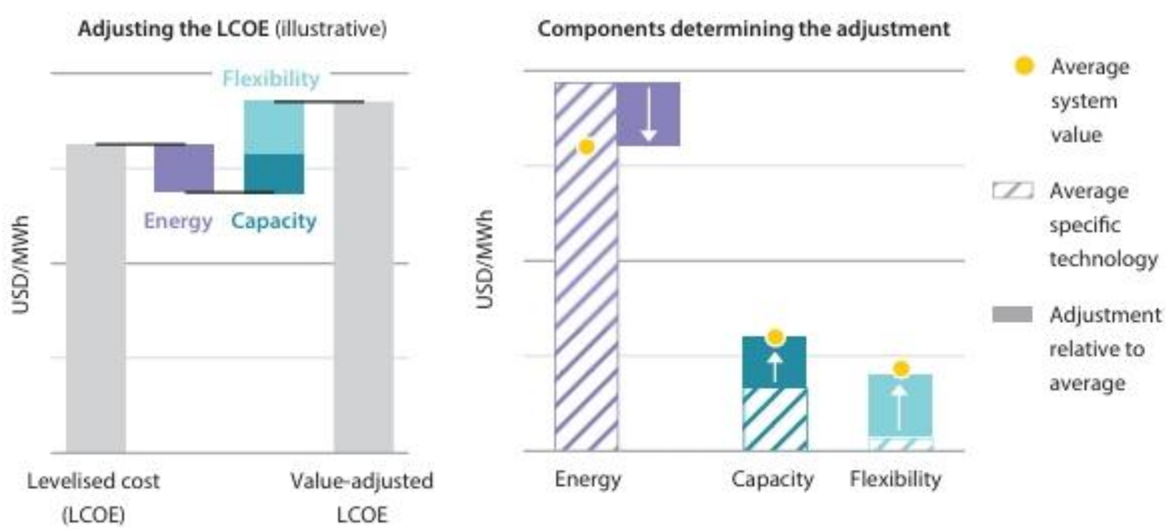
Using the LACE and LCOE, the EIA calculates a value ratio, which is the LACE divided by the LCOE, as shown below. The value-cost ratio highlights that a resource that displaced high marginal cost resources – i.e. one with a high LACE and has a low LCOE – provides significant value to the grid and will have a value-cost ratio greater than one. Essentially, this unit will cost less to build and operate than the marginal cost of units that it is displacing. Conversely, if a resource typically displaces low marginal cost energy, but has a high LCOE (a value-cost ratio below 1), it provides a more limited value to the grid. In this case, the unit will cost more to build and operate than the marginal cost of the energy it is displacing.

Figure 8 Value-Cost Ratio EIA

$$\text{value-cost ratio} = \frac{\text{LACE}}{\text{LCOE}}$$

The International Energy Agency (IEA) created what it calls the Value-adjusted levelized cost of electricity (VALCOE).[12] Similar to the EIA, the IEA notes that "LCOE is not a complete metric of competitiveness, as it lacks representation of the value provided to the system." The IEA notes that grid operators and policy makers need to "look beyond the LCOE." The VALCOE calculates the revenue of three different grid services – energy, flexibility and capacity – for a specific resource type and compares them to the grid average for these services. The sum of the difference between the resource-specific values and the grid average provides a "value adjustment" that moves from the LCOE to the VALCOE. The following graph provides an illustrative example.

Figure 9 VALCOE Metric

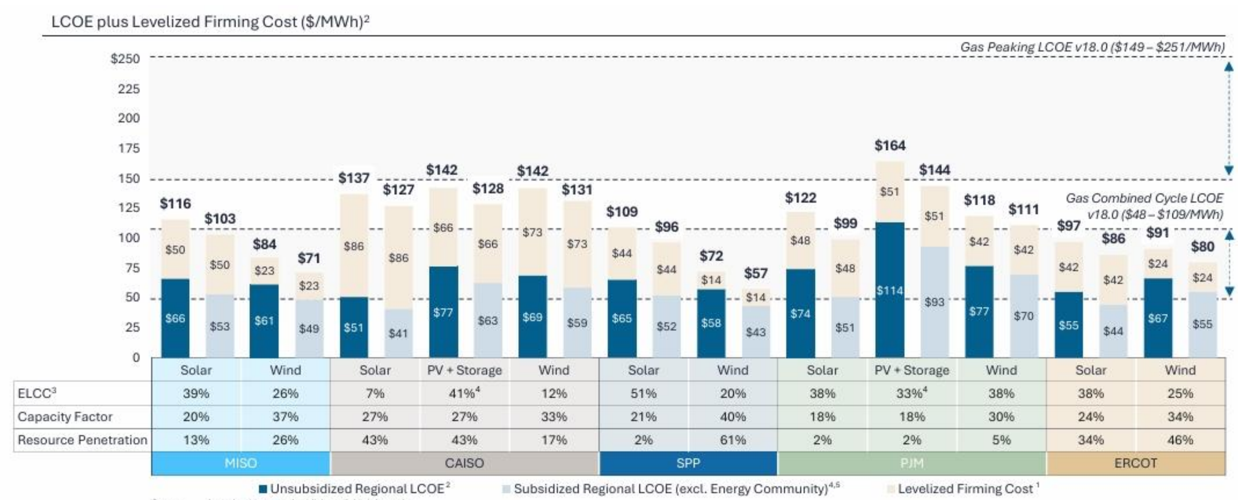


Combining costs and value provides a more robust basis for evaluating competitiveness across technologies than costs alone.

[12] [Projected-Costs-of-Generating-Electricity-2020.pdf]

The Lazard LCOE report has also started to incorporate the cost of "firming" supply from intermittent resources, such as wind and solar, to address one of the common shortcomings of the standard LCOE metric – namely, that intermittent resources require the support of firm capacity. The Lazard approach incorporates the cost of firm capacity to make up the difference between the installed capacity and the amount of capacity that is used for reliability metrics. The following graph highlights how the cost of firming up intermittent capacity increases the LCOE for these resource types. In some instances, the first of firming increases the LCOE of intermittent resources by more than two-fold.

