CLEAN ENERGY CANADA

Cost of Renewable Generation in Canada

Final Report

December 2022

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ACCELERATING THE CLEAN ENERGY TRANSITION

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1. Introduction

Project Context

- Dunsky was retained by Clean Energy Canada (CEC) to **develop and apply a method to translate existing resource cost data and forecasts for key renewable energy resources** into rigorous cost estimates for new projects across Canada.
- The scope and focus of the analysis is centered on applying this method to develop cost estimates for **new solar, wind and energy storage deployments in Alberta and Ontario** over the next decade.
- This work offers several **contributions to energy and climate discussions in Canada:**
  - A reproducible approach for estimating localized costs of renewable generation in Canada;
  - A reference for governments, utilities, environmental groups, researchers and other stakeholders in Canada's energy ecosystem in their assessments of energy pathways and policy; and
  - Important insights into the competitiveness of renewables resources in Canada today and in the future.

2. Approach

Forecast Approach Overview

1. **Research and catalogue** forecasts and relevant information outside the region
2. Develop a **partition** of the generating resource costs
3. Research the **regional costs**, including any recently completed projects or Power Purchase Agreements (PPAs), utility projections from IRPs, interviews with local developers, etc.
4. **Adjust or replace** the costs in the partition based on the regional research where appropriate
5. **Combine** the forecast components into a localized generating resource cost forecast

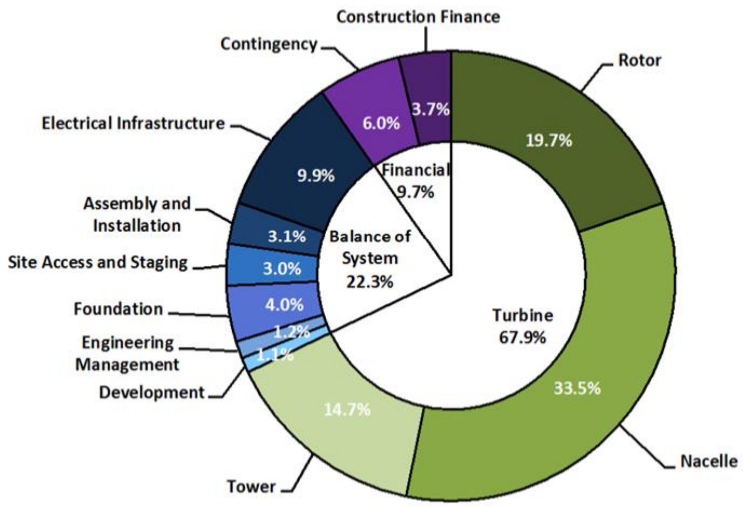
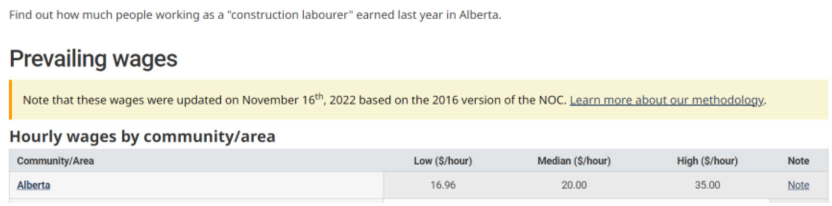


Figure ES1. CapEx for the land-based reference wind power plant project
Source: NREL

NREL's ATB is an example of a forecast that partitions resource costs, and it is one of the sources used for this project


Find out how much people working as a "construction labourer" earned last year in Alberta.

Prevailing wages

Note that these wages were updated on November 16th, 2022 based on the 2016 version of the NOC. Learn more about our methodology.

