PEMBINA institute

Towards a Clean Atlantic Grid

Clean energy technologies for reliable, affordable electricity generation in New Brunswick and Nova Scotia

Jan Gorski | Binnu Jeyakumar

January 2022

| photo: Dennis Jarvis @Flickr

PEMBINA institute

Towards a Clean Atlantic Grid

Clean energy technologies for reliable, affordable electricity generation in New Brunswick and Nova Scotia

Jan Gorski and Binnu Jeyakumar

January 2022

Recommended citation: Gorski, Jan and Binnu Jeyakumar. Towards a Clean Atlantic Grid: Clean energy technologies for reliable, affordable electricity generation in New Brunswick and Nova Scotia. The Pembina Institute, 2022.

ISBN 1-897390-55-6

The Pembina Institute
219 19 Street NW
Calgary, AB
Canada T2N 2H9
Phone: 403-269-3344

Additional copies of this publication may be downloaded from the Pembina Institute website, www.pembina.org

About the Pembina Institute

The Pembina Institute is a national non-partisan think tank that advocates for strong, effective policies to support Canada's clean energy transition. We employ multi-faceted and highly collaborative approaches to change. Producing credible, evidence-based research and analysis, we consult directly with organizations to design and implement clean energy solutions, and convene diverse sets of stakeholders to identify and move toward common solutions.

pembina.org

twitter.com/pembina   facebook.com/pembina.institute

Donate to the Pembina Institute

Together, we can lead Canada's transition to clean energy. Your gift to the Pembina Institute directly supports environmental education and innovative research that advances understanding and action on critical energy and environmental issues.

pembina.org/donate

Acknowledgements

The Pembina Institute partnered with RMI, who conducted the modelling. The introduction and methodology sections of the report contain matter adapted from RMI's publications. The authors would like to thank the following individuals for their contributions to this report: Spencer Williams, Louise Comeau, Gurprasad Gurumurthy, Tom Green, Stephen Thomas, Richard Hendriks, and Patrick Bateman.

Contents

List of Figures

List of Tables

Executive summary

Worldwide, the electricity sector is going through a profound shift as clean energy resources and technologies have now become cheaper than conventional sources of energy, coal-fired electricity plants are retiring, and citizens are demanding sources of energy with low (or no) greenhouse gas emissions. As more countries pledge to have a net-zero economy by 2050, there is an increased urgency to rapidly shift to low- or zero-carbon energy sources to supply the electricity grid so it can support electrification efforts in other economic sectors (e.g., electric vehicles). In fact, the International Energy Agency's scenario modelling shows that developed countries need to achieve net-zero electricity grids by 2035 for the world to cost-effectively reach net-zero by 2050.

As grid operators, policy makers and utility managers 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?

In Canada this question is important as our federal government has committed to completing a nationwide phase-out of coal-fired electricity by the end of 2029 and achieving a net-zero grid by 2035, all while meeting new demand as homes and vehicles continue to electrify. Nova Scotia and New Brunswick are critical regions due to their reliance on coal power and increasing interest in expanding transmission lines between Atlantic provinces and Quebec to create a unified grid known as the "Atlantic Loop."

In this study, we examined the cost of providing reliable electricity in New Brunswick and Nova Scotia using clean energy portfolios compared against natural gas and nuclear power plants, which are currently proposed as the default replacement for coal. We defined clean energy portfolios as a diverse, balanced mix of commercially available zero-carbon electricity supply and demand management options, including solar, wind, battery storage, energy efficiency, demand flexibility, and imported hydroelectricity. In all cases, we found that **clean energy portfolios provide the same services as gas and nuclear power plants at a lower cost per unit of energy over the lifetime of the energy source**, even without reliance on imported hydroelectricity (Figure 1).

However, the availability of imported hydroelectricity can make clean energy portfolios even cheaper in the Atlantic provinces. As we move towards a net-zero grid, imported hydroelectricity can play an even more important role. It can enable a buildout of more solar and wind by filling the gaps when there is no wind or solar power. In the short term, local solar, wind, and energy efficiency projects will be needed anyways and will create local jobs and economic benefits.

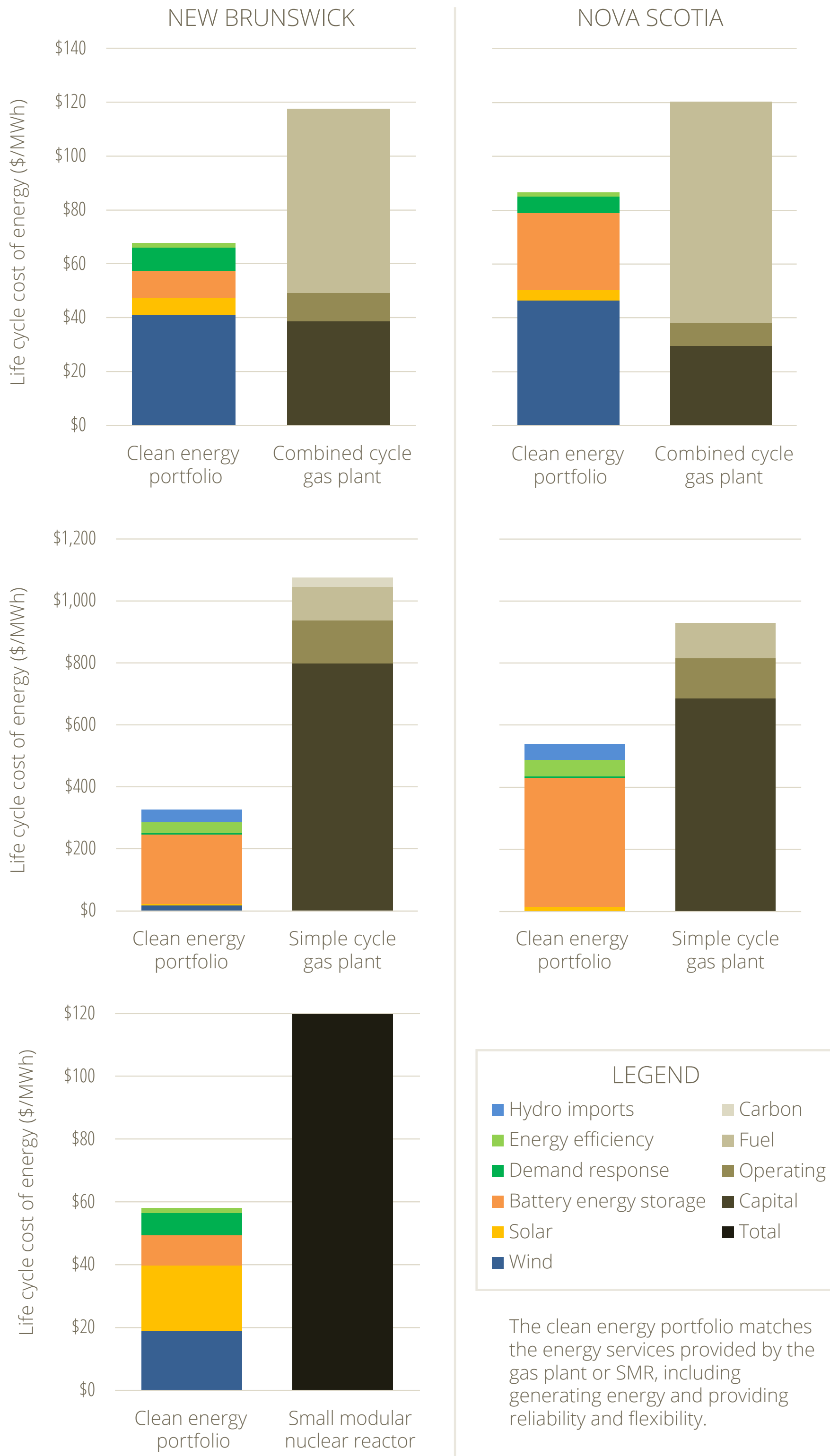

Figure 1. Cost of electricity generation from clean energy portfolios compared to natural gas plants and small modular nuclear reactors in New Brunswick and Nova Scotia

With modelling from RMI, we compared clean energy portfolios against two types of gas-fired power plants: combined cycle plants, which provide steady power, and simple cycle plants, which provide peak power. In New Brunswick, we also compared clean energy portfolios against another energy option the province is considering: small modular nuclear reactors (SMRs).

