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Reliable, affordable: The economic case for scaling up clean energy portfolios

A study comparing clean energy portfolios and natural gas for electricity generation

Jan Gorski and Binnu Jeyakumar

October 2019

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Executive summary

Worldwide, the electricity sector is going through a profound shift as clean energy technologies become cheaper than conventional sources of energy, higher emissions plants retire, other assets reach end of life, and citizens demand less carbon-intensive sources of energy.

As grid operators, policy makers and utilities consider how they respond to these trends, the key question facing them is: Can clean energy solutions deliver a reliable supply of electricity in an affordable manner?

Canada is facing this very question as it looks to complete a nationwide phase-out of coal-fired power by the end of December 2029, with Alberta, Saskatchewan, New Brunswick and Nova Scotia all retiring their conventional coal plants. For the most part, natural gas is considered to be the default replacement.

We decided to test the economic case for clean energy sources to meet this new demand, focussing on Alberta where uptake could be more challenging than anywhere else in Canada given the low cost of natural gas, yet opportune given the province's abundant renewable energy resources.

New modelling from the Pembina Institute and the Rocky Mountain Institute compared the cost of generating electricity via clean energy portfolios against new gas plants in Alberta. Clean energy portfolios consist of non-emitting sources: wind, solar, battery energy storage, demand flexibility and energy efficiency. These were compared against two types of gas plants: combined cycle plants, which provide steady power, and simple cycle plants, which provide peak power. In both cases, the clean portfolios provide the same services as the gas plant at a lower cost over the lifetime of the energy source (Figure 1).

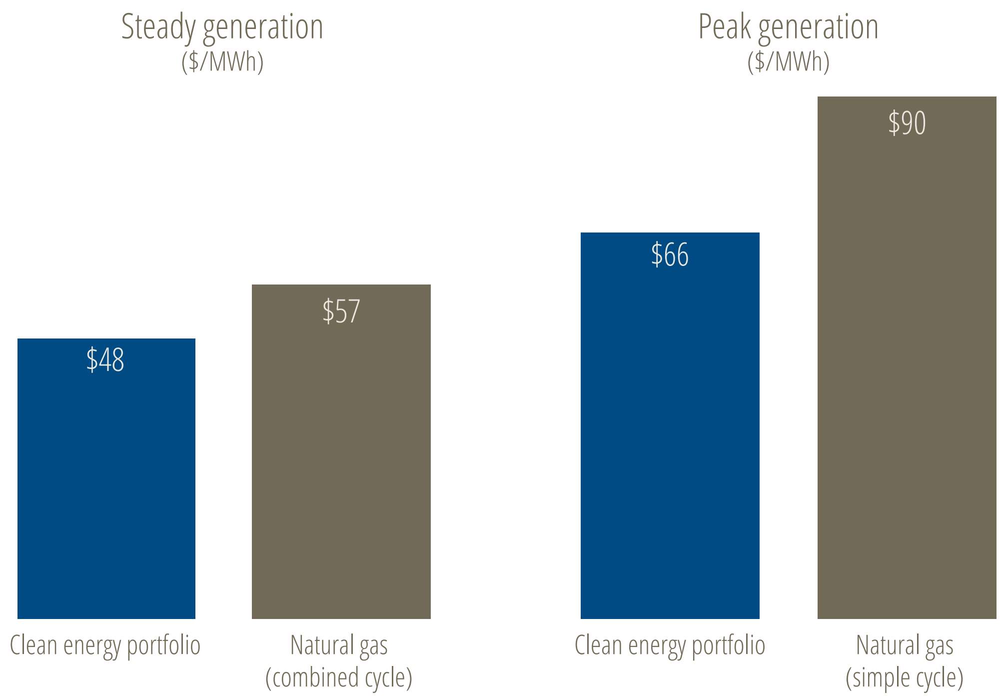

Figure 1. Cost of steady and peak electricity generation by natural gas plants and by a clean energy portfolio

Clean energy technologies such as renewables and battery storage have seen a dramatic drop in cost in recent years. At the same time, there is increasing recognition of the role of energy efficiency and demand flexibility in reducing overall demand and managing peak demand. Compared to both types of gas plants, the clean energy portfolio produces more energy (included as a benefit), along with equivalent capacity and flexibility, at a lower cost to consumers.

Future trends are expected to reduce the cost and improve the capabilities of clean energy portfolios even further:

- Costs of wind, solar and storage are expected to continue to decline.
- Energy efficiency potential will grow over time.
- Gas prices are predicted to rise from current historic lows.
- Across Canada, the carbon price is set to increase from $30 per tonne to $50 per tonne, according to federal policy.
- The performance of solar, wind and battery technologies will continue to improve.

Even in Alberta, where low gas prices give natural gas plants a cost advantage, this plant by plant comparison reveals that natural gas struggles to compete against clean energy portfolios. The case for clean energy is even stronger: The modelling does not account for the additional benefits of grid reliability provided by the battery energy storage component of the clean energy portfolio. There are no subsidies assumed for any technology or energy source, and while the cost of clean energy portfolios includes the cost of building transmission lines, the gas plant costs do not include the cost of any new gas pipelines that would be needed.

While gas plants may continue to play a role in Alberta’s electricity grid, non-emitting clean energy portfolios will reduce consumer costs, as well as climate and health impacts.

As other Canadian provinces such as Saskatchewan, New Brunswick and Nova Scotia phase out coal, or look to add new capacity to meet demand, further analysis to compare clean energy portfolios with new gas plants is warranted. Along with providing affordable electricity, clean energy portfolios can offer employment and economic development opportunities for a just transition to workers and communities that are affected by retirement of existing generating units. It is essential then that investment in these technologies is coupled with well-designed training and support programs that will enable Canadian workers to take advantage of the rapidly expanding global clean energy industry.

This economic analysis is particularly important as all levels of government decide how to meet the changing demands from the electricity system, and as they seek to develop skills and technological expertise to meet the growing global demand for decarbonized energy.

1. Comparing natural gas and clean energy portfolios

Canada has committed to phasing out heavy-polluting coal power by 2030 to reduce greenhouse gas emissions and improve air quality. As this transition occurs, and as electricity needs grow, new power generation will be needed. When considering how to meet electricity needs, the economics as well as grid services provided by different technologies must be examined.