Hourly wages by community/area

Community/Area	Low ($/hour)	Median ($/hour)	High ($/hour)	Note
Alberta	16.96	20.00	35.00	Note

Wage data from Canada's Job Bank is an example of regional costs incorporated into the forecast

Additional Details on the Forecast Approach are Available in the *Generating Resource Forecast Cost Methodology Documentation* provided with this report and the forecast model

Key Assumptions and Sources

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General Assumptions

- Levelized Cost of Natural Gas is $3.77[1] per MMBtu. Fuel Cost Projections are from the IESO APO 2022.
- Carbon Tax is assumed to increase by $15/ton from $65/ton to $170 by 2030 and stay constant. For project costs, we assume the tax is levelized over the project life.
- **Key Financial Assumptions[2]**
  - Interest rate = 6%
  - Discount Rate = 3%
  - Debt Equity Ratio = 70%

Technology Assumptions

Gas Generators

	Single Cycle Gas Turbine (SCGT)	Combined Cycle Gas Turbine (CCGT)
Heat Rate	9720 Btu/kWh	6360 Btu/MWh
Capacity Factor	15%	60%
Carbon Emissions	0.447 tonne per MWh	0.337 tonne per MWh
Design Life	25 years	25 years

Renewable Resources

	Solar	**Wind**
Capacity Factor	22% [AB], 20%[ON]	35% [AB], 40%[ON]
Design Life	Increases from 32 to 42	Increases from 30 to 40
AC/DC Sizing	1.34 to 1.42	-

Energy Storage

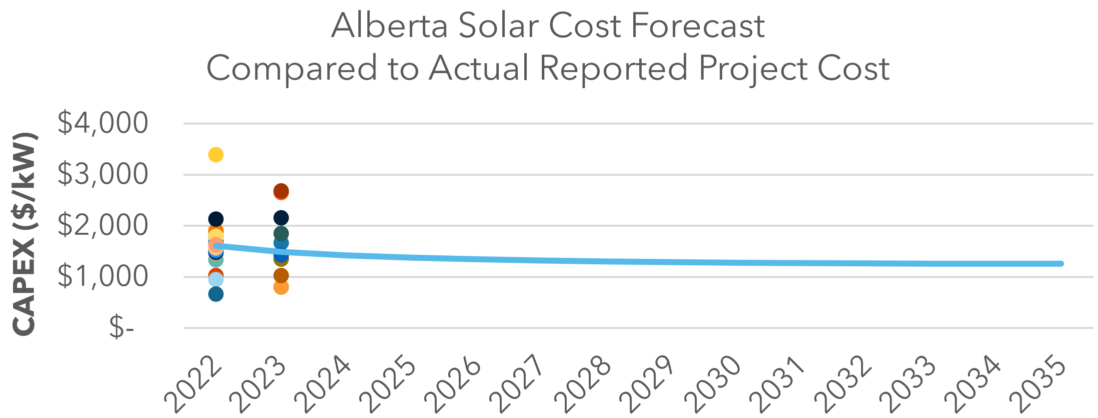
	4-Hour	**8-Hour**
System Sizing Ratio [RE]	60%	60%
DOD	80%	80%

1. All figures are in 2022 real CAD

2. Detailed assumptions are documented in the model. We've included descriptions next to the calculations where appropriate.

Calibration and Benchmarking to Actual Costs

1. We collected cost data for recent projects **to benchmark against and adjust the forecast**.
   - Alberta data were extracted from https://majorprojects.alberta.ca/
   - Ontario data were based on IESO interconnection and individual project research
2. Dunsky also **interviewed developers** and our internal experts on resource costs.
3. These data were used to **create an adjustment**, when appropriate, in the forecast that is called out in the model.



The points in the graph are individual Power Purchase Agreements (PPAs) in Alberta. Forecasts are of project costs and do not necessarily reflect the price of a PPA where a developer has residual value.