Clean energy portfolios provided the same services as gas plants and SMRs at a lower cost even when imported hydroelectricity was not considered (Figure 1). In 2019, the Pembina Institute compared the economics of clean energy portfolios to those of new gas plants in Alberta and found the same results: clean energy portfolios were not only the most affordable, but also provided reliable energy services.

The case for clean energy is likely even stronger than shown by the analysis because some of the benefits of clean energy portfolios and costs of gas plants are not captured by the modelling (e.g., benefits of grid reliability provided by battery storage). For example, the cost of clean energy portfolios includes the cost of building transmission lines to connect new renewables to the grid. Meanwhile, the gas plant costs do not include the cost of any new gas pipelines or LNG facilities that would be needed given the lack of access to natural gas in the Atlantic provinces.

There are other considerations that will also likely increase the costs of gas plant operations over time. Carbon capture will eventually be needed to address emissions from gas plants. These costs are not yet factored in because gas plants currently face no meaningful carbon price in either Atlantic province. There is a possibility that the electricity system in these two provinces will face a stronger price on carbon in the future, making the cost of natural gas power even more expensive.

While gas plants may continue to play a role in the Atlantic electricity grid for many years, non-emitting clean energy portfolios can reduce consumer costs, as well as climate and health impacts. Along with providing affordable electricity, clean energy portfolios can offer employment and economic development opportunities for workers and communities that are affected by retirement of existing power plants. It is essential that investment in clean 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.

Momentum for clean electricity is on the rise. Clean energy technologies such as wind, solar, 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. And there is keen interest in expanding transmission lines to bring more hydroelectricity resources from Quebec and Newfoundland and Labrador into New Brunswick and Nova Scotia.

The investments we make in the next decade will have long term impacts, and any investment in power plants that generate emissions must be carefully evaluated. Clean energy resources including wind, solar, battery storage, energy efficiency, demand flexibility, hydroelectricity, and clean energy imports enabled by transmission interties will play a pivotal role in creating a Canada-wide net-zero grid that is clean, reliable and affordable.

1. Comparing natural gas and clean energy portfolios

1.1 Grids in transition

Canada recently committed to a net-zero grid by 2035, aligning with what the International Energy Agency's net-zero scenario shows is needed to maintain global warming below 1.5°C.[1] This announcement builds on Canada's previous commitment to phase out heavy-polluting coal power by 2030 to reduce greenhouse gas emissions and improve air quality. As this transition occurs, and as the demand for electricity grows with increasing electrification of other sectors, new generation capacity will be needed. When considering how to meet electricity needs, both the economics and the grid services provided by different technologies must be examined.

Balanced mixes of clean energy technologies and resources — "clean energy portfolios" — are emerging as a strong solution to meet both climate goals and electricity demands across Canada. In 2019, the Pembina Institute compared the economics of clean energy portfolios to those of new gas plants in Alberta as the province was planning to phase out coal. Our analysis found that clean energy portfolios were not only the most affordable option, but also provided reliable energy services.[2] In Alberta, this transition away from coal has been accelerated by an effective carbon pricing mechanism that has led to the utilities themselves planning for a phase-out of coal-powered electricity by 2023.

Both Nova Scotia and New Brunswick are now under pressure to phase out coal power, making clean energy portfolios of high relevance in these regions. On November 5, 2021, the Government of Nova Scotia committed to coal phase-out by 2030.[3] To address this commitment, Nova Scotia Power has filed a plan that is currently under review by the Nova Scotia Utility and Review Board. New Brunswick's bid for an equivalency agreement that would

---

[1] International Energy Agency, *Net Zero by 2050: A Roadmap for the Global Energy Sector* (2021), 117. https://iea.blob.core.windows.net/assets/beceb956-0dcf-4d73-89fe-1310e3046d68/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf

[2] Jan Gorski and Binnu Jeyakumar, *Reliable, affordable: The economic case for scaling up clean energy portfolios* (Pembina Institute, 2019). https://www.pembina.org/pub/reliable-affordable-economic-case-scaling-clean-energy-portfolios

[3] Government of Nova Scotia, *Environmental Goals and Climate Change Reduction Act,* Bill No. 57. https://nslegislature.ca/legc/bills/64th_1st/3rd_read/b057.htm

have allowed New Brunswick Power to continue operating the Belledune Generating Station past the 2030 federal deadline was rejected by the federal government on November 25, 2021.[4]

While the Integrated Resource Plan in both Nova Scotia and New Brunswick have yet to be updated to reflect the 2030 coal phase-out, it is clear that the generation capacity from coal will not be available in either province for long.

As a replacement for coal, natural gas has typically been the first source considered by utilities and governments — but this should be reconsidered given the rapid improvements in clean grid technologies. New Brunswick is also planning on small modular nuclear reactor (SMR) technology reaching maturity in time to replace its coal plant, but the aggressive timelines that would be needed make this technology an uncertain investment. In contrast, clean energy resources and technologies are ready to implement today.

The impact of more imported hydroelectricity on the economics of clean energy portfolios was also examined in this study. While some imported hydroelectricity is currently available, completion of the Atlantic Loop — expanded transmission lines between the Atlantic provinces and Quebec — would increase the availability of this resource. The federal government has expressed interest in supporting strategic transmission projects, including the Atlantic Loop,[5] while the premiers of the Atlantic provinces recently committed to collaborate to provide reliable, sustainable, and affordable electricity and see the Atlantic Loop transmission network playing a key role.[6]

This study compares the economics of building new natural gas plants and SMRs against clean energy portfolios, including imported hydroelectricity, to replace coal plants and meet new demand for electricity in New Brunswick and Nova Scotia. We completed this analysis 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. A comparison against SMRs was also done for New Brunswick given the province's interest in developing the technology and using it to replace coal power.

[4] Jacques Poitras, "No extension past 2030 for Belledune coal-fired power plant, Ottawa says," CBC News, November 25, 2021. https://www.cbc.ca/news/canada/new-brunswick/belledune-coal-plant-ottawa1.6262023

[5] Environment and Climate Change Canada, *A Healthy Environment and a Healthy Economy* (2020). https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/climate-plan-overview/healthy-environment-healthy-economy.html

[6] Government of Newfoundland, "Atlantic Premiers Working Together to Improve Health Care and Promote Prosperity," news release, September 28, 2021. https://www.gov.nl.ca/releases/2021/exec/0928n07/

This study uses a modelling tool developed by RMI. Parts of Section 1 below reproduce, with permission and with some changes, material from RMI's publications.[7, 8]

1.2 Clean energy portfolio resources

Few proposed alternatives to conventional power plants and our current electricity supply rely on a single technology or resource. Rather, they typically rely on a diverse, balanced portfolio of commercially available and emerging resource options. Together, these resources form clean energy portfolios that can effectively complement, defer, or avoid investment in traditional grid infrastructure such as natural gas and fossil fuels. Portfolios modelled in this study include five main resources: renewable energy, battery energy storage, energy efficiency, imported hydroelectricity and demand flexibility.