Figure 10 Lazard LCOE with Firming Costs[13]



2.6 Hydro-Specific Concerns Over the LCOE Approach

From a hydro-specific context, various reports that compare different resource types either do not typically include large-scale hydropower or undertake a financial analysis that does not directly align with hydropower's long-term lifespan that, in some cases, can result in a large portion of a site's infrastructure lasting for a century or more. While adjustments to the LCOE metric that attempt to capture the "value" of a particular resource type can attempt to address some of this concern, it will not typically incorporate the long-term value of a large-scale hydropower resource.

One report by the U.S. Department of Energy confirmed this shortcoming, noting that many "formal market value streams send price signals that do not align with either the development or operation timeframes for" a hydropower project.[14] The report also highlighted that given the long-term asset and operational life of hydropower, the full value is only "captured across its physical life, which often exceeds 50 years." As such, any valuation metric of energy – such as the LCOE – which is geared toward financing and development metrics of 20 – 30 years will inevitably undervalue hydropower projects.

[13] Note that hydro facilities are not included in Lazard's LCOE calculations, as there has been limited development of new hydro in recent years and costs for each facility is incredibly site-specific. In contrast, there has been thousands of MWs of new wind, solar and BESS development in the last decade and costs are more broadly similar across different regions and development sites, although site specific conditions – such as a foggy or less iridescent jurisdiction – needs to be considered when evaluating costs.

[14] energy.gov/eere/water/articles/hydropower-vision-report-full-report

Most reports that analyze the value of hydropower compared to alternative resources focus on the failure of current market mechanisms to either fully compensate hydro assets or promote the development of expansion or new hydro. The U.S. National Hydropower association, for example, highlighted the need for system operators to ensure hydropower is “accurately valued and fully compensated for its contributions to the grid.”[15] Another U.S. Department of Energy report on hydropower concluded that “not all services that hydropower provides are currently monetized” but that “new markets for grid services are emerging that can offer alternative revenue streams.”[16] Overall, the report concluded that the traditional forms of revenue for hydropower plants – wholesale energy markets – no longer provided “stable revenue.”

None the reports reviewed – including both the most common LCOE publications or IRPs from utilities and grid operators across Canada – provided a detailed methodology for how to properly value large-scale hydropower and its long-term value. As such, while the LCOE is important, it needs updated or modified to ensure that energy investments are compared on an apples-to-apples basis that include factors such as capacity needs, terminal value and other realistic financial parameters. These will be discussed in more detail in the following sections.

[15] NHA-HydropowerAtRisk-WhitePaper.pdf

[16] Hydropower Value Study: Current Status and Future Opportunities

3. STAKEHOLDER COMMENTARY

Power Advisory interviewed a number of different stakeholders to gauge their sentiment regarding how large-scale hydropower projects are evaluated compared to alternative resources, with a particular focus on the benefits and drawbacks of the standard Levelized Cost of Energy (LCOE) metric. While the LCOE was discussed in more detail in the previous section, at a high-level the metric is intended to provide a simplified cost of energy from different resource types (i.e. wind, solar, hydro and so on). As noted, LCOEs for different resources are often used as one comparator to determine the most cost-effective supply options.

The interviews were conducted with many of the leading utilities and system operators across Canada, including those overseeing vertically integrated utilities, as well as project developers that currently own and operate hydropower assets. Importantly, the interviews also included developers of non-hydro assets in order to provide context on how the LCOE metric is utilized by both hydro and non-hydro proponents.

While many the stakeholders had a range of opinions on how to accurately and fairly evaluate large-scale hydropower compared to alternative resources, there were a few predominant themes.

3.1 LCOE is simplified metric that can be used at an initial screening phase

Many of the different stakeholders that oversee large-scale development either as vertically integrated utility and/or system operator suggested that the LCOE is useful during the initial screening phase of a long-term supply plan or similar analysis on how to cost effectively meet future supply needs. For example, one of the key inputs of an IRP or long-term supply plan is either the capital cost or LCOE of different resource types. These cost assumptions are then incorporated in various different supply buildouts to meet forecasted supply needs. The LCOE provides a simplified view of the "cheapest" available energy resource to meet supply needs. From an initial screening perspective, stakeholders suggested that the LCOE can be used as part of the initial step in determining the most cost-effective supply buildout from an energy perspective, but must then be supplemented by additional analysis (as discussed later in this report) to understand the total system cost of different supply options.

A few stakeholders noted that a simplified LCOE metric is particularly useful when comparing similar resource types that have the same – or nearly identical – attributes. For example, if there are multiple hydropower projects that are being considered for development, the simplified LCOE approach can help screen the most cost-effective option among that same resource type. The LCOE is useful when comparing similar resource types, as it does not have to address the shortcomings or benefits of comparing one resource type – wind versus hydropower, for example – to another from a broader system perspective or long-term planning horizon. When only comparing hydropower projects, for example, the LCOE does not need to account for the value of capacity or other grid-wide benefits, as would be required when comparing it to a wind (or solar) project. An LCOE comparison between the same resource type provides a more apples-to-apples comparison and is useful in screening the lowest cost option among a particular group of projects.

3.2 The LCOE does not account for the long-term value of hydropower

Many stakeholders stressed that not all resource types have a similar operating life and the long-term nature of hydropower assets is not directly accounted for in the LCOE metric. As it relates to hydropower, various components will have an operating life that can stretch to up to 100 years. While some components – turbines and other mechanical components – will have an operating life of up to 50 years (or shorter), the major capital works (i.e. the dam itself) may last beyond 100 years, as can be seen at multiple hydropower facilities operating across Canada and the United States that were built more than a century ago. A facility with long-term components – i.e. ones that can last for multiple generations – can continue to operate much longer than other resource types that require a more limited up-front capital investment. Many alternative resources that require less up-front capital investment will appear to be more cost effective from a simplified LCOE perspective but will require more capital investment over a long-term horizon, such as 50 to 100 years when they will have to be nearly fully replaced multiple times.