Solar Inverter Cost Declines	$68	$66
Locational Price Insights		
Alberta Battery Inverter Costs (CA$2022/kW)		
Developer Adjustment	$87.00	
Average Alberta Battery Inverter Costs (CA$2022/kW)	**$87.00**	
Ontario Battery Inverter Costs (CA$2022/kW)		
Developer Adjustment	$92.00	
Ontario Battery Inverter Costs (CA$2022/kW)	**$92.00**	

Adjustments based on developer research and feedback are included in the forecast model and noted as “Developer Adjustment”

3. Key Results

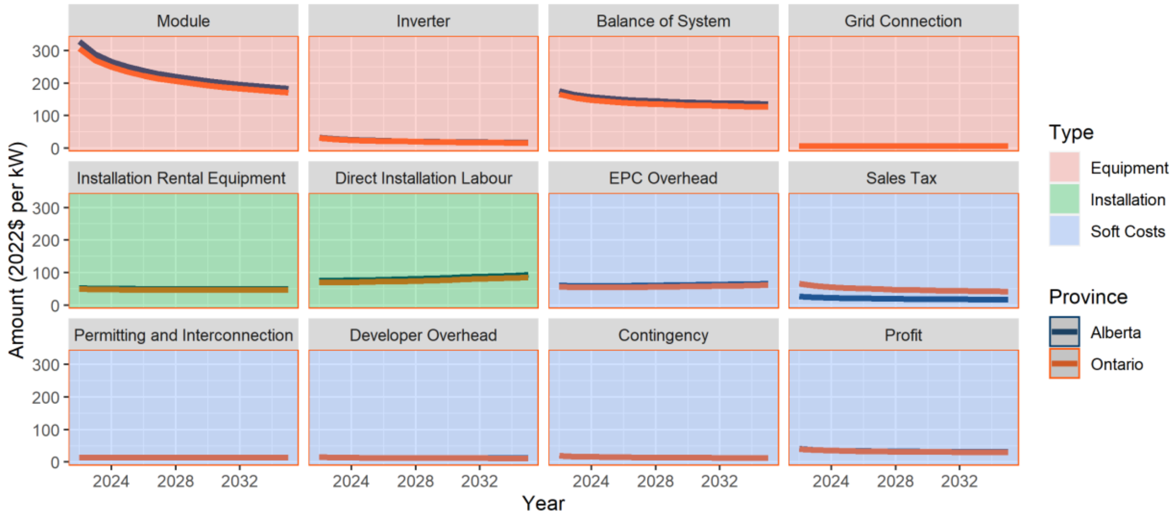
Study Outcomes

The key outcome of the analysis is a reference for Canada-specific estimated costs for key renewable energy technologies that extends beyond direct use of U.S. benchmarks.

The analysis covers:

- **Technologies:** Solar, Wind and Energy Storage (4-hour, and 8-hour) + SGCT and CCGT for benchmarking
- **Provinces:** Ontario and Alberta
- **Timeframe:** Annual forecast for 2022 to 2035
- **Components:** up to 12 discrete cost categories for each technology that cover equipment, installation & soft costs
- **Metrics:** Capital cost (CAPEX) [$/kW], Operating Cost (OPEX) [$/kW/year] and Levelized Cost of Energy (LCOE) [$/kWh]

The report focuses on key outputs and insights. The appendix to this report and the accompanying Excel model provide detailed results.



Considerations and Limitations

The results from the analysis should be interpreted with the following considerations:

- **The developed costs represent the cost of a resource for a given year of installation.** All costs are presented in $2022 Real Canadian Dollars (CAD) and reflect the full unsubsidized deployment costs without considering any incentives or tax benefits. While our research included looking at recent Power Purchase Agreements, the estimates provided are intended to represent project costs, not the likely price of PPAs, which are priced with consideration of residual value when the PPA expires.
- **While LCOE is an insightful and easy metric to benchmark different technologies' costs, it has limitations**.
  - Levelized cost of energy (LCOE) calculations are based on assumptions on typical performance and characteristics of the technology and resource and intended to serve as a reference point, however project costs are highly sensitive to numerous project- and location-specific factors that will results in higher or lower costs.
  - Calculation of LCOE involves assumptions about fuel prices, energy generation, financing costs, capital costs, etc that simplify these assumptions into a single number when each parameter may have different risks and uncertainties inherent in their estimation.
  - It only reflects the cost of producing energy, not the value of that energy when it is produced.
- **The analysis focuses on developing a single scenario for cost trajectories based on the various available data from literature**, however several global and local uncertainties exist around future technology and financial factors that could impact the cost of renewable deployments in Canada.
- **In benchmarking renewables to gas generation, we consider the most reasonable counterfactual** (e.g. combined cycle turbine, single-cycle peaker, etc.) to allow for an appropriate comparison, but recognize that the impact of renewable and storage resources on reliability depends on the underlying system and requires more detailed analysis of the capacity contribution of each resource in the context of local demand and supply pattern.