Utilities and project developers have expanded the range of services available from clean energy resources. They are increasingly able to actively manage renewable energy, energy efficiency, demand flexibility, and storage in order to provide multiple services to customers, and the grid at large.

Renewable energy

Utility-scale solar photovoltaics or onshore wind turbines that provide weather-dependent, non-dispatchable energy. Wind and solar can now provide the lowest cost energy to the grid, even with a variable output. These resources used to be seen by grid operators and planners as providing only variable non-dispatchable energy, but smart inverters have recently allowed grid operators to demonstrate the ability of renewable energy projects to provide flexibility and ancillary services.

Battery energy storage

Dedicated battery storage units that can be charged as energy is available. In addition to supplying power at times of peak demand, battery energy storage can now provide a wide range of services needed to keep the grid running including capacity, energy balancing, and

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

[8] Charles Teplin, Mark Dyson, Alex Engel, and Grant Glazer, *The Growing Market for Clean Energy Portfolios* (RMI, 2019). https://rmi.org/insight/clean-energy-portfolios-pipelines-and-plants/

flexibility.[9] These services are now being recognized in the design and operation of storage systems.

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). Efficiency investments used to be valued based solely on energy savings, but planners are also beginning to value the peak demand savings and reduced ramp rates associated with this resource.

Demand flexibility

Controls to enable a shift in when we use electricity without reducing overall energy use or service quality (e.g., thermal storage in water heater tanks, smart thermostats and other technologies not included in the modelling, including managed charging of electric vehicles). Traditional demand flexibility (also referred to as demand response or demand-side management) programs typically reduce electricity demand peaks 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. Provinces that now have demand flexibility programs include Saskatchewan, Quebec, Nova Scotia, New Brunswick, and Ontario.

Hydroelectricity imports

Imported hydroelectric power from Newfoundland and Labrador and Quebec, which can serve as a reliable source of electricity at times when other resources (e.g., wind, solar) are not available. Those same provinces can also accept excess wind and solar energy instead so that it doesn't go to waste (through curtailment). Some hydroelectric resources (e.g., pumped hydro) can also store excess wind and solar power, acting as a battery.

[9] Thomas Bowen, Ilya Chernyakhovskiy, and Paul Denholm, *Grid-Scale Battery Storage Frequently Asked Questions* (National Renewable Energy Laboratory, 2019). https://www.nrel.gov/docs/fy19osti/74426.pdf

Small modular nuclear reactors (SMRs)

SMRs are nuclear reactors smaller than 300 megawatts (MW) that can be manufactured in a factory, avoiding the cost overruns of constructing large-scale nuclear power plants. SMRs were not considered as part of a clean energy portfolio because they are not commercially available. The first demonstration project in New Brunswick will not be in service until between 2030 and 2035.[10] Large infrastructure projects such as nuclear plants have historically faced delays in construction. In contrast, the technologies included in clean energy portfolios are affordable and available right now. SMRs are analyzed separately against the clean energy portfolios in this study.

The services provided by clean energy portfolios resources are summarized in Table 1 below.

Table 1. Grid services provided by clean energy portfolio resources

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
Imported hydroelectricity*	Energy generator	Can supply capacity at peak load	Can actively respond to ramp events, in both directions.	

* Services provided by hydroelectric power depend on contract agreement.

[10] OPG, Bruce Power, NB Power and SaskPower, *Feasibility of Small Modular Reactor Development and Deployment in Canada* (2021). https://www.opg.com/innovating-for-tomorrow/small-modular-nuclear-reactors/

Source: Adapted from RMI[11]

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.[12]

1.3 Declining cost of clean energy

Prices of clean energy have fallen dramatically in recent years compared to traditional thermal power plant costs. The cost of building new natural gas plants on the other hand, has plateaued, but is subject to the volatility of natural gas prices which have recently risen.[13] The opposite is true for clean energy with the cost of wind, solar, and battery energy storage falling by 70%, 89%, and 89%, respectively, since 2009–2010.[14, 15]

Clean energy resources are now cheaper than the operating costs of existing coal and nuclear generation, never mind the levelized cost of new thermal power plants. The costs of these resources, especially battery energy storage, are expected to continue declining as economies of scale drive down production costs. The costs of wind and solar are projected to decline in New Brunswick and Nova Scotia based on global trends, and we are now at an important juncture where the cost of solar is expected to drop faster than the cost of wind (Figure 2). The large declines in the cost of battery packs in North America (Figure 3) are also expected to continue (note the cost of battery energy storage systems includes other components besides the battery pack).

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

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

[13] 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

[14] Silvio Marcacci, "Renewable Energy Prices Hit Record Lows: How Can Utilities Benefit From Unstoppable Solar And Wind," *Forbes*, July 21, 2020. https://www.forbes.com/sites/energyinnovation/2020/01/21/renewable-energy-prices-hit-record-lows-how-can-utilities-benefit-from-unstoppable-solar-and-wind/?sh=6306d7182c84

[15] Veronika Henze, "Battery Pack Prices Cited Below $100/kWh for the First Time in 2020, While Market Average Sits at $137/kWh," *BloombergNEF*, December 16, 2020. https://about.bnef.com/blog/battery-pack-prices-cited-below-100-kwh-for-the-first-time-in-2020-while-market-average-sits-at-137-kwh/

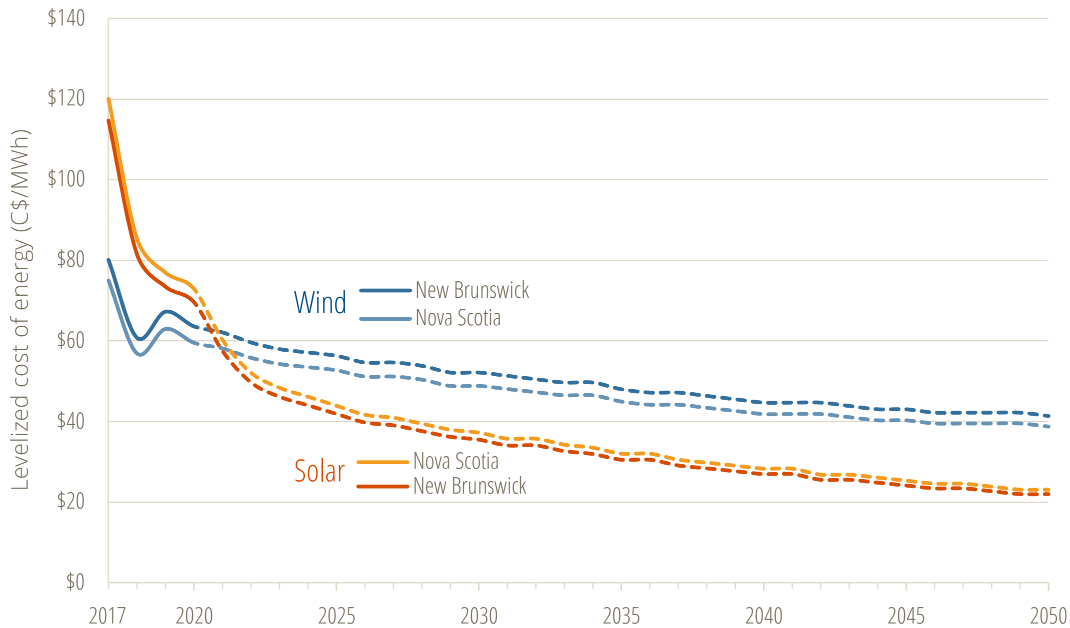

Figure 2. Historical and forecast cost decline for wind and solar in New Brunswick and Nova Scotia

Data source: Canada Energy Regulator, CERI and BloombergNEF[16,]