While the LCOE metric includes the operating lifespan of each individual resource type, it does not account for significant divergences between the value that a long-term life asset such as hydropower provides system operators – or society more generally. As noted above, given the long-term nature of many components of a hydropower project – particularly the capital works – there is often what is known as a "residual value" of an asset beyond 50 years. Many stakeholders highlighted that the residual value of hydropower is much higher than nearly all other resource types. As can be seen recently with a number of large hydropower projects – Churchill Falls and the James Bay complex, among many others – a hydropower facility continues to provide value well beyond 50 years without having to full reconstruct it. It is, in essence, a multi-generational asset. Many stakeholders noted that the typical LCOE metric does not incorporate any value beyond the standard operating life that is used to calculate the LCOE. As such, it essentially assumes that an asset is "run-to-failure" over its operating life and that underpins its per-unit cost. To operate many non-hydro resources beyond their initial operating life would require significant capital investment on nearly every component and supporting investment – with that "rebuild" cost not reflected in a simplified LCOE. Conversely, the need for a near complete overhaul of an asset at the end of 25 to 30 years means that the residual value of that asset is low or negligible. When the residual value is incorporated in the up-front capital cost, long-term assets such as hydropower can be the more cost-effective supply option.

3.2 The LCOE does not provide a system-wide approach to value

Many stakeholders noted that long-term supply plans or IRPs take a system-wide view that incorporates many different requirements of an electricity grid beyond energy needs. The need and value of capacity, for example, was highlighted by multiple system operators as a vital to long-term planning, with the value of capacity not typically incorporated in the simplified LCOE metric.

To maintain reliability, system operators must ensure that the installed resources will be available during peak demand hours – this is commonly referred to as "capacity value." Solar, for example, does not typically provide any energy during peak demand hours in winter-peaking jurisdictions such as Quebec and Newfoundland and Labrador (and nearly every other province apart from Ontario). As such, its capacity value – i.e. the amount of energy that it will provide throughout the peak demand hours – is zero. While the system operator may incorporate solar supply in its overall energy needs, it must also ensure that it has the necessary resources to be available during peak demand hours. Hydropower – particularly large hydropower facilities – typically has a very high capacity value, meaning that they can be relied upon to provide energy during peak demand hours.

Many stakeholders noted that the total system cost – notably the cost to procure both energy and capacity (and other more technical needs commonly referred to as ancillary services) – is one of the primary factors in determining the optimal and cost-effective supply mix for the entire grid. The LCOE metric does not provide the total system cost, as it only provides the cost of energy and not the cost of additional capacity. When comparing hydropower to alternative resources such as wind and solar – which have much lower capacity values – the LCOE metric under-values hydropower and does not provide an accurate supply cost.

Other stakeholders also noted that the flexibility and high capacity value of hydropower and other baseload resources (such as gas-fired generation) can allow for greater integration of more variable resources such as wind and solar. In essence, the high capital cost of hydropower can allow for more "lower" cost energy from an LCOE perspective to be added to the grid. This can help reduce the overall system cost while limiting emissions. Again, the system-wide value of a resource that is both flexible and can provide baseload power is not reflected in a simplified LCOE metric.

3.3 Developing a long-term asset such as hydropower is difficult under most existing commercial arrangements

A number of stakeholders also highlighted that many existing commercial arrangements make it difficult to develop new hydro projects, which is made worse by a simplified LCOE comparison to other resource types that make these resources appear to be more cost-effective. As noted extensively throughout interviews with various stakeholders, hydropower projects have a very long operational and economic lifespan, which is often much longer than available commercial contracts and financing from most system operators. Typical Power Purchase Agreements (PPAs) across Canada and the United States are typically for 20 to 30 years, with a small number of contracts – predominantly for hydropower projects – extending to 40 years or longer. Given that the commercial contract is much shorter than the operational economic lifespan, potential developers of hydropower projects must either take the risk that they will recover the remaining value of the asset through an additional contract at the end of the term length, or incorporate the capital costs into a shorter PPA term length – increasing the LCOE and making hydropower appear uncompetitive when compared to other resource types.

Long-term assets like hydropower require long-term thinking by system operators or other procurement agencies. Short-term metrics such as the LCOE – while useful – can support short-term commercial arrangements that under-value hydropower compared to alternative resources.

4. ALTERNATIVES AND ADJUSTMENTS TO THE LCOE

There are a number of alternative ways to calculate the LCOE to more accurately reflect the cost of different resource types, particularly when comparing long-term assets such as hydropower to resources with much shorter operational lifespans. A number of the alternatives described below can be used in conjunction with one another, as each alternative focuses on one drawback of the simplified LCOE discussed previously in this report. These options are not exhaustive and many system operators will have grid or provincial-specific requirements that may be incorporated when comparing the cost of different supply options.

Notably, many system operators calculate a “total system cost” metric, which incorporates a range of different supply options to determine the lowest cost resource mix on a system-wide basis. While this approach may be appropriate from a grid or system operator perspective, it often focuses on grid-specific requirements and jurisdictional-specific cost allocation (and cost recovery) and does not provide a uniform metric to compare different supply resources across different jurisdictions. The approaches described below are intended to provide a more realistic and transparent method of calculating LCOEs for a range of different supply options that can be used across different jurisdictions and can be provided to policymakers and other stakeholders to better reflect the individual cost of supply from a range of resource types.