This study seeks to compare the economics of building electricity plants powered by natural gas against clean energy portfolios, using Alberta as an example. This is done for two distinct types of gas plants: steady generation (combined cycle) plants, which are designed to provide a consistent supply of electricity, and peak generation (simple cycle) plants, which supply electricity demand during peak hours. The modelling ensures that clean energy portfolios provide the same key services as each type of gas plant.

This study uses a modelling tool developed by the Rocky Mountain Institute (RMI). The sections below reproduce, with permission and with some changes, material from RMI's publications.[1]

1.1 What are clean energy portfolios

Few proposed alternatives to new power plants and our current electricity supply rely on a single technology. Rather, they typically rely on a diverse, balanced portfolio of mature and emerging resource options. Together, these resources form clean energy portfolios that can effectively complement, defer, or avoid investment in traditional grid infrastructure. Portfolios usually include renewable energy, battery energy storage, energy efficiency and demand flexibility.

Renewable energy

Distributed and utility-scale solar photovoltaics and wind turbines that provide weather-dependent, non-dispatchable energy.

[1] Mark Dyson, Alex Engel and Jamil Farbes, *The Economics of Clean Energy Portfolios* (Rocky Mountain Institute, 2018). https://rmi.org/insight/the-economics-of-clean-energy-portfolios/

Battery energy storage

Dedicated battery storage assets providing capacity, energy balancing, and flexibility via controlled charging and discharging.

Energy efficiency

Physical measures, software controls, or other strategies to reduce the amount of energy required to perform a given service (e.g., LED lighting, insulation and smart thermostats to reduce cooling and heating energy use).

Demand flexibility

Load controls to enable electricity consumption to shift through time without reducing overall energy use or service quality (e.g., thermal storage in water heater tanks, managed charging of electric vehicles).

1.1 Trends supporting the growth of clean energy portfolios

Clean energy portfolios can avoid significant investment and operational costs associated with new gas-fired power plants, as shown by cost trends, expanding capabilities, and emerging best practices.

Four emerging trends combine to suggest that well-designed portfolios of clean energy resources can cost-effectively provide all grid services that would otherwise be met by construction of new gas-fired power plants.

Costs

Prices of clean energy portfolio technologies have fallen dramatically in recent years, such that they can compete even with currently low, but inherently volatile, costs of new gas-fired generation.

Furthermore, carbon emissions are increasingly a financial risk given the scientific consensus on climate change. It is extremely unlikely that the cost of GHG emissions will not increase over the lifetime of any emitting infrastructure built today or in the future.

Services

Pilots and scaled deployment have begun to demonstrate the ability of renewable energy to provide dispatchable capacity and other reliability services, often as well as thermal power plants.

Planning approaches

Advances in planning approaches and software tools can allow utilities and market operators to accurately account for the resource potential and capabilities of renewable energy.

Procurement processes

Emerging best practices in resource procurement can allow utilities and system operators to efficiently procure renewable energy at scale.

1.2 Cost of clean energy portfolios

Prices of clean energy technologies have fallen dramatically in recent years compared to traditional thermal power plant costs. The cost building new natural gas plants has plateaued and is very dependent on natural gas prices, which are at historic lows in Alberta.[2] The opposite is true for clean energy portfolio technologies like wind, solar, and battery energy storage, with technology prices falling by 66%, 86%, and 73%, respectively, since 2009–2010. Data from 2017 and early 2018 suggest that these resources are already more economical than just the operating costs of existing coal and nuclear generation, let alone the levelized cost of new thermal power plants. The cost of these technologies, especially battery energy storage, are expected to continue declining as economies of scale drive down production costs (see Figure 2 and Figure 3).

[2] OpenEI, "Transparent Cost Database," Overnight capital cost and fixed operating cost, historical trends of natural gas combined cycle and combustion turbines. https://openei.org/apps/TCDB/#blank

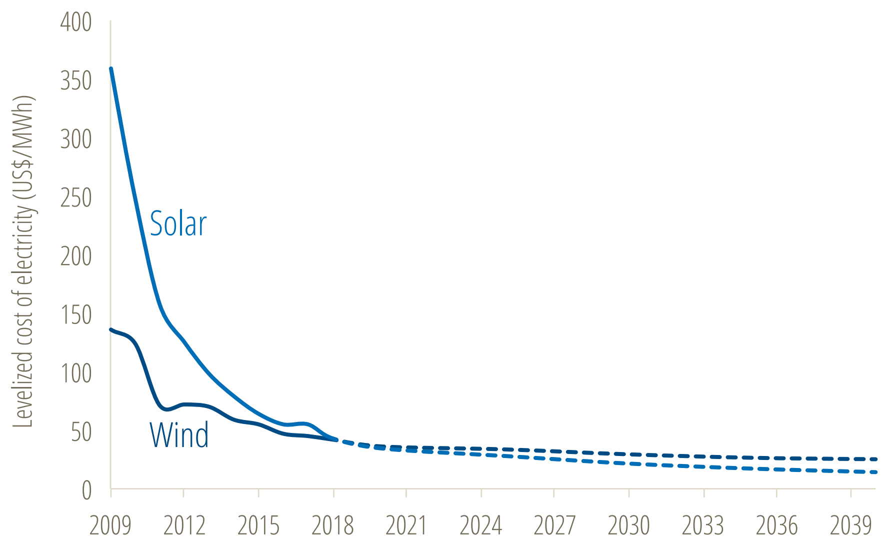

Figure 2. Historical and forecast cost decline for wind and solar

Data source: Lazard and BloombergNEF[3]