Key Takeaways

In addition to the developed cost estimates, the analysis highlights three key insights that reaffirm the role and competitiveness of renewables as critical resources for Canada's clean energy transition:

1. Solar and wind already offer competitive or cheaper energy than natural gas generation in Ontario and Alberta (both with and without consideration of carbon pricing)*, with additional significant cost declines on the horizon.

2. Renewables paired with storage offer compelling opportunities for dispatchable grid resources that can contribute to capacity needs at increasingly more competitive costs relative to gas peakers.

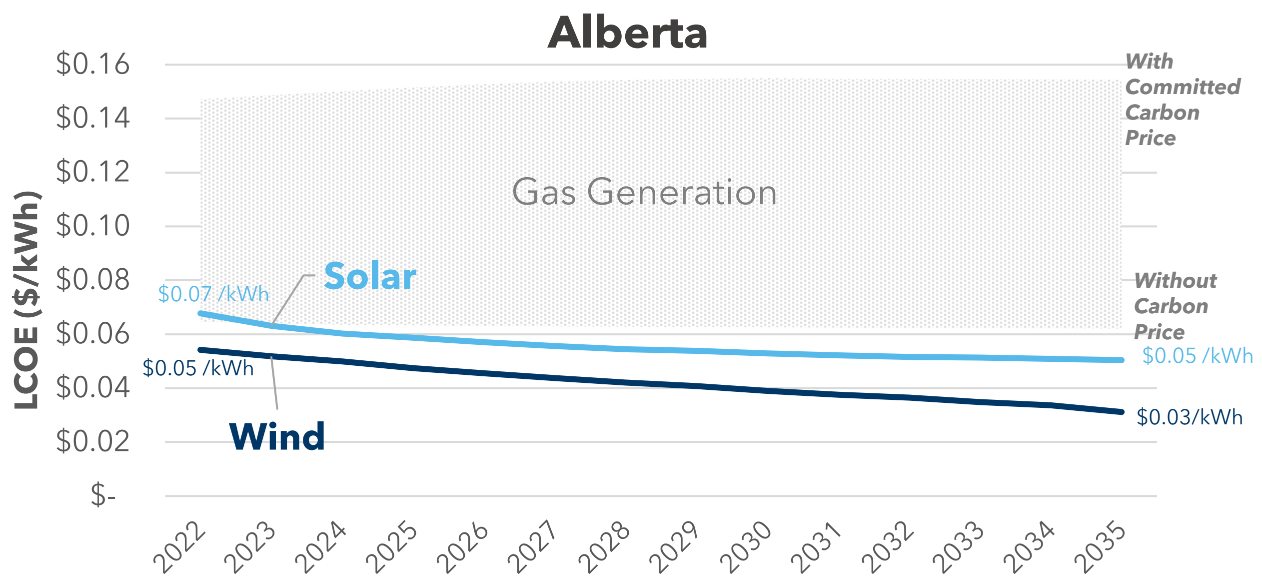
3. While costs are directionally aligned across jursidctions, several regional factors are impacting deployment costs, both between the U.S. and Canada as well as among the provinces.