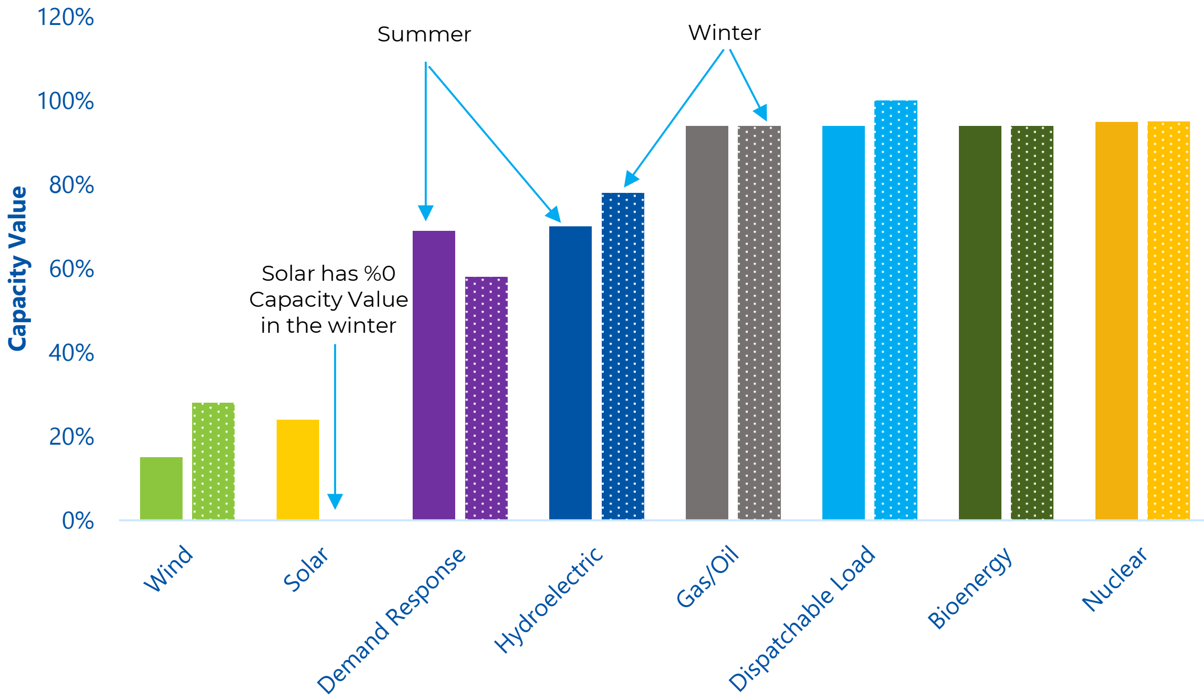
The following LCOE adjustments have been applied to hydro, wind and solar resources for comparative purposes. While there are other supply options available to some system operators and utilities, these options are either not widely available across the country (nuclear), are facing more stringent restrictions due to decarbonization policies (gas-fired generation) or are not an incremental supply resource (storage). The combination of supply and the potential for new developments from hydro, wind and solar is prevalent in nearly every jurisdiction across Canada. It should also be noted that the values for capital and operating costs are representative – they will range significantly across hydro projects and, to a lesser, extent between wind and solar projects. Nonetheless, the values used for capital and fixed operating costs – particularly for wind and solar – are based on high-level industry-wide estimates.

4.1 Capacity Value Approach

Different resource types provide a range of what is referred to as “capacity value”. As discussed previously in this report, the capacity value of a particular resource is – at a very high level – the amount of installed capacity from an asset that will be capable of providing energy during peak demand hours. If a 100 MW facility is expected to be capable of providing 90% of its capacity during peak demand hours, it will have a capacity value of 90 MWs (or 90%). Conversely, a solar facility in a winter-peaking jurisdiction will have a capacity value of 0 MWs, as it is not expected to provide any energy during peak demand hours.

While an LCOE metric is useful in determining what the cost of energy is from a particular resource type (with the known deficiencies described throughout this report), it provides limited insight into the cost or value of capacity to the grid. System operators and other planners must consider the cost of capacity when undertaking IRPs or long-term supply plans, as capacity is a key metric in maintaining the reliability of the grid. As an example, the IESO in Ontario provides its assessment of the capacity value of different resource types operating in Ontario during the summer and winter months, with the capacity value changing between the different seasons based on resource output and demand shapes.

Figure 11 IESO Peak Demand Capacity Value Estimates[17]



As shown in the Figure above, all resources (in a summer-peaking jurisdiction) will naturally be expected to be counted on to provide some amount of energy during peak demand hours (this represents its capacity value). Based on the IESO's estimates, a 100 MW wind asset will provide 15 MW of capacity in the summer (and 24 MW in the winter), while for a solar asset – again, in a summer-peaking jurisdiction such as Ontario – it is 24 MW in the summer and 0 MW in the winter. Hydropower assets have a high capacity value of 70 MW and 78 MW in the summer and winter, respectively, while most thermal assets will have a high capacity value of more than 90 MW in both seasons.[18] If a system operator were to build an entire system of solar resources, for example, the values above show that each 100 MW of installed solar capacity will only count as 24 MW of "firm" capacity in the summer months and 0 MW in the winter. As such, every MW of installed solar capacity in a winter-peaking jurisdiction will need to be fully backed by an alternative resource. Conversely, a system that is entirely hydro units will receive 70 MW for every 100 MW of installed capacity in the summer.

The simplified LCOE provides the cost of procuring energy from a particular resource – as the LCOE is determined by the total amount of energy the installed capacity provides in a typical year – but it does not address the capacity needs of the grid. Low capacity-value resources – such as wind and solar – may provide "cheaper" energy from an LCOE perspective, but will require additional investment from a capacity perspective.

---

[17] The values come from the IESO's 2025 Annual Planning Outlook. Summer peak load typically occurs in the June to August months, while winter peak demand typically occurs between December and February: https://www.ieso.ca/-/media/Files/IESO/Document-Library/planning-forecasts/apo/2025/Supply-Adequacy-and-Energy-Outlook-Module-Data.xlsx

[18] Hydro facilities typically have a higher capacity factor in the winter due to hydrological conditions.