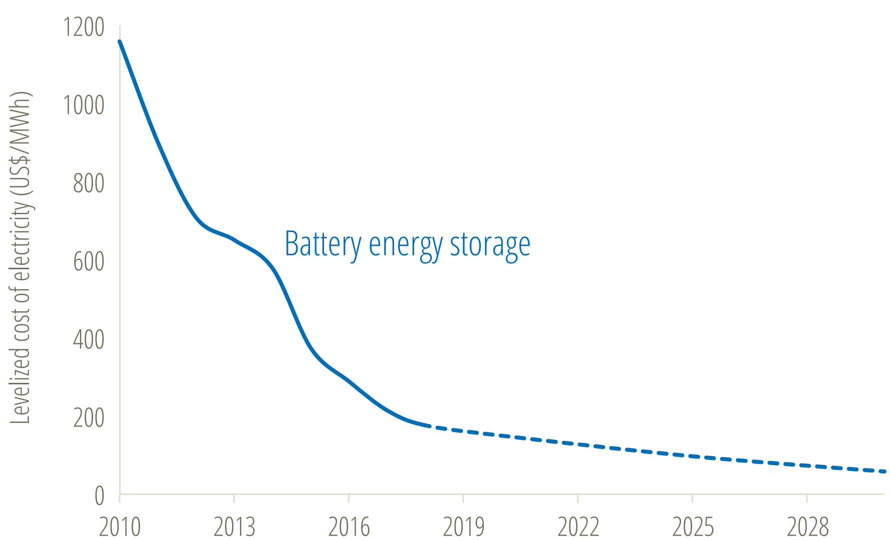

Figure 3. Historical and forecast cost decline for battery energy storage

Data source: Lazard and BloombergNEF[4]

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[3] Lazard, *Levelized Cost of Energy Analysis* (LCOE 12.0). https://www.lazard.com/perspective/levelized-cost-of-energy-and-levelized-cost-of-storage-2018/ ; BloombergNEF, *New Energy Outlook 2018*. https://about.bnef.com/new-energy-outlook/

[4] Lazard, *Levelized Cost of Storage Analysis* (LCOS 4.0) (2018). https://www.lazard.com/perspective/levelized-cost-of-energy-and-levelized-cost-of-storage-2018/; BloombergNEF, "A Behind the Scenes Take on Lithium-ion Battery Prices," March 5, 2019. https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/; *New Energy Outlook 2018*.

1.3 Services provided by clean energy portfolios

Utilities and project developers have expanded the range of services available from clean energy portfolio technologies. Utilities and third-party operators are increasingly able to actively manage renewable energy, energy efficiency, demand flexibility, and storage in order to provide multiple services to customers, utilities, and the grid at large.

> **Renewable energy:** Wind and solar can now provide the lowest cost energy to the grid, even with a variable output. These resources used to be valued by grid operators and planners as providing only variable nondispatchable energy, but smart inverters have recently allowed grid operators to demonstrate the ability of renewable energy projects to provide flexibility and ancillary services.
>
> **Energy efficiency:** Efficiency investments used to be valued based solely on energy savings, but planners are also beginning to value the peak demand savings and load-shape improvements (i.e., reduced ramp rates) associated with this resource.
>
> **Demand flexibility:** Traditional demand response programs typically provide peak load savings for a small number of hours per year, but a new generation of programs can now provide active flexibility and thus more value to the grid, including renewable energy integration. Demand flexibility programs have benefitted from the reduced prices and increased capabilities that result from lower connectivity costs and machine learning approaches.
>
> **Battery energy storage:** Battery energy storage has historically been deployed and operated to provide a limited number of services to the grid (e.g., demand-charge management in commercial buildings, solar self-consumption), but can technically provide at least 13 distinct sources of value to the grid. New projects are increasingly being designed and operated to include more of these services.

These services are summarized in Table 1 below.

Table 1. Grid services provided by clean energy portfolio components

Resource	Service			
	Energy	Peak Capacity	Flexibility	Additional Network Stability
Renewable energy	Energy generator	Can reliably produce at capacity credit during peak hours	Balanced portfolios can reduce ramp rates	When available, can provide reserves, frequency regulation, and voltage support
Battery energy storage	n/a	Provides active power injection	Can actively respond to ramp events, in both directions	Can provide reserves, frequency support (including synthetic inertia), voltage support, and black start
Energy efficiency	Reduces consumption	Reduces peak load	Flattens ramps	Can help avoid certain voltage support requirements
Demand flexibility	n/a	Reduces peak load	Can actively respond to ramp events, in both directions	Current-generation active load management technologies can provide reserves and frequency regulation

Source: Adapted from RMI[5]

All new gas plants are planned and built to provide different combinations of near constant energy production, peak capacity, and/or flexibility to balance load and renewable energy variability, while some are also expected to be used to meet network-specific needs (e.g., voltage regulation, black start). Experience across the U.S. suggests that well-designed clean energy portfolios can provide all of these same technical services.[6]

[5] *The Economics of Clean Energy Portfolios.*

[6] *The Economics of Clean Energy Portfolios.*

2. Reducing electricity costs using renewables

2.1 Case study Alberta

The modelling analysis compared a portfolio of renewable energy, storage, demand flexibility, and energy efficiency against a prototypical new combined cycle and simple cycle gas plant. (See Appendix A for methodology and modelling assumptions.)

Results in Figure 4 show that a portfolio of wind, solar, storage, demand flexibility, and energy efficiency can generate electricity in Alberta at a lower cost to consumers than gas plants while providing the same services.

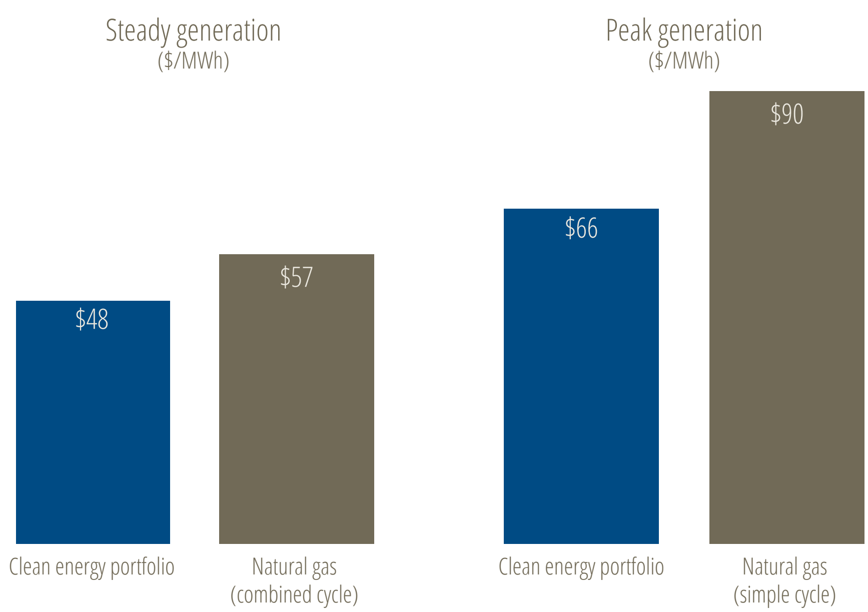

Figure 4. Cost of steady and peak electricity generation by natural gas plants and by a clean energy portfolio

The figures below compare the full cost (capital and operating), nameplate capacity, energy output, actual capacity, and ramping of clean energy portfolios and gas plants for both combined cycle and simple cycle gas plants.