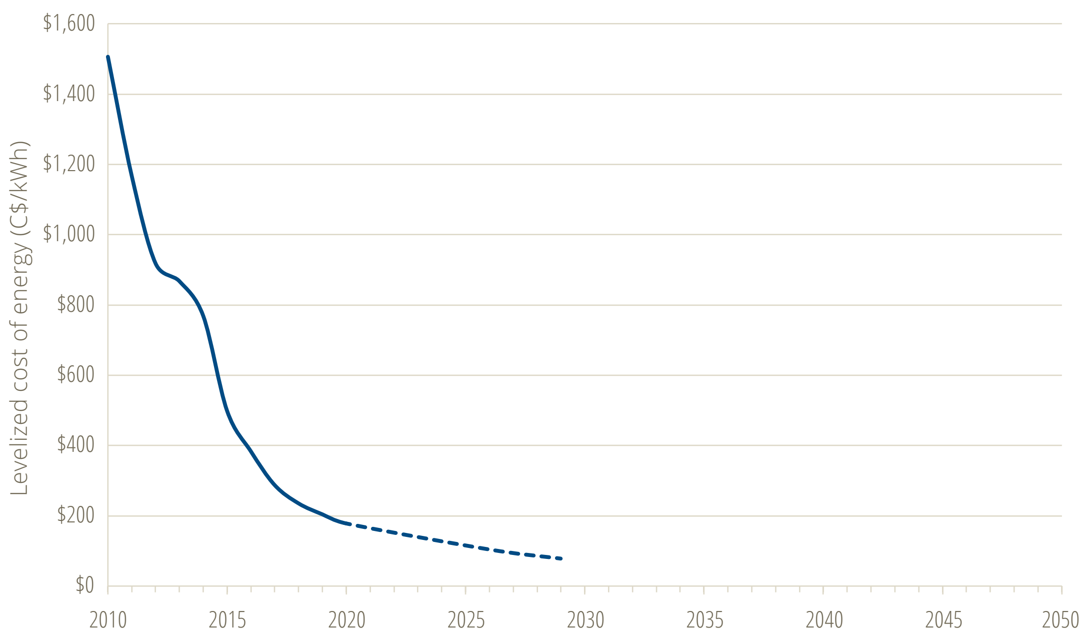

Figure 3. Historical and forecast cost decline for battery packs

Data source: BNEF[17]

[16] Solar and wind costs are based on estimates from Canadian Energy Regulator (solar) and CERI (wind) scaled to real contract prices for wind and solar in Alberta, with future cost projections based on BNEF forecast declines. For more details, see Section A.4 in the Appendix which lists data sources.

[17] "Battery Pack Prices Cited Below $100/kWh for the First Time in 2020."

1.4 Opportunities and challenges for large scale integration of wind and solar

This analysis considers only the replacement of a single generating facility and helps illustrate alternatives that are available. Broader system-level modelling is required to address questions around the level of renewable penetration that can be accommodated due to reliability concerns during emergencies and long-term shortages of wind or solar power.

In looking at the broader system, it should be noted that renewables also provide ancillary services that maintain grid stability and security. These include voltage regulation, frequency response, ramping and system inertia.

Recent studies show that these services from renewables are not as restrictive as assumed in most modelling and planning exercises. New technologies can meet the demands of the grid, even with large amounts of renewables.[18, 19] Improvements in technologies such as smart inverters in combination with advanced plant controls allow renewables to provide many of the same ancillary services that conventional power plants typically provide. The full range of available solutions should be considered when evaluating the potential of clean energy portfolios.

New Brunswick Power has stated in their Integrated Resource Plan that some existing generation is not flexible and cannot be taken offline (e.g., nuclear, run-of-river hydro, must-take contracts).[20] These constraints must be considered in system modelling and can be alleviated with more transmission capability to neighboring regions.

[18] Paul Denholm, Trieu Mai, Rick Wallace Kenyon, Ben Kroposki, and Mark O'Malley, *Inertia and the Power Grid: A Guide Without the Spin* (National Renewable Energy Laboratory, 2020), v. https://www.nrel.gov/news/program/2020/inertia-and-the-power-grid-a-guide-without-the-spin.html

[19] Clyde Loutan and Vahan Gevorgian, *Avangrid Renewables Tule Wind Farm* (2020), 5. https://www.caiso.com/Documents/WindPowerPlantTestResults.pdf

[20] New Brunswick Power, *Integrated Resource Plan* (2020), 42. https://www.nbpower.com/media/1490323/2020-irp-en-2020-11-17.pdf

2. Reducing electricity costs using renewables

2.1 New Brunswick and Nova Scotia analysis

The modelling analysis compared a clean energy portfolio of renewable energy, battery energy storage, imported hydroelectricity, demand flexibility, and energy efficiency against a prototypical new combined cycle or simple cycle gas plant in New Brunswick and Nova Scotia with parameters as outlined in Table 2. In New Brunswick a comparison against small modular nuclear reactors (SMRs) was also done given the province's interest in developing the technology as a replacement for coal power. 2030 was chosen as the start date for an SMR; however, it is not certain that SMRs will be commercially available by then. Clean energy portfolios were assembled for each province; the life cycle cost of energy ($/MWh), total cost ($) and capacity (MW) of the resulting portfolios is presented here. See Appendix A for methodology and modelling assumptions.

Table 2. Modelling parameters for natural gas and SMR plants

Power plant	Province	Plant size (MW)	In service date	Capacity factor*
Natural gas, combined cycle	Nova Scotia	400	2025	52%
Natural gas, simple cycle	Nova Scotia	100	2025	2%
Natural gas, combined cycle	New Brunswick	467	2030	52%
Natural gas, simple cycle	New Brunswick	100	2030	2%
Small modular nuclear reactor	New Brunswick	400	2030	82%

* The capacity factor is the fraction of total annual hours that the plant is in operation.

While adding imported hydroelectricity made clean energy portfolios even cheaper, it is included only for simple cycle gas plants in both provinces, where total cost is important since these plants are used less frequently. The cost of clean energy portfolios also accounts for the value of energy generated by wind and solar at times when it isn't required to meet the energy services provided by the gas plant.

The results show that a clean energy portfolio can generate electricity in New Brunswick and Nova Scotia at a lower life cycle cost to consumers than gas plants or SMRs while providing the same services (Figure 4).