The Capacity Value approach increases the LCOE of each resource based on the cost of capacity that needs to be procured to match its installed capacity. Typically, all assets provide some form of capacity, although solar provides no capacity in winter-peaking jurisdictions. While all grid operators value capacity, the mechanism and how they obtain the price of this value can range due to different market designs or procurement approaches. Many jurisdictions with de-regulated, competitive wholesale electricity will have a separate capacity auction. Energy is sold in the wholesale market, while capacity is sold in the capacity auction – with the two streams typically accounting for the total value of the asset to the grid (among other more value streams). Other grids – particularly across Canada that are majority owned and operated by Crown corporations – contract for assets on a long-term basis or determine the value of capacity through a regulated approach. Some jurisdictions, such as Ontario, have a hybrid approach that includes both an annual Capacity Auction and long-term contracting for capacity.

In any case, the value of capacity ranges in different jurisdictions. For simplicity purposes, the long-term value of capacity that Hydro Quebec files to its regulator can be used as a benchmark for the long-term cost of new capacity to provide an example of how the Capacity Value approach would work. Based on its most recent rate application to the provincial regulator, the value of long-term capacity is $166k/kW-year (or $166,000/MW-year). The Capacity Value LCOE will then translate this value to a $/MWh basis and add this cost to the LCOE based on its capacity value during peak demand hours, as shown in the following example.

The following table provides an example of the inputs used to calculate the capacity-adjusted LCOE for a winter-peaking jurisdiction, which is expected to be standard demand shape for all Canadian jurisdictions if space-heating is converted from natural gas/fuel oil to electricity as part of broader decarbonization policies (and is the current demand shape in all province apart from Ontario).

The installed capital cost for a 100 MW hydropower project is compared to a solar and wind asset in a winter-peaking jurisdiction. The capacity cost attributed to the asset is the cost of purchasing capacity to account for the difference between its accredited capacity during peak demand hours – 78% for a hydro, 0% for a solar and 15% for wind – and its installed capacity. This is, essentially, additional capacity that a system operator must procure for each resource type based on its expected output during peak demand hours. The $166K/MW-year capacity cost is then converted to a $/MWh value based on the annual capacity factor and supply from the asset. For a hydropower facility, this amounts to $7.58/MWh for the cost of additional capacity compared to $105.28/MWh for solar and $46.02 for wind. The calculation to determine the capacity cost is:

*Capacity Cost = (Annualized Long-Term Capacity Cost / Annual Energy Volume) * (1-Capacity Value for Peak Load)*

Or

*Hydro Power Capacity Cost ($/MWh) = ($166,000/(8760*55%)*(1-78%) = $7.58/MWh*

The capacity cost is then added to the simplified LCOE value to provide an apples-to-apples comparison between the resources. Prior to the capacity value, the LCOE for a hydropower asset was $138.95/MWh compared to $99.61/MWh for a solar project. After the capacity cost is included, the hydro asset's LCOE has increased to $146.53/MWh compared to $204.89/MWh for a solar asset.

Table 1 Capacity Value LCOE[19]

	Hydropower	Solar	Wind
CAPEX ($/kW)	$10,000	$1,928	$2,900
FOM ($/kW-year)	$35	$17	45
Project Life (years)	50	30	25
Capacity Factor	55%	18%	35%
Annualized CAPEX ($/MW-year)	$63,444,286	$14,006,710	$22,685,748
Annual FOM	$3,500,000	$1,700,000	$4,500,000
Annualized Cost	$66,944,286	$15,706,710	$27,185,748
Annual Generation	481,800	157,680	306,600
Nominal LCOE	$138.95	$99.61	$88.67
Capacity Value ($/MW-Year)	$166,000	$166,000	$166,000
Capacity Value for Peak Load	78%	0%	15%
Capacity Value Attributed to Asset	$7.58	$105.28	$46.02
Pre-Capacity Value LCOE	$138.95	$99.61	$88.67
Capacity Value LCOE	$146.53	$204.89	$134.69

4.2 Residual Value Approach

Another adjustment to the simplified LCOE metric is to utilize a residual value component in determining the LCOE. As discussed previously in this report, the residual value is the remaining value of a particular asset at the end of its operational life, which is included in the LCOE calculation. There are multiple methodologies for determining the residual value.