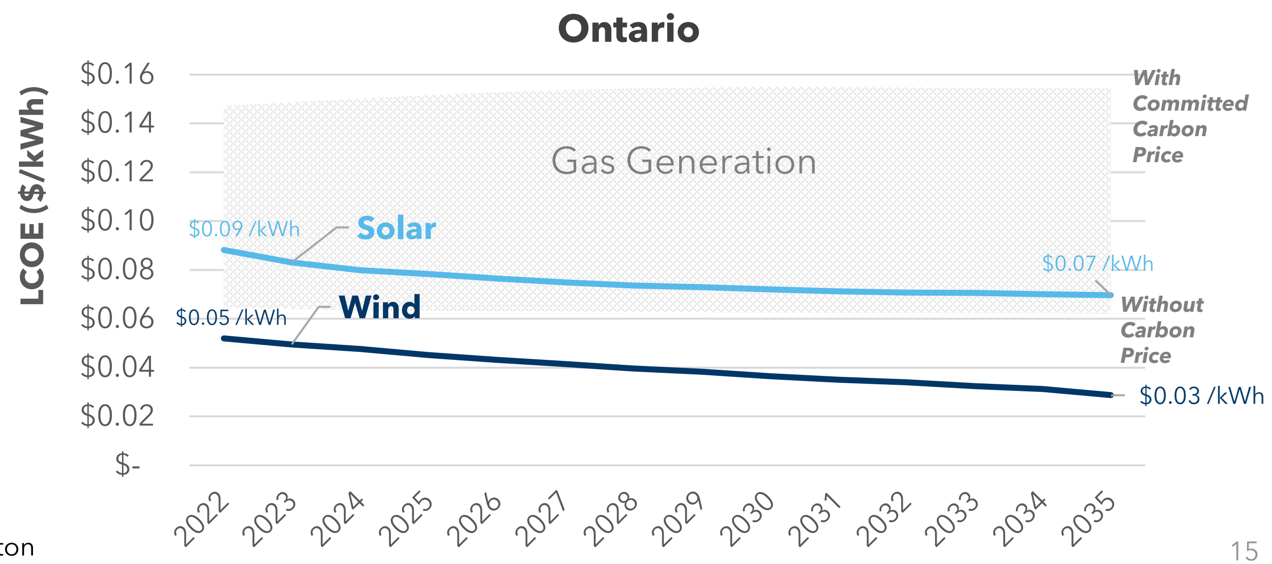
* The comparison depends on uncertain future costs and performance with different risk profiles for generating technologies. However, given current expectations, these technologies are competitive when comparing the expected cost per MWh of electricity produced.

Takeaway #1: Cost of Renewables in Canada

Solar and wind are already competitive with natural gas generation in Ontario and Alberta (both with and without consideration of carbon pricing) with additional significant cost declines on the horizon.

- Comparing the LCOE of new solar, wind and gas deployments in both provinces highlights that cost of energy production from renewables today is lower than that from gas resources considering carbon pricing.
- Even without considering a carbon price, renewables in both provinces (particularly in Alberta) are at – or fast approaching – cost-parity with gas generation.
- In addition to being cost competitive today, cost are expected to further decline by an additional ≈40% by 2035, compared to relatively flat costs* for new gas deployments.