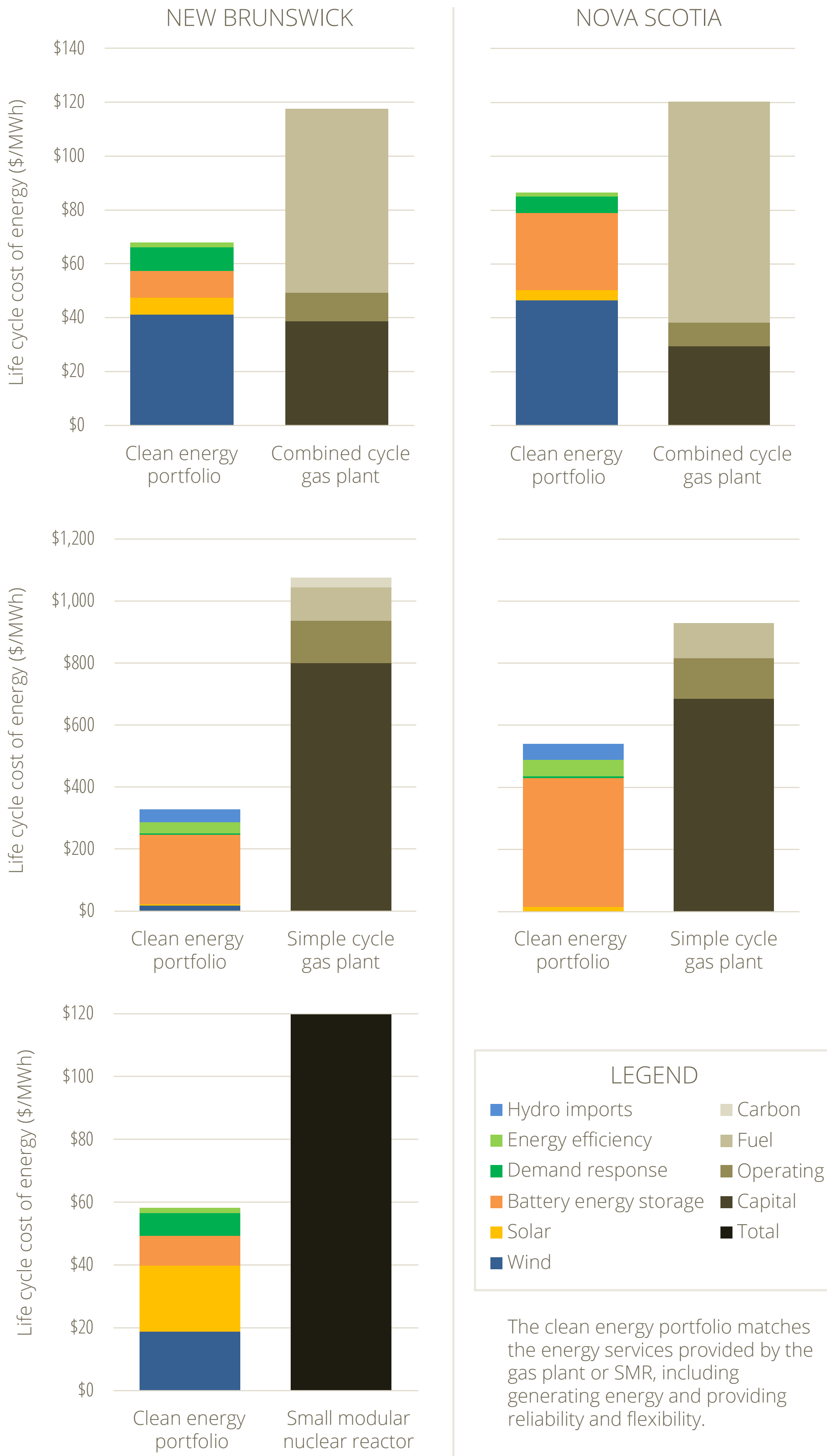

Figure 4. Cost of electricity generation from clean energy portfolio compared to natural gas plants and small modular nuclear reactors in New Brunswick and Nova Scotia

Our analysis shows that clean energy portfolios can cost-effectively provide the same services that will likely be required of the proposed gas plants. However, there may be periods when services from the gas plant would be needed that the clean energy portfolio, as described, would not be able to meet (for example, emergency backup power on days with no wind). Planners with knowledge of actual plant demands may find that our described clean energy portfolio can do the job, or that it might require a different combination of resources.

Often, finding the best combination of resources requires new tools and processes that reflect emerging trends and requirements rather than past conditions. RMI's *How to Build Clean Energy Portfolios* describes the all-source procurements now used by a growing number of utilities in the U.S. to determine and procure the best set of resources that meet their needs.[21] Using all-source procurement, the most recent cost and operational data from competitive bids would inform the composition of the clean energy portfolios to serve the needs of the grids in New Brunswick and Nova Scotia.

In both provinces the total cost of clean energy portfolios is similar to that of combined cycle gas plants (Figure 5). The clean energy portfolio costs include both capital and operating costs. For simple cycle gas plants, which are expected to see very limited operation in any given year, the total cost is more important than the cost per unit of energy in the main modelling scenario (no hydroelectricity imports; not shown here). In New Brunswick, the total cost of the clean energy portfolio was the same as the gas plant when imported hydroelectric power was available (Figure 6). In Nova Scotia, the total cost of the clean energy portfolio was more than the gas plant even with hydroelectricity.

Whether comparing clean energy portfolios to a combined cycle plant (Figure 5), a simple cycle plant (Figure 6), or an SMR (Figure 7), the total capacity of the clean energy portfolios is larger than the business-as-usual plant for all cases. The breakdown of capacity of the clean energy resources is shown in Table 3.

This analysis shows that clean energy portfolios have a significant role to play in the Atlantic grid of the future. Full system modelling is needed to determine the best combination of energy sources as the Atlantic provinces look to replace coal power and meet growing electricity demands.

[21] Lauren Shwisberg, Mark Dyson, Grant Glazer, Carl Linvill, Megan Anderson, *How to Build Clean Energy Portfolios: A Practical Guide to Next-Generation Procurement Practices* (RMI, 2021). https://rmi.org/how-to-build-ceps/