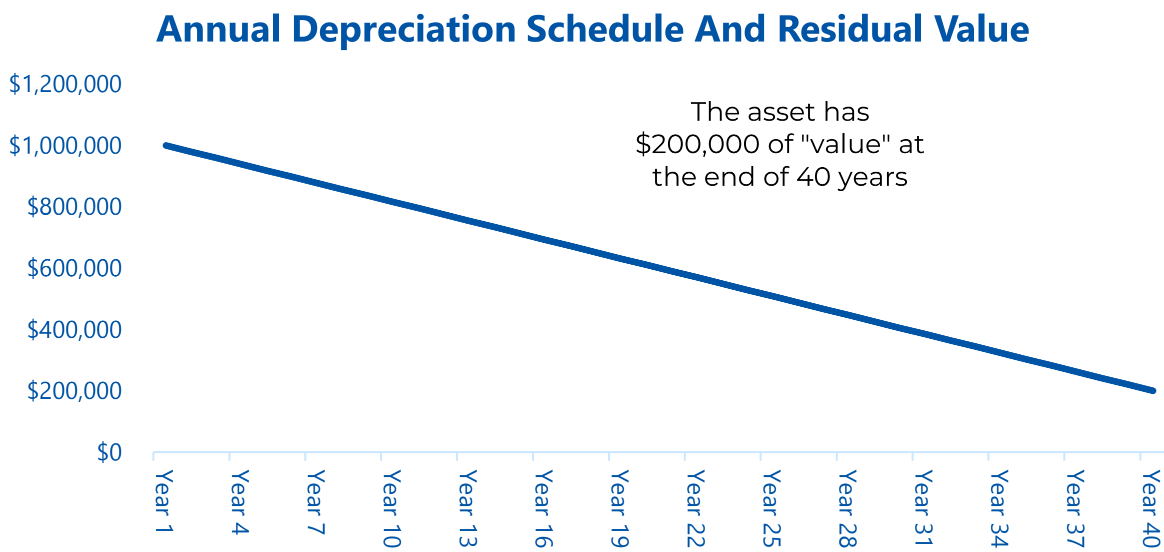
One option is to incorporate an accounting or rate-regulated approach to determine the remaining value of the installed assets at the end of the operating life. In this example, a number of the components of a hydropower plant will continue to have an accounting life beyond 40 or 50 years – in short, these assets will not be fully depreciated from an accounting perspective[20]. Civil works of a hydropower facility will last well beyond 50 years. If, for example, the major civil works of a hydropower plant have 20% of their value remaining after depreciation over the forecasted operating life, this value can be used to offset the up-front capital cost and reduce the LCOE. The figure below highlights how this would work for a $1 million investment that has $200,000 left of accounting value remaining after depreciation. The $200,000 of remaining value of asset offsets the up-front capital cost, which would reduce the LCOE. While utilizing a long-term operational life can also reduce the levelized cost, most of the benefits will occur well into the future and will be minimized through the discount rate and have a limited impact on the LCOE. Simply

[19] For simplicity purposes, each of the examples is compared to either a wind or solar facility. This is intended to isolate the impact of one type of adjustment to the LCOE calculation and how it impacts one particular resource type. In the final section in this chapter, all of the different adjustments are considered to compare a hydropower facility to both a wind and solar asset.

[20] We use 40 years here as an example, as this is the typical accounting life for capital assets, as determined by the Ontario Energy Board (OEB). Different jurisdiction will have a range of amortization periods.

extending the operating life in the LCOE also does not account for different depreciation schedules for the various components of the resource, is less accurate and does not explicitly address residual value.

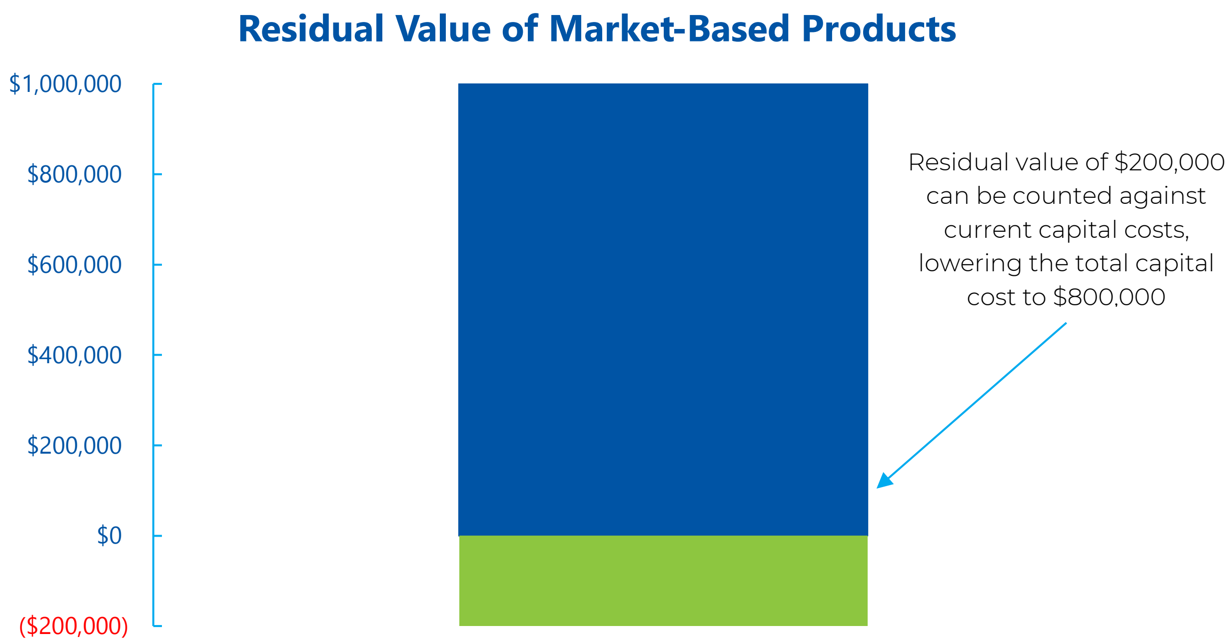
Figure 12 Depreciation Example



Another option is to calculate market-based revenues net of costs that the asset will earn in the years beyond the calculated operational life. For example, if the asset is expected to earn $50/MWh (net of costs) for all supply beyond the 50-year forecasted operational life, the value of that energy will be discounted to the present and can be used to offset the up-front capital cost. The result is a net lower capital cost and lower LCOE. The figure below highlights this approach, with the $1,000,000 capital investment being reduced by the $200,000 of residual value beyond the 40-year life (or whatever operational life is considered for the asset). The net capital cost used to calculate the LCOE becomes $800,000. For long-term assets such as hydropower, the residual value of supply beyond a 40 or 50-year contract can be significant. The recent Memorandum of Understanding (MOU) between Hydro Quebec and Newfoundland and Labrador Hydro (NLH) is example of an asset providing value well beyond the operational life assumed in most LCOE calculations.