Figure 5 shows the total cost, both capital and operating, of clean energy portfolios compared with natural gas plants. Although the total cost of clean energy portfolios is slightly higher than those of combined and simple cycle gas plants, portfolios provide more energy than the gas plants (as shown in Figure 7). Figure 6 shows that the capacity provided by clean energy portfolios is greater than that of the gas plants. Figure 8 shows the important role of storage in the capacity provided by clean energy portfolios.

Figure 9 shows that the clean energy portfolios meet the flexibility constraints. The "Top Hour" column shows how each resource contributes to meeting the largest increase in net load. The "Fixed Ramp" column represents the results of a constraint that requires that non-solar clean energy portfolio resources can make up for the largest four-hour decline in fixed-tilt solar output. Storage is able to play a large role here because it can contribute twice its nameplate capacity, since we assume that at the beginning of the four-hour decline, storage is charging, and by the end, it is discharging. The "Tracking Ramp" column is the same as the "Fixed Ramp" except that it looks at the largest four-hour decline in single-axis tracking solar rather than fixed-tilt solar.

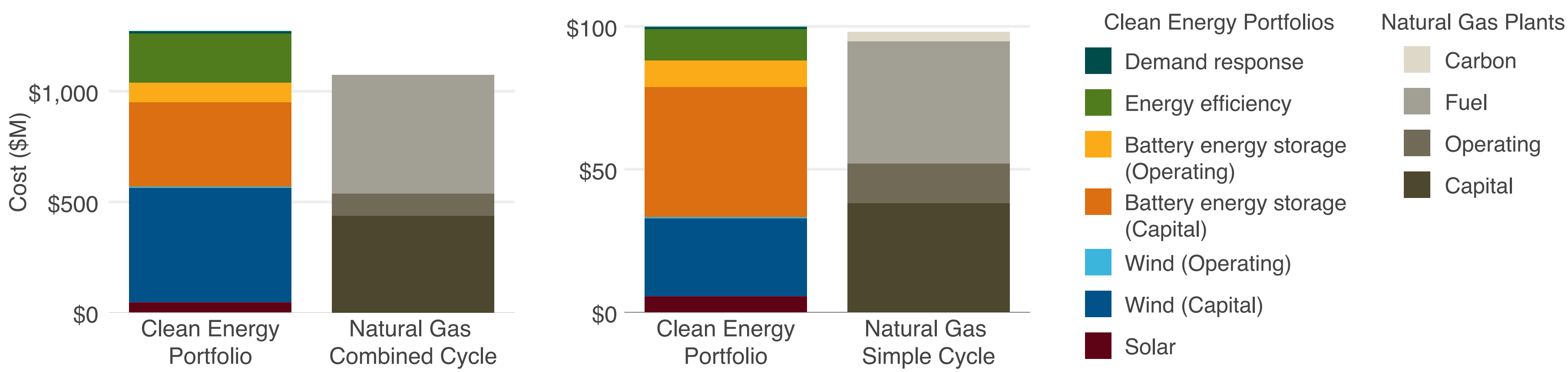

Figure 5. Total cost: clean energy portfolios vs. combined cycle gas plant and simple cycle gas plant

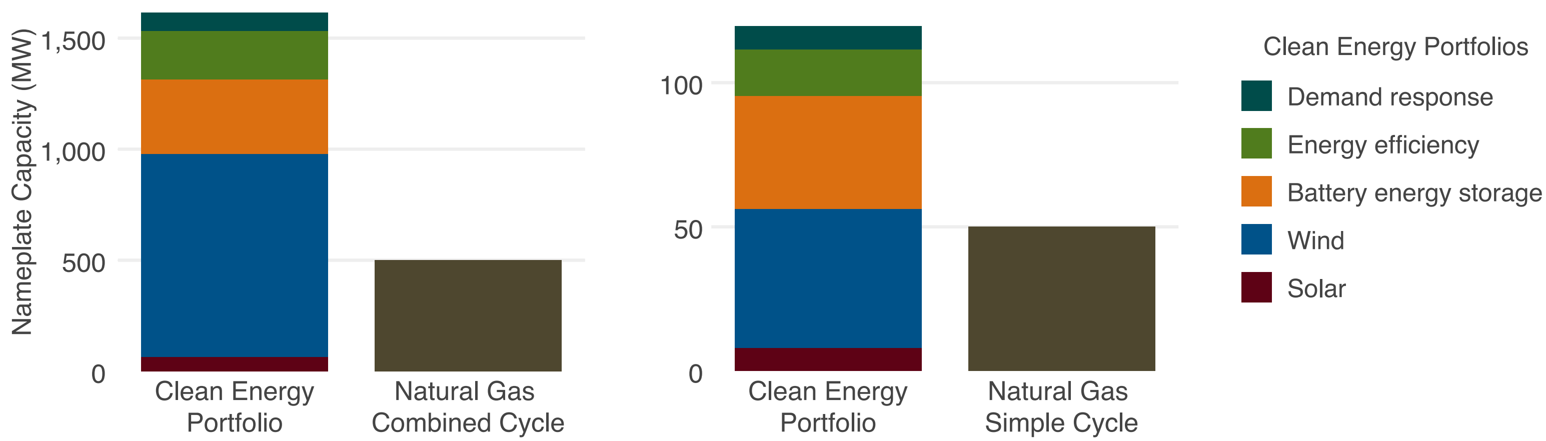

Figure 6. Nameplate capacity: clean energy portfolios vs. combined cycle gas plant and simple cycle gas plant