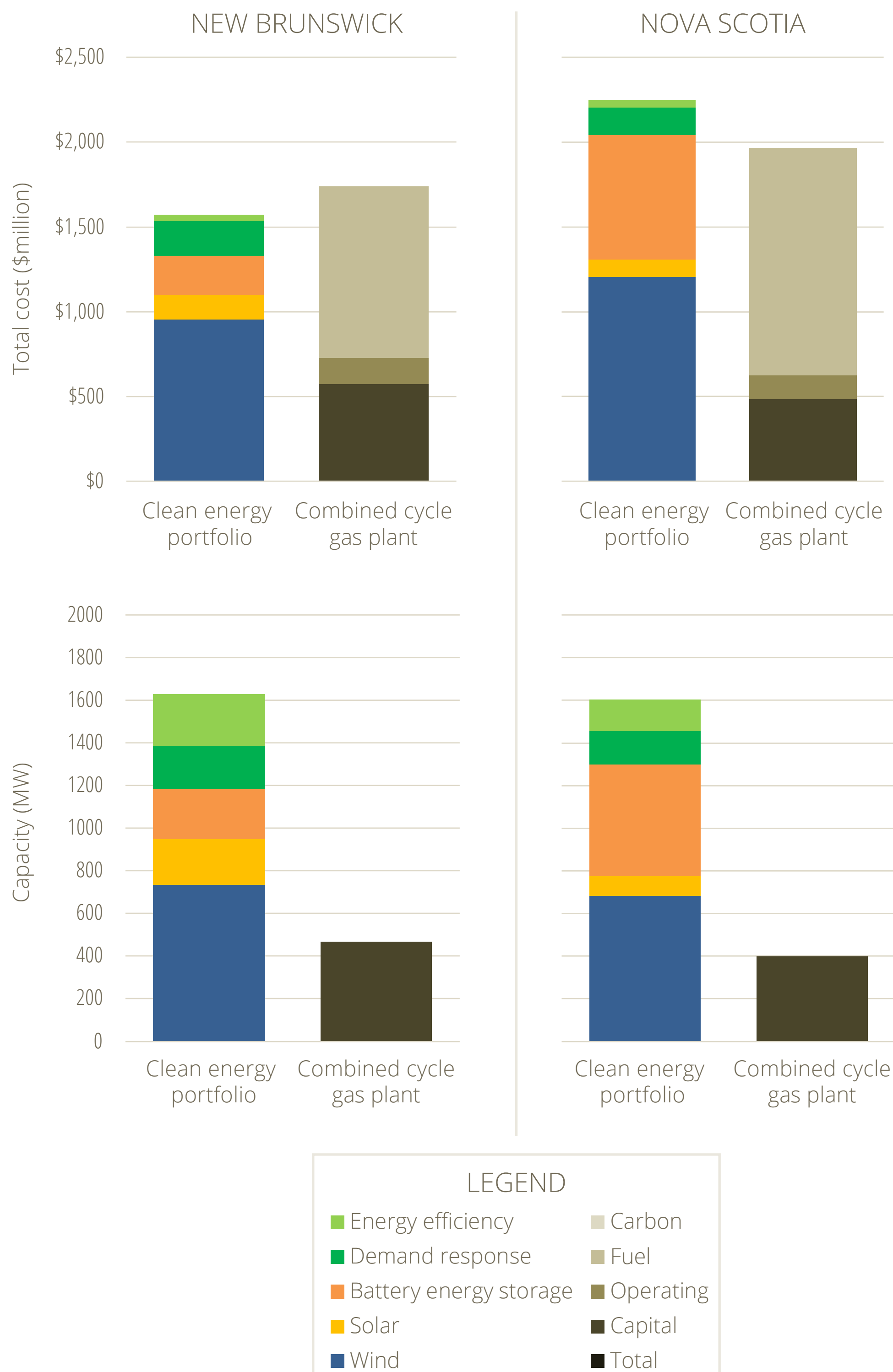

Figure 5. Total cost and capacity of clean energy portfolio compared to combined cycle natural gas plants in New Brunswick and Nova Scotia

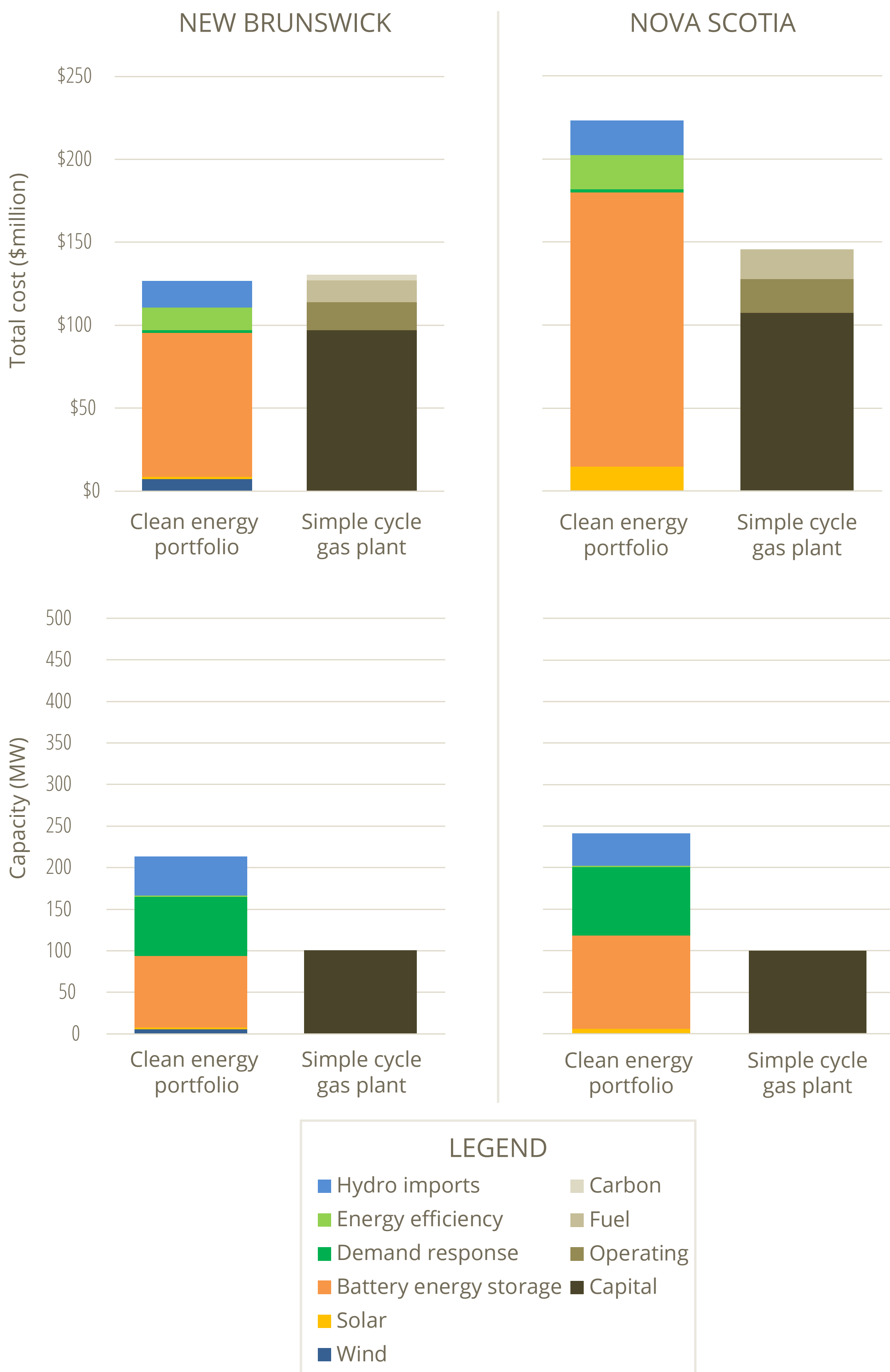

Figure 6. Total cost and capacity of clean energy portfolio compared to simple cycle natural gas plants in New Brunswick and Nova Scotia