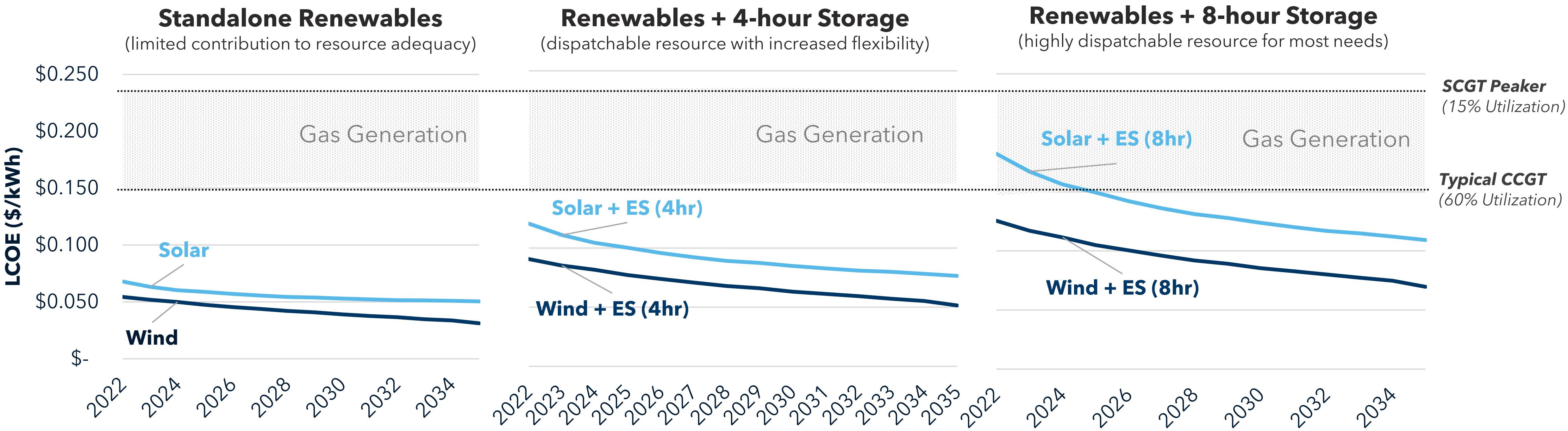


* Flat costs depend on a stable natural gas price and carbon pricing that does not exceed $170 per ton

Takeaway #2: Renewables + Storage as a Resource

Renewables paired with storage offer compelling opportunities for dispatchable grid resources that can contribute to capacity needs at increasingly more competitive costs relative to gas peakers.

- While standalone renewables do contribute to resource adequacy, pairing variable renewables with energy storage provides greater flexibility and versatility to contribute to system needs (e.g. capacity, balancing services)
- Most emerging system needs are likely to be met through 4- hour and 8-hour duration energy storage, which are quickly becoming cost-competitive with costs of typical gas peakers.