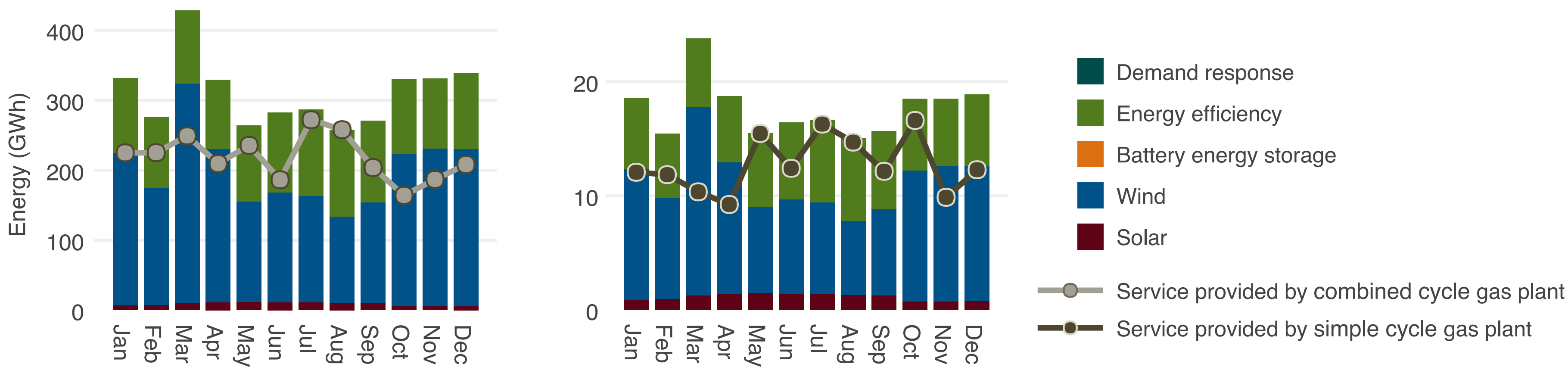

Figure 7. Electricity generation: clean energy portfolios vs. combined cycle gas plant and simple cycle gas plant

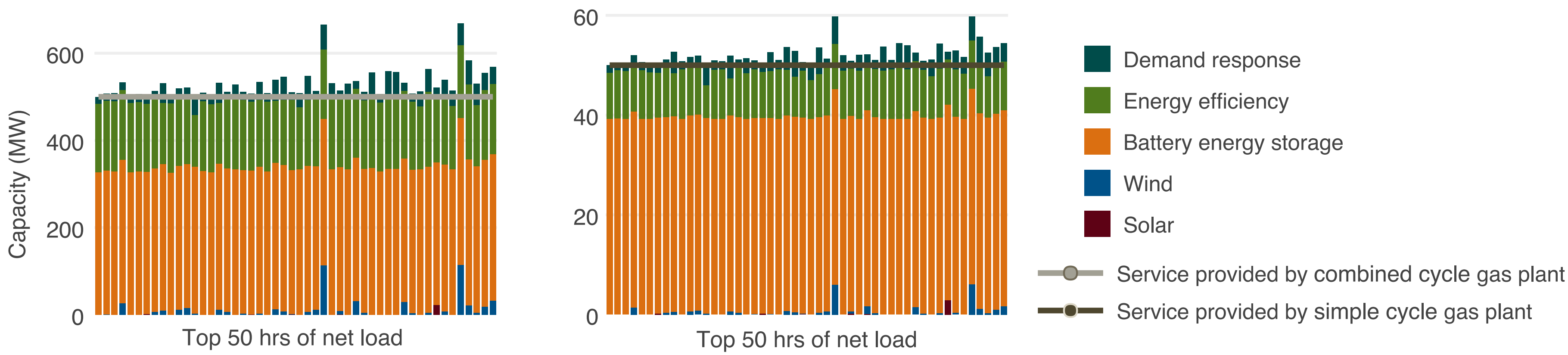

Figure 8. Capacity: clean energy portfolios vs. combined cycle gas plant and simple cycle gas plant

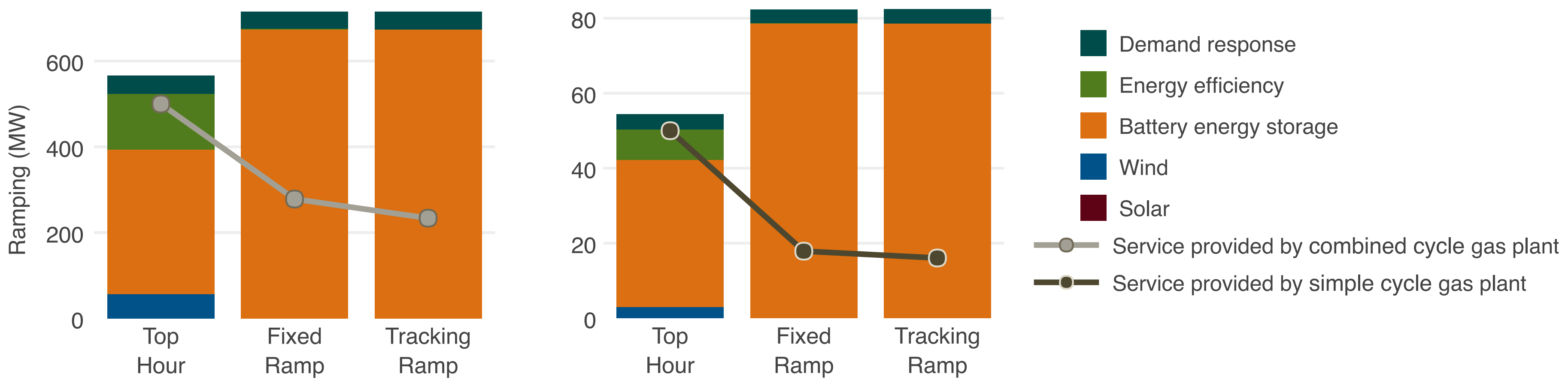

Figure 9. Ramping ability: clean energy portfolios vs. combined cycle gas plant and simple cycle gas plant

Figure 10 shows the highest load on the system for each hour of each month in Alberta. Alberta's electricity demand peaks in the winter, with the highest loads occurring in the afternoon and evening.