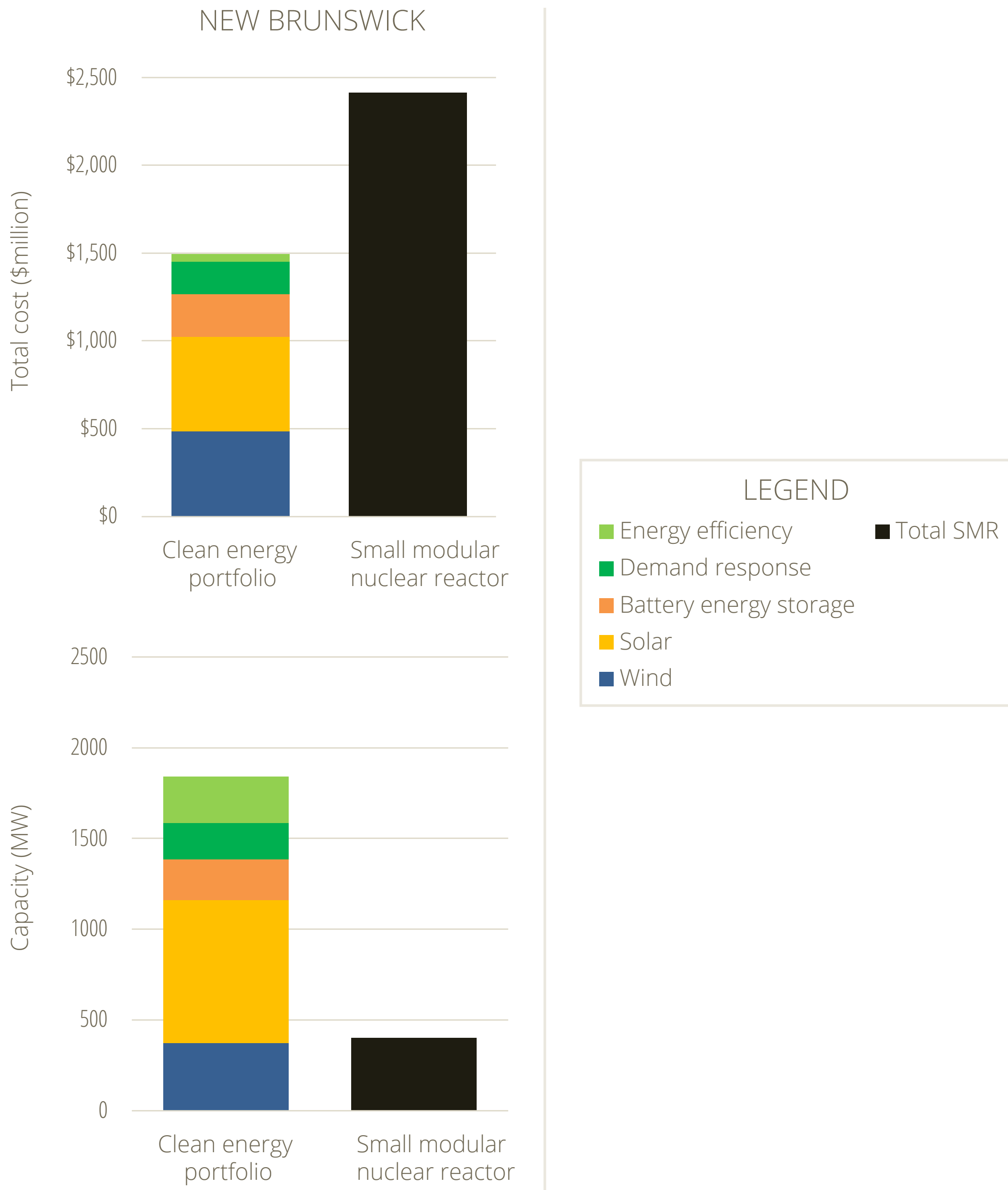

Figure 7. Total cost and capacity of clean energy portfolio compared to small modular nuclear reactors in New Brunswick

Table 3. Total capacity in MW of clean energy resources compared to gas plants and SMRs in Nova Scotia and New Brunswick

	Nova Scotia		New Brunswick		
	Natural gas, combined cycle scenario	Natural gas, simple cycle scenario	Natural gas, combined cycle scenario	Natural gas, simple cycle scenario	SMR scenario
Wind	0	0	735	6	0
Solar	95	6	213	2	787
Battery energy storage	523	113	235	87	223
Demand flexibility	157	82	204	71	204
Energy efficiency	145	2	242	2	254
Hydroelectric imports	0	39	0	47	0

2.2 Sensitivity analysis

A sensitivity analysis was done to see if important variables have an impact on the modelling outcomes.

Hydroelectric imports

The availability of hydroelectric imports was examined due to interest in the Atlantic Loop. In our main modelling scenario, imported hydroelectric power was not considered. When the availability of imported hydroelectric power was included, it reduced the cost of the clean energy portfolios in all cases.

Alternative gas plant capacity factors

Alternate gas plant capacity factors were examined due to the range of possibilities in how much gas plants are used as seen in the utility integrated resource plans. The capacity factors for gas plants used in the main modelling scenario were 52% for combined cycle gas plants and 2% for simple cycle gas plants. The modelling from the Nova Scotia Integrated Resource Plan shows that in some cases the capacity factors for combined cycle gas plants could be higher (80%) or lower (20%) meaning that these plants are used more or less often.[22] For simple cycle gas plants, the capacity factor could be as high as 8%. In our model, higher capacity factor (higher gas plant usage) improved the cost savings of clean energy portfolios, while lower capacity factor for combined cycle gas plants brought the cost of clean energy portfolios closer to, but still cheaper than, the gas plant.

Federal carbon price

The federal carbon price was modelled to anticipate a more stringent carbon pricing system in the two provinces, which may be triggered by recent changes to how the federal government evaluates equivalency of provincial carbon pricing systems. In our main modelling scenario, the provincial carbon pricing systems currently in place in New Brunswick and Nova Scotia were applied. Gas plants face a very small cost increase compared to clean energy portfolios due to the provincial systems currently in place in these provinces. These systems are described in more detail in the Appendix.

A scenario where both provinces are under the federal output-based pricing system was also modelled. Under this scenario, combined cycle gas plant cost increased significantly while the cost of simple cycle gas plants increased by only a small amount.

SMR cost uncertainty

High- and low-cost scenarios for SMRs were modelled given the uncertainty in their costs. Under all scenarios, clean energy portfolios were cheaper than SMRs.

[22] Nova Scotia Power, *2020 Integrated Resource Plan* (2020), Appendix F: Modeling Results Tables. https://irp.nspower.ca/files/key-documents/E3_NS-Power_2020_IRP_Report_final_Nov-27-2020.pdf

3. Key takeaways for the transition to a clean grid in New Brunswick and Nova Scotia

The analyses of New Brunswick and Nova Scotia are an instructive illustration of the opportunities available to not only reduce emissions from the electricity sector, but also to seek lowest cost options that can benefit consumers.

1. Clean energy portfolios can provide **low-cost, reliable electricity**. The required technologies are mature and available now in New Brunswick and Nova Scotia. As these provinces phase out coal, clean energy portfolios should be prioritized over SMRs, which are not yet commercially available, and gas plants, which will require finding a way to source gas and are subject to the volatility of gas prices. These technologies may play a limited role in the grid, but clean energy portfolios are readily available now at a lower cost and their deployment should be prioritized.
2. Clean energy portfolios can help deliver not only affordable electricity but also **jobs and economic development opportunities** in New Brunswick and Nova Scotia. Providing support to workers affected by phasing out coal to help them transition to new careers is paramount. Clean energy investments coupled with well-designed training and support programs can enable workers to take advantage of the rapidly expanding global clean energy industry.
3. Concerns about grid stability can be addressed — **renewables can provide the ancillary services** needed to ensure a stable and secure grid when combined with the latest technology.
4. The availability of **additional hydroelectric imports** from Quebec and Newfoundland and Labrador through completion of the Atlantic Loop **can complement local renewable resources** in New Brunswick and Nova Scotia and reduce the total cost of electricity. Imported hydroelectricity can enable more development of local wind and solar resources (and thus local jobs) by providing energy when solar and wind are not available.

Appendix A. Methodology

A.1 The clean energy portfolio model

The clean energy portfolio model[23] uses a three-step approach to compare the economics of gas plants and small modular nuclear reactors (SMRs) to clean energy:

1. Estimate the services of the proposed gas plant/SMR
2. Combine a clean energy portfolio consisting of wind, solar, battery energy storage, imported hydroelectricity, energy efficiency, and demand flexibility to match the services from the gas plant/SMR
3. Compare total net lifetime cost of each option on a net-present value basis.

The model constructs least-cost portfolios of clean energy resources that would provide services equivalent to those provided by a natural gas power plant.

Each clean energy portfolio must provide the same or more monthly energy and as much capacity during the top 50 net peak-demand hours as the gas plant/SMR under consideration.

Data sources are summarized in Section A.4 below.

A.2 Key assumptions

Table 4. Modelling parameters for natural gas and SMR plants

Power plant	Province	Plant size (MW)	In service date	Capacity factor
Natural gas combined cycle	Nova Scotia	400	2025	52%
Natural gas simple cycle	Nova Scotia	100	2025	2%
Natural gas combined cycle	New Brunswick	467	2030	52%
Natural gas simple cycle	New Brunswick	100	2030	2%
Small modular nuclear reactor	New Brunswick	400	2030	82%

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

Plant size: The gas and nuclear plants were modelled using the parameters below based on the typical of sizes of these types of plants proposed by the utilities in these two provinces in their 2020 Integrated Resource Plans and the size of the existing coal plants in New Brunswick for the SMR scenario.

In service date: The in service date was selected based on the earliest year for new gas plant builds as indicated in the provincial 2020 Integrated Resource Plans.