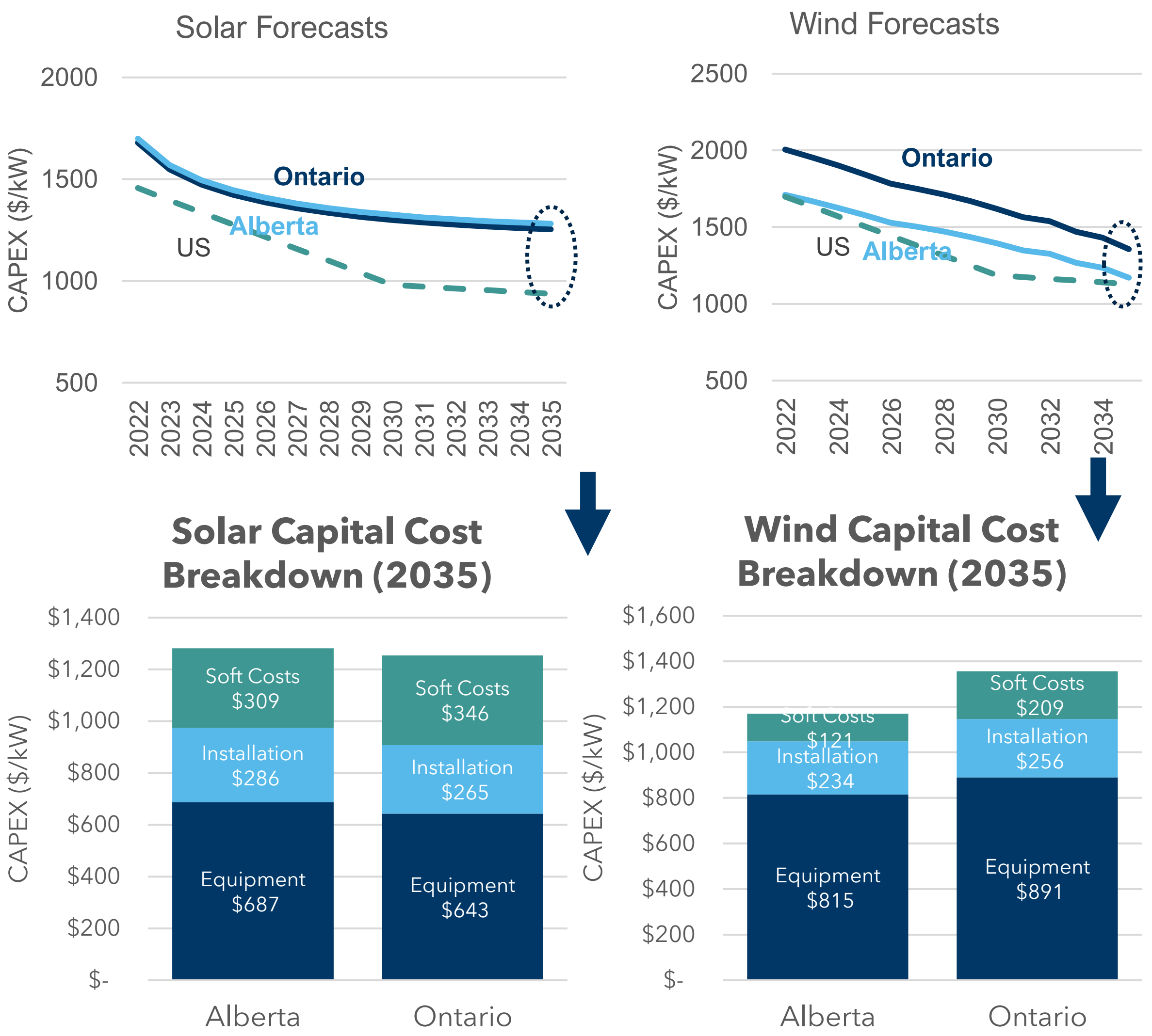


* Figures reflect the forecasted costs for renewables and storage in Alberta, however similar trends were observed in Ontario.

Takeaway #3: Regional Variation in Costs

While costs are directionally aligned across jurisdictions, several regional factors are impacting deployment costs, both between the U.S. and Canada as well as among provinces

- Regional variation in LCOE is predominantly driven by varying resource potential and other project-level drivers (e.g. interconnection costs)
- Equipment costs are relatively unchanged for solar among jurisdictions, with slightly more notable differences in the wind.
- Differences in regional capital costs are predominantly attributable to variations in installation costs (in particular labour costs) and soft costs (in particular transportation costs, taxes and EPC overheads)



*U.S. values reflect cost projections from the National Renewable Energy Laboratory (NREL)'s Annual Technology Baseline (ATB); a widely used industry benchmark for renewable energy cost projections. Specifically, we use the "Moderate" scenario from NREL ATB as reflective of expected U.S. cost trends.

Considerations for Policy- and Decision-Makers

The key takeaways from the study also provide some insight into implications and priorities for Canadian policy- and decision-makers to consider:

- Renewables should be prioritized for addressing energy needs in Canada to contribute to reducing emissions from the electricity sector, lowering system costs, and increasing energy security.
- Removing barriers to energy storage in Canada is critical to be able access the expanded utility renewables paired with storage can bring to Canadian utilities, system operators and grids.
- Leveraging jurisdiction-specific renewable energy cost figures are critical to understanding the real costs associated with their commissioning.
- In addition to equipment cost declines driven by technological improvements, Canada needs to identify and pursue opportunities for reducing soft costs of renewable deployment

Considerations for Future Research

Additional iterations of this work and further research should be focused on addressing:

- Costs of renewable and storage developments in other Canadians provinces;
- Costs of additional emerging clean energy technologies and long-duration energy storage;
- Expanded local industry engagement to capture regional drivers and refine costing assumptions;
- More comprehensive look at the capacity contribution of different technologies; and
- The full value-stack of services and benefits renewables and storage can bring Canadian grids.

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