Hour \ Month	1	2	3	4	5	6	7	8	9	10	11	12
0	7166	6986	6609	6374	6313	6355	6430	6395	6194	6375	7349	7327
1	7095	6879	6547	6357	6263	6302	6384	6369	6130	6357	7316	7247
2	7074	6862	6546	6394	6292	6308	6386	6353	6257	6391	7338	7220
3	7123	6911	6617	6592	6376	6393	6484	6518	6425	6609	7406	7250
4	7321	7115	7068	7017	6688	6709	6662	6784	6875	7105	7589	7473
5	7756	7566	7610	7450	7241	7250	7131	7125	7336	7743	8089	7945
6	8330	8121	7732	7639	7516	7587	7552	7483	7548	7958	8592	8475
7	8492	8236	7801	7723	7709	7892	7863	7738	7655	7928	8595	8621
8	8443	8219	7864	7765	7802	8097	8109	7925	7766	7930	8583	8603
9	8463	8263	7880	7884	7916	8218	8253	8076	7798	7988	8576	8651
10	8433	8333	7817	7874	7904	8244	8345	8142	7798	7968	8567	8677
11	8366	8265	7838	7913	7950	8299	8442	8246	7803	7999	8510	8569
12	8355	8258	7815	7912	7954	8326	8441	8323	7802	7945	8558	8603
13	8363	8249	7835	7831	8003	8322	8444	8338	7822	7989	8514	8662
14	8407	8266	7888	7900	7977	8326	8366	8305	7847	8109	8538	8760
15	8561	8434	7927	7893	7898	8298	8244	8250	7797	8153	8853	9011
16	8994	8630	7934	7689	7645	8073	8076	7986	7599	8207	9234	9274
17	8861	8705	8084	7655	7646	8030	7954	7848	7728	8145	9106	9145
18	8782	8657	8119	7737	7638	7787	7837	7881	7800	8052	8977	9004
19	8661	8504	8016	7667	7637	7556	7712	7823	7487	7824	8839	8933
20	8399	8214	7721	7301	7374	7470	7579	7427	7134	7393	8684	8657
21	7964	7843	7383	6826	6927	7096	7257	7041	6821	6949	8254	8299
22	7561	7362	7012	6583	6606	6726	6858	6670	6509	6643	7827	7836
23	7306	7131	6732	6367	6396	6485	6581	6497	6323	6469	7517	7505

Figure 10. Maximum electrical load in Alberta by hour of each month in MW.

2.2 Case studies from the U.S.

Similar modelling conducted by RMI of the 88 gas plants that are currently proposed in the U.S. found that 90% would be more expensive than clean energy portfolios. Investment in clean portfolios instead of new gas capacity would save customers over $29 billion in the U.S. and reduce CO_2 emissions by 100 million tons per year — equivalent to approximately 5% of current annual emissions from the U.S. power sector. Due to the projected drop in the cost of clean portfolios, RMI estimates that by 2035, clean portfolios are likely to be cheaper than the operating costs of 90% of the proposed gas plants. This would create a substantial risk of stranded assets for investors and highlights the need to critically evaluate the electricity systems we choose to build in Canada. The climate and health advantages of a clean energy portfolio have long been apparent, now clean energy also has the economic advantage — not only from a climate and health perspective, but also from the economic side.[7]

2.3 Considerations for analyzing the economics of clean energy portfolios in other Canadian provinces

A clean energy portfolio is the more affordable option while providing the same services as natural gas in Alberta, where conditions are especially favorable for natural gas due to low natural gas prices and high winter demand. In the U.S. the clean energy portfolios out-compete 90% of proposed new gas plants on cost. But what about Saskatchewan, New Brunswick and Nova Scotia, which will all need new sources of electricity as they phase out coal?

Given the strong evidence for the affordability of clean portfolios from Alberta and the U.S., clean energy portfolios should be seriously analyzed in these provinces as well. Before province-specific modelling can be done, important data needs to be compiled for these provinces including energy efficiency potential, demand-side management, and seasonal load profiles (both summer and winter peaks), and the extent of carbon subsidies for natural gas through industrial carbon pricing systems. Important trends are explained below, with data references and electricity system conditions summarized in Table 2.

Saskatchewan

Renewable energy resources are similar to Alberta but gas prices are twice as expensive. Given strong evidence of the economic advantage of clean energy portfolios in other jurisdictions, we

[7] *The Growing Market for Clean Energy Portfolios.*

recommend similar economic analysis as a top priority as Saskatchewan tackles phasing out coal.

New Brunswick

While renewable energy resources are slightly weaker than in Alberta, natural gas prices in New Brunswick are twice as expensive. Given strong evidence of the economic advantage of clean energy portfolios in other jurisdictions, we recommend similar economic analysis as a top priority as New Brunswick tackles phasing out coal.

Nova Scotia

Gas prices are significantly higher in Nova Scotia. Renewable energy resources are not quite as plentiful as in Alberta and Saskatchewan. Given strong evidence of the economic advantage of clean energy portfolios in other jurisdictions, we recommend similar economic analysis as a top priority as Nova Scotia tackles phasing out coal.

Table 2. Summary of electricity system conditions for selected Canadian provinces

Metric	Alberta	Saskatchewan	New Brunswick	Nova Scotia
Current generation from coal[8]	37,000 GWh (60%)	12,000 GWh (48%)	2,090 GWh (16%)	4,840 GWh (50%)
Current electricity mix: [9]				
Coal	52%	44%	18%	58%
Gas	36%	36%	17%	9%
Hydro	3%	14%	23%	11%
Nuclear	0%	0%	33%	0%
Wind	7%	5%	6%	13%
Solar	0%	0%	0%	0%
Other	1%	2%	2%	9%
Natural gas prices[10]	$4.0/GJ	$7.9/GJ	$7.9/GJ	$8.8/GJ
Renewable energy resources[11]	Excellent	Excellent	Good	Suitable

[8] Environment and Climate Change Canada, *National Inventory Report 1990-2017: Greenhouse Gas Sources and Sinks in Canada* (2019), 2017 data. http://www.publications.gc.ca/site/eng/9.506002/publication.html

[9] Canada Energy Regulator, *Canada's Energy Future 2018: Energy Supply and Demand Projections to 2040,* Electricity Generation: Reference Case. https://apps.cer-rec.gc.ca/ftrppndc/dflt.aspx?GoCTemplateCulture=en-CA

[10] *Canada's Energy Future 2018,* End-Use Prices: Industrial: Reference Case (Avg, 2022 to 2040).