One concern around calculating the residual value based on market revenues is the inherent uncertainty of market-based products beyond 40 years. Given this uncertainty, a residual value that is determined though market-based products will be highly speculative and uncertain. Additionally, market-based values will vary depending on the resource type. If, for example, there is a large-scale build-out of solar resources, then the residual value of supply from a solar resource (if there is any) will likely be low and reduced over time. The complexity, uncertainty and unlikelihood of accurately forecasting a market-based residual value can make this approach challenging from the perspective of a system operator or long-term planning agency. The accounting methodology to determine residual value is more straightforward and less subject to forecast uncertainty, but still remains subject to forecasts around the depreciated value of the asset.

Figure 13 Residual Value Example



4.3 Real LCOE Approach

Converting a typical LCOE value – which is typically presented in nominal dollars – into "real" dollars can eliminate the impact that inflation assumptions can have on an LCOE, particularly for long-term, high capital cost resources. Using a real discount rate – which strips out the impact of inflation in the discount rate – will reduce the discount rate and result in a more apples-to-apples comparison between short and long-term assets. In essence, the real discount rate reduces the overall cost of a project, as it will "smooth" the costs of project over a long time period.

Consider the following example, which compares a hydro project to a wind project using a real versus nominal LCOE approach. The underlying assumptions in terms of financial metrics and installed MWs are shown in the following table.

Table 2 Financial and Capacity Assumptions

Real Discount Rate	4%
Inflation Rate	2%
Installed Capacity (MW)	100

The financial assumptions and installed capacity are incorporated into a simplified LCOE metric using both the real and nominal approach. In both cases, the LCOE is a function of the total costs – including both fixed capital and operating costs – that are converted into an annual payment and then further converted into an energy payment based on the expected amount of supply provided each year from the asset. The simplified calculation for the LCOE is:

LCOE = Annualized Capital and Operating Costs / Total Annual Energy

The annual payment separates the total cost of the project into individual years (the "project life" in the table below"), with the annual payment determined by the up-front capital cost and the real discount rate. In the nominal LCOE example in the following table, the LCOE for hydro is $138.95/MWh compared to $88.67/MWh for a wind project – a more than $50/MWh spread in the "economics" between the two resource types utilizing a simplified LCOE.

Table 3 Nominal LCOE Calculation

	Hydropower	Wind
CAPEX ($/kW)	$10,000	$2,900
FOM ($/kW-year)	35	45
Project Life (years)	50	25
Capacity Factor (%)	55%	35%
Annualized CAPEX ($/MW-year)	$63,444,286	$22,685,748
Annual FOM ($)	$3,500,000	$4,500,000
Annualized Cost	$66,944,286	$27,185,748
Annual Generation (MWh)	481,800	306,600
Nominal LCOE ($/MWh)	**$138.95**	**$88.67**

Using the same assumptions in terms of capital costs and project operating life – but calculating the LCOE on a real basis – produces different LCOEs for both projects. The LCOE for the hydro project has decreased to $103.88/MWh compared to a decrease to $75.22/MWh for the wind project – a spread of $28/MWh between the two projects, or around half of the spread from the nominal calculation. The result is that from a simplified LCOE perspective, the hydropower project's economics compared to the wind project have improved, although it remains more expensive before incorporating other adjustments discussed below.

Table 4 Real LCOE Calculation

	Hydropower	Wind
CAPEX ($/kW)	$10,000	$2,900
FOM ($/kW-year)	35	45
Project Life (years)	50	25
Capacity Factor (%)	55%	35%
Annualized CAPEX ($/MW-year)	$46,550,200	$18,563,469
Annual FOM ($)	$3,500,000	$4,500,000
Annualized Cost	$50,050,200	$23,063,469
Annual Generation (MWh)	481,800	306,600
Real LCOE ($/MWh)	**$103.88**	**$75.22**

The primary factor in shifting the LCOE higher between the real and nominal LCOE is the discount rate. In the nominal approach, the discount rate is higher, as it includes inflation and pushes up the annual payment required to recover the cost of the initial capital investment. In the real LCOE calculation, the reverse occurs – with the discount rate being lower and the annual payment required to recover the initial capital investment is reduced. Long-term assets with high up-front capital costs will be more heavily impacted by the using a real versus nominal calculation.

4.4 Replacement Chain Approach

Replacement chain analysis is a capital-budgeting technique that can be used to compare projects with unequal operational and economic lifespans. Directly comparing costs of projects with unequal lifespans can present misleading outcomes, as different time horizons distort net present value ("NPV") calculations – as shown in the Real Value method described previously in this report. A replacement chain analysis effectively normalizes the project lifespans by requiring that shorter duration projects be extended through multiple iterations until the lifespan of these repeated iterations ("the replacement chain") matches the lifespan of the longer duration project. This enables a like-to-like comparison of the costs of the two projects in present value terms.

As noted, hydropower projects can typically have lifespans of 100 years, or more, whereas a wind project may only have a 25-year lifespan. A replacement chain analysis of the two projects would require that the wind project be repeated four times, i.e., built and re-powered three times, in order to match the lifespan of the 100-year hydropower project for the LCOE calculation. The hydropower CAPEX is incurred once over the 100-year project lifespan, whereas the wind project CAPEX is incurred every 25 years during the same time period. Analyzing the wind project over 25 years using the classical LCOE approach will make the LCOE look much less expensive than hydropower, which has a higher initial capital cost, but the repeated reinvestment costs incurred for the wind project raises its LCOE when using the replacement chain analysis.

Table 5 Replacement Chain Example

	Replacement Chain		Classical LCOE	
	Wind	Hydro	Wind	Hydro
Capacity (MW)	100	100	100	100
Capacity Factor (%)	35%	55%	35%	55%
CAPEX ($/kW)	$290.0	$1,000.0	$290.0	$1,000.0
Re-Powering CAPEX 1 ($/kW)	$290.0	*NA*	*NA*	*NA*
Re-Powering CAPEX 2 ($/kW)	$290.0	*NA*	*NA*	*NA*
Re-Powering CAPEX 3 ($/kW)	$290.0	*NA*	*NA*	*NA*
OPEX ($/kW)	$4.5	$3.5	$4.5	$3.5
PV Total Costs	$565.2	$1,085.8	$402.5	$1,350.0
LCOE ($/MWh)	**$74.11**	**$88.43**	**$80.80**	**$109.95**

In the example above, the replacement chain approach reduced the LCOE spread between a wind and hydropower plant from around $29/MWh to $14/MWh – or nearly cutting the spread in economics between the two assets in half.