Capacity factor: The average annual capacity factors were selected based on the median values for gas plants from all scenarios in the Nova Scotia Integrated Resource Plan and the 2020/2021 value for the existing nuclear plan in New Brunswick for the SMR case. The monthly capacity factor distribution was based on monthly capacity factors from modelling by the Canada Energy Regulator. The monthly capacity factors were scaled to align with the average annual capacity factors.

Carbon pricing: In the main modelling scenario, the provincial carbon pricing systems were used to calculate the price on carbon for natural gas plants in New Brunswick and Nova Scotia.

Nova Scotia has a cap-and-trade system which places a cap on electricity sector emissions, but doesn't set any facility limits. Based on analysis of the cap and Nova Scotia Power's Integrated Resource Plan, it is unlikely that electricity plants in Nova Scotia will face a price on carbon under the province's current system.

New Brunswick has an output-based pricing system which sets a threshold for gas plants of 420 tonnes CO_2e/GWh. Gas plants that have an emissions intensity above this threshold must pay a price on carbon. Combined cycle plants are already below this threshold, while simple cycle plants are above it but only pay a small price on carbon on average because they are not used very often.

A scenario where both provinces are under the federal output-based pricing system was also modelled. Under the federal carbon pricing system, the GHG intensity threshold declines from 370 tonnes CO_2e/GWh in 2021 to 0 in 2030. The cost to combined cycle gas plants increased significantly while the cost to simple cycle gas plants increased by only a small amount.

The federal carbon price schedule was used, with the carbon price reaching \$170/t CO_2e by 2030. Table 5 shows the carbon costs to natural gas plants in both provinces. The difference in cost by province is due to different in-service dates.

Table 5. Carbon costs to natural gas plants based on federal industrial carbon pricing system

Province	Carbon cost ($/MWh)	
	Combined cycle	Simple cycle
New Brunswick	$60	$72
Nova Scotia	$54	$76

Gas prices: The model uses the National Energy Board's 2020 Canada's Energy Future evolving case natural gas prices for the industrial sector adjusted to remove the price on carbon, which is accounted elsewhere in the model.

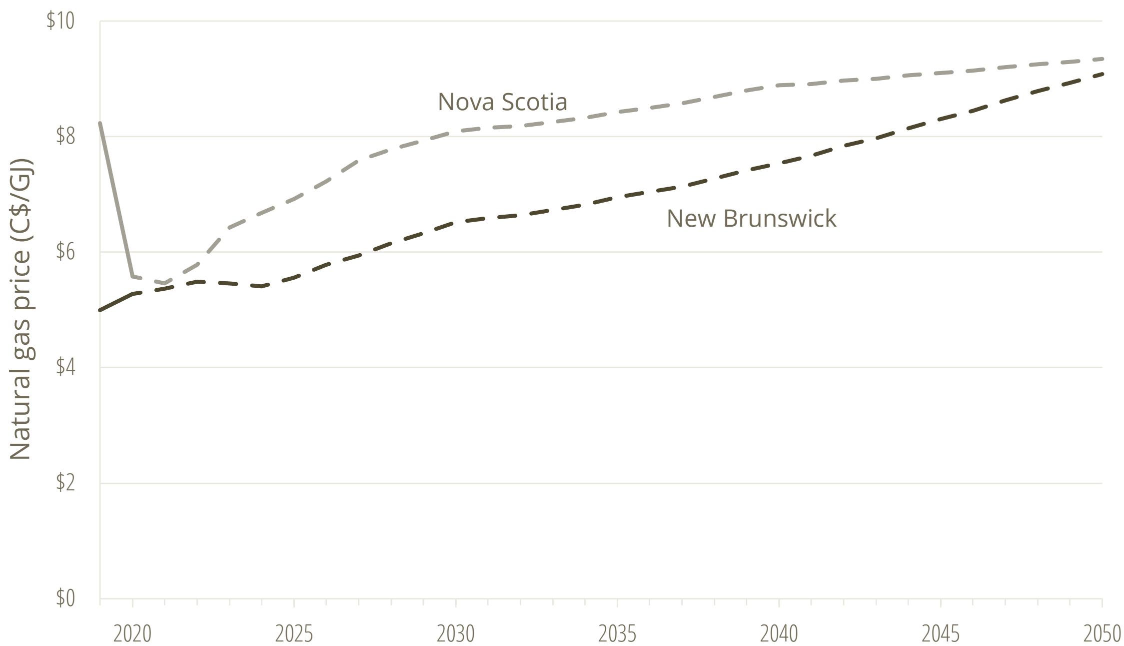

Figure 8. Forecast natural gas price in New Brunswick and Nova Scotia

Data source: Canada Energy Regulator[24]

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 and demand flexibility potential: Energy efficiency and demand flexibility potential is based on data from the New Brunswick Power demand side

[24] Canada Energy Regulator, Canada's Energy Future Data Appendices. https://apps.cer-rec.gc.ca/ftrppndc/dflt.aspx?GoCTemplateCulture=en-CA

management plan, Nova Scotia's energy efficiency data and data from the Natural Resources Canada comprehensive energy use database.

Extra generation: The extra energy generated by wind and solar above and beyond what is needed to match the output of the gas or SMR plant is valued at a cost of $15/MWh.

Hourly system load: Figure 9 and Figure 10 show the highest load on the system for each hour of each month in New Brunswick and Nova Scotia. Electricity demand in both provinces peaks in the winter, with the highest loads occurring in the afternoon and evening.

New Brunswick

Hour \ Month	1	2	3	4	5	6	7	8	9	10	11	12
0	2032	1893	1693	1465	1159	1087	1104	1104	1030	1203	1595	1901
1	1980	1842	1665	1454	1138	1059	1067	1071	1005	1184	1539	1841
2	1968	1836	1662	1460	1133	1044	1043	1049	994	1179	1524	1826
3	1971	1840	1670	1472	1139	1042	1031	1037	991	1182	1524	1825
4	1988	1855	1696	1509	1162	1055	1031	1040	999	1205	1537	1840
5	2028	1892	1745	1572	1208	1083	1046	1062	1032	1257	1575	1877
6	2092	1957	1864	1717	1324	1184	1118	1136	1134	1398	1648	1943
7	2236	2103	2012	1862	1461	1315	1232	1245	1257	1552	1791	2079
8	2382	2243	2062	1866	1483	1359	1310	1322	1299	1581	1923	2220
9	2407	2239	2042	1827	1471	1373	1364	1374	1324	1570	1933	2262
10	2376	2181	2003	1791	1454	1380	1399	1409	1335	1549	1903	2238
11	2331	2124	1962	1759	1443	1379	1421	1435	1339	1525	1874	2192
12	2289	2069	1911	1709	1411	1359	1422	1429	1324	1485	1842	2142
13	2229	2012	1866	1669	1390	1351	1425	1431	1312	1463	1805	2084
14	2188	1976	1827	1626	1364	1334	1415	1419	1298	1440	1786	2037
15	2153	1945	1810	1610	1356	1334	1416	1422	1301	1441	1770	2006
16	2164	1952	1833	1632	1378	1360	1436	1442	1328	1478	1792	2028
17	2253	2012	1856	1628	1373	1357	1433	1436	1331	1489	1875	2132
18	2328	2067	1867	1618	1359	1338	1413	1414	1316	1510	1935	2210
19	2331	2122	1911	1637	1352	1323	1382	1382	1319	1537	1920	2187
20	2314	2115	1944	1688	1368	1314	1357	1371	1327	1511	1892	2167
21	2282	2088	1905	1670	1381	1310	1348	1355	1268	1450	1847	2135
22	2214	2034	1832	1594	1310	1258	1292	1275	1178	1361	1779	2081
23	2117	1954	1750	1513	1218	1163	1193	1182	1095	1276	1692	1994

Figure 9. Average electrical load in New Brunswick by