[11] Sara Hastings-Simon, Barend Dronkers, *Wind and solar in Alberta* (Pembina Institute, 2016). https://www.pembina.org/pub/wind-solar-alberta/

3. What does this mean for Canada?

The case study of Alberta and analyses conducted in other jurisdictions are an instructive illustration of the opportunities available to provinces across Canada in terms of not only reducing emissions from the electricity sector but also seeking lowest cost options that can benefit consumers.

1. In Alberta, the official projections by the Alberta Electric System Operator assume that most of the capacity of the retiring coal plants will be replaced by gas plants.[12] However, as this study shows, non-emitting renewable energy portfolios can reduce consumer costs along with climate and health impacts while delivering the same or greater services as gas plants. While gas may continue to play a role in Alberta's electricity system, the economic and climate advantages of clean energy portfolios should be given serious consideration as the province continues to phase out coal.
2. Alberta has one of the most favourable conditions for gas plants given the low price of gas in the province. As other Canadian provinces phase out coal or look to add new capacity to meet growing demand, research should be conducted to compare clean energy portfolios with new gas plants in the context of other provinces.
3. Clean energy portfolios can help deliver not only affordable electricity but also employment and economic development opportunities. As Canada phases out coal, providing support to workers to help them transition to new careers is paramount. Clean energy investments coupled with well-designed training and support programs can enable Canadian workers to take advantage of the rapidly expanding global clean energy industry.

[12] Alberta Electric System Operator, *AESO 2019 Long-term Outlook* (2019). aeso.ca/assets/Uploads/AESO-2019-Long-term-Outlook.pdf

Appendix A. Methodology

A.1 The clean energy portfolio model

The clean energy portfolio model[13] constructs least-cost portfolios of clean energy resources that would provide services equivalent to those provided by a natural gas power plant. The model uses a net present value approach to minimize lifetime cost.

Two prototypical gas-fired power plants were modelled, each entering service in 2022 in Alberta:

- 500 MW combined cycle turbine (to provide steady generation)
- 50 MW simple cycle combustion turbine (to provide peak generation).

Each was compared against a clean energy portfolio — consisting of renewable energy (wind and solar), battery energy storage, energy efficiency, and demand flexibility — that matches the electricity services provided by the natural gas plant. These services include at least the same monthly energy output and rated capacity during the region's peak demand.

The model ensures that each clean energy portfolio can provide the same or more monthly MWh and as much capacity during the top 50 peak-demand hours in Alberta as the gas plant under consideration.

Key assumptions

Carbon pricing: A portion of the external climate costs of carbon pollution are accounted for in electricity generation under the Alberta carbon competitiveness incentive regulation (CCIR) in place at the time of publication. Under the regulation, all electricity producers receive a carbon credit for their emissions up to an intensity of 370 t CO_2e/GWh and must pay for their emissions above this threshold, both at a rate of $30 per tonne of CO_2e. This adds value to the clean energy portfolios worth $18/MWh when compared to combined cycle gas plants and $11/MWh compared to simple cycle gas plants. These credits are included in the cost of the clean energy portfolios. However, even without these carbon credits, the costs of the clean energy portfolios are still in line with the historical cost of electricity in Alberta over the last 10 years. With

[13] Rocky Mountain Institute, *Clean Energy Portfolio Model and Output Description* (2019).

further increases in the price of carbon as per the federal carbon pricing backstop, the economics of clean energy portfolios will improve even more.

Gas prices: The model uses the National Energy Board's 2018 Canada's Energy Future reference case natural gas prices.

Infrastructure costs: The cost of new transmission needed to tie new renewables into the system is included in the capital and operational costs of renewables, but the cost of new gas pipelines is not included in the natural gas models.

Energy efficiency: Energy efficiency potential is based on data from Energy Efficiency Alberta.

The sections below are reproduced, with permission and with some changes, from RMI's publications.[14]

A.2 Model approach and methodology

The model assesses each case using an original RMI modelling tool to develop estimates of the net present value of expenditures on capital costs and operating costs for both the clean energy portfolio and the equivalent gas plant in each case. The model includes four components:

1. The **service requirement model** estimates the energy, capacity, and flexibility provided by the business-as-usual plant. We model the plant's contribution to system-level reliability by including an approximation of effective load carrying capacity for renewables.
2. The **resource potential assessment** estimates the regional potential of renewable energy, end-use and sector-level energy efficiency, and sector-level demand flexibility.
3. The **resource cost assessment** estimates present values of capital costs and operational costs for available clean energy portfolio resources.
4. The **clean energy portfolio optimizer** identifies the lowest-total-cost clean energy portfolio of available resources that can provide the same services identified by the service requirement model.

[14] *Clean Energy Portfolio Model and Output Description; The Economics of Clean Energy Portfolios.*

A.2.1 Service requirement model

This component estimates future hourly system net load starting in the first year of service of the modelled plant. The model is based on projected load growth and planned renewable additions. It identifies the 50 peak net-load hours across all seasons to calculate capacity service requirements, and the single hour of highest system net-load increase to calculate flexibility constraints. Alberta's hourly load profile is based on 2010 data from AESO.[15] Monthly energy service requirements are based on the gas plant operating profiles based on the most recent AESO market data.

Monthly energy consumption data by sector is from the Alberta Utilities Commission 2017 sales data normalized to average load profile for each sector from 2013 to 2017.[16] Annual energy consumption by end use is from Natural Resources Canada's Comprehensive Energy Use Database 2016 data.[17] Hourly energy consumption by end use is based on U.S. data.[18]

A.2.2 Resource potential assessment

The resource potential assessment module performs bottom-up estimates of energy efficiency and demand flexibility potential by end use, along with top-down estimates that constrain total potential across end uses for each customer sector. In addition to the bottom-up and top-down estimates to constrain energy efficiency and demand flexibility, the model also constrains energy efficiency and demand flexibility at the plant-level. The amount of energy from energy efficiency is constrained to 50% of the gas plant's projected generation.