The replacement chain approach to calculating an LCOE ensures that relatively short-lived non-hydro renewable resources like wind and solar are fairly compared to relatively longer-lived hydropower resources by modelling the repeated investments in non-hydro renewable resources. This approach aligns the time horizon of the analysis, avoids bias and gives policymakers and investors a much more realistic view of the long-term cost competitiveness of hydropower. Given the similarity of this approach to the Real

Value adjustment described previously, this is an alternative to that approach that achieves a similar result and would be used in lieu of that methodology.

4.5 Incorporating Multiple Adjustments to the LCOE

There are multiple methodologies that can be used to adjust the simplified LCOE metric to better account for both the different operational and system-wide values and characteristics for different assets. The various approaches discussed in this report can be combined to provide a more holistic value of assets, particularly hydropower compared to resources that are typically presented as more cost-effective when based on a simplified LCOE model.

The analysis discussed below combines three of the different methodologies described in this report to generic hydro, wind and solar assets. The report focuses on these resource types, as they are all non-emitting energy resources that can be built in multiple provinces across the country. While gas-fired generation remains an option for most system operators, decarbonization policies will increasingly require that it operate more as a capacity rather than energy resource – i.e. it will be dispatched infrequently and relied upon to serve demand in peak demand hours and not run as a baseload resource. While nuclear power is prevalent in Ontario – and to a lesser extent in New Brunswick – it was not considered in this analysis as its role in other provinces is currently limited.

The table below compares the simplified LCOE in conjunction with the different modifications proposed in this report. Based on the simplified LCOE, hydropower is the highest cost resource at $138.95/MWh, while wind is the lowest cost resource at $88.67/MWh. The adjustments result in the following changes:

1. The "Capacity Value" approach adds an associated capacity cost for all resources (assuming a winter-peaking jurisdiction) that materially increases the cost of energy from a solar resource, as nearly every MW of installed capacity would need to be supported by an additional MW of procured capacity. The additional capacity cost for solar power is very high, as it receives no capacity credit – i.e. it does not provide energy during peak demand hours – and all of the related capacity costs are included in its energy output, which has a low capacity factor of 15%.

2. The "Real Value" approach lowers the LCOE for all resources, but is most impactful for hydropower given its high capital cost and operational and economic life.

3. The "Residual Value" approach – which assumes that 10% of a hydropower facility's up-front capital cost continues to have value beyond the 50-year economic life – reduces the LCOE by $13/MWh.[21] The other resource types are assumed to have no capacity value at the end of their operational life given that they are typically "run-to-failure". A more detailed assessment of the different technology types would better define residual value for all assets.

4. The replacement chain approach ensures that assets are compared over a 100-year timeframe and the high percentage of initial capital spend that would need to be repeated multiple times for a wind and solar asset compared to hydropower are accounted for in the calculation. Note that this approach is not shown in the table below, as it is similar in design to the Real Value approach.

Once all of the adjustments are considered, the LCOE for a hydropower facility is the lowest among the different resource types. While policymakers may not consider all of the different values described in this

[21] Note that 10% is a high-level estimate. The actual value could be significantly higher given that many of the major civil works of a hydropower facility will continue to be operational with limited capital investment.

report, they should consider at least one of them, particularly the "Capacity Value" adjustment, as capacity needs are vital to maintain reliability.

	Hydropower	Solar	Wind
Pre-Adjustment LCOE	$138.95	$99.61	$88.67
Capacity Value Adjustment	$7.58	$105.28	$46.02
Residual Value Adjustment	($13.17)	$0.00	$0.00
Real Value Adjustment	($35.06)	($13.45)	($18.12)
Adjusted Total LCOE	**$98.29**	**$191.44**	**$116.57**

5. CONCLUSION AND NEXT STEPS

While the LCOE metric can provide a useful metric to understand the cost of different supply resources at a high-level, it fails to fully capture the value of long-term assets such as hydropower that can provide a range of benefits to system operators. The approaches described in this report provide a more realistic cost of different non-emitting supply resources compared to hydropower projects.

Policy makers and system operators should consider utilizing the various alternative approaches when comparing large-scale hydropower projects to other sources of non-emitting supply. Based on the findings in this report, the following factors should be considered when comparing new supply options to meet forecasted demand growth.

1. The long-term nature of hydropower needs to be considered in any analysis, as the multi-generational aspect of large-scale hydropower projects can significantly benefit ratepayers over multiple generations. The long-term considerations should incorporate either the residual value of hydropower projects beyond 50 years or the replacement costs of alternative sources of supply over multiple decades.

2. The capacity value of hydropower – and the associated reduction in total system costs that it can produce – must be included in any comparison of the cost-effectiveness of different supply options.

Hydropower has been the cornerstone of multiple provincial grids over the last century and, in many cases, has helped maintain cost-effective electricity rates. Ensuring that any cost comparison metric – such as the LCOE – accurately captures that value is vital as provincial grids across the country push to meet growing demand.

As typically used as a screening tool, the LCOE has limited value unless it incorporates additional metrics to make an apples-to-apples comparison. Ultimately, many of the hydro facilities that have been built in Canada have helped to integrate low-cost renewables into provincial electricity grids. As decarbonization continues to bring more electricity load to the grid and more variable resources are built, the need for the capacity and flexibility from hydropower will continue to be vital to maintain reliability. Decision-making on new supply resources must incorporate the range of needs facing a complex electricity grid and cannot be whittled down to a simplified financial metric, such as the LCOE