Top-down estimates for energy efficiency potential are calculated from Energy Efficiency Alberta's 2018 study, based on economic potential for energy efficiency savings by sector.[19] Demand flexibility achievable participation by sector is calculated

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[15] AESO, *Hourly Load Data for Years 2005 to 2015*. http://www.aeso.ca/downloads/Hourly_load_data_(2005-2015).xlsx

[16] Alberta Utilities Commission, "Annual electricity data." http://www.auc.ab.ca/pages/annual-electricity-data.aspx

[17] Natural Resources Canada, "Comprehensive Energy Use Database." http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/menus/trends/comprehensive_tables/list.cfm

[18] Amory Lovins, *Reinventing Fire* (Rocky Mountain Institute, 2014). https://rmi.org/insight/reinventing-fire/

[19] Energy Efficiency Alberta, *2019-2038 Energy Efficiency and Small-Scale Renewables Potential Study* (2018), prepared by Navigant Consulting. https://www.efficiencyalberta.ca/app/uploads/EEA-Potential-Study-Report-2019-2038.pdf

from Federal Energy Regulatory Commission state-level potential data.[20] Bottom-up, end-use-specific energy efficiency estimates are calculated from Energy Efficiency Alberta's 2018 study of energy efficiency potential, the number of customers, and average energy savings for a given end-use technology. Demand flexibility end-use potential is estimated in the same fashion, based on a number of devices from Residential Energy Consumption Survey and Commercial Building Energy Consumption Survey, along with typical peak reduction from enabling demand response for those end uses.[21] Renewable energy-supply profiles are sourced from AESO historical data for wind[22] and CERI Study 168 for solar.[23] Capacity factors for wind are in the range of 30% to 35% for the last decade, but new wind turbines are able to achieve capacity factors above 40%.[24]

The plant-level energy efficiency constraint limits the amount of energy that can be provided by energy efficiency to a specific proportion of the gas plant's annual energy production. The plant-level demand response constraint limits the amount of capacity that can be provided by demand response to a specific proportion of the gas plant's nameplate capacity based on the coincident load of each demand response end use.

The modelled capabilities of renewable energy, energy efficiency, and demand flexibility to meet the grid service requirements explicitly take into account the hourly correlation between resource availability and the system-level net-load profile modelled in future years. The model also de-rates the ability of demand flexibility and battery energy storage to provide capacity and flexibility during long-duration peak-load events. To ensure that demand flexibility providing capacity does not lead to customer fatigue or excessive "rebound" in other hours, we model the costs associated with control strategies that can shift load while maintaining customer comfort (e.g., precooling using air conditioning, water heater storage tank temperature stratification).

[20] U.S. Federal Energy Regulatory Commission, *A National Assessment of Demand Response Potential* (2009). https://www.ferc.gov/legal/staff-reports/06-09-demand-response.pdf

[21] U.S. Energy Information Administration: "Residential Energy Consumption Survey." https://www.eia.gov/consumption/residential/; "Commercial Building Energy Consumption Survey." https://www.eia.gov/consumption/commercial/

[22] AESO, Hourly metered volumes by generation type, unpublished.

[23] Canadian Energy Research Institute, *A Comprehensive Guide to Electricity Generation Options in Canada* (2018). https://ceri.ca/studies/a-comprehensive-guide-to-electricity-generation-options-in-canada

[24] U.S. Department of Energy, 2016 Wind Technologies Market Report (2017), vii. https://www.energy.gov/sites/prod/files/2017/08/f35/2016_Wind_Technologies_Market_Report_0.pdf

A.2.3 Resource cost assessment

Renewable energy and energy-storage capital costs and operational costs and annual capital cost declines are taken from Lazard's Levelized Cost of Energy Analysis – Version 11.0[25] and Levelized Cost of Storage Analysis – Version 3.0[26], from BloombergNEF[27], and from price contracts from Alberta's renewable electricity program.[28] The cost of new transmission needed to tie new renewables into the system is included in the capital and operational costs of renewables. The cost of new gas pipelines, however, is not included in the cost of gas plants. Energy efficiency resource costs are based on national average costs of running an effective energy efficiency program, and are adapted for specific end-use resources from the levelized savings weighted-average costs from the Lawrence Berkeley National Laboratory.[29] Demand flexibility cost estimates are also program based, and calculated for each sector from the 75th-lowest percentile annual demand response program costs reported by utilities on EIA's Form 861.

Natural gas prices are from the National Energy Board's 2018 Canada's Energy Future reference scenario.[30]

A.2.4 Clean energy portfolio optimizer

The clean energy portfolio optimizer draws on the other components to find the lowest-cost portfolio of resources that can provide at least as much monthly energy, capacity during the 50 peak hours, and single hour ramp capability during the highest period of system-level net-load ramp as the equivalent natural gas-fired power plant, while staying within resource potential limitations.

Our modelling constraints do not necessarily guarantee that the identified clean energy portfolio can dispatch at exactly the same level as the equivalent gas plant during each hour of the modelled years. Such a criterion would be overly conservative as it would

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[25] Lazard, *Levelized Cost of Energy Analysis* (LCOE 12.0). https://www.lazard.com/perspective/levelized-cost-of-energy-and-levelized-cost-of-storage-2018/

[26] Lazard, *Levelized Cost of Storage Analysis* (LCOS 4.0) (2018). https://www.lazard.com/perspective/levelized-cost-of-energy-and-levelized-cost-of-storage-2018/

[27] BloombergNEF, *New Energy Outlook 2018*. https://about.bnef.com/new-energy-outlook/

[28] AESO, "REP results." https://www.aeso.ca/market/renewable-electricity-program/rep-results/

[29] Lawrence Berkeley National Laboratory, *Trends in the Program Administrator Cost of Saved Electricity 2009–2013*.

[30] Canada Energy Regulator, *Canada's Energy Future 2018: Energy Supply and Demand Projections to 2040*. https://www.cer-rec.gc.ca/nrg/ntgrtd/ftr/2018/index-eng.html

assume a dispatch profile that depends on the gas plant's marginal cost structure, and would ignore the cost structure differences between renewables relative to other dispatchable resources that would lead to least-cost resource dispatch. By enforcing constraints to meet system-level capacity and flexibility needs at least as well as the gas plants, while producing an equal or greater amount of electricity each month, the portfolio optimizer ensures that all system needs can be met while taking into account the opportunities to dispatch clean energy portfolio resources according to their real cost structures, not according to the cost structure of natural gas-fired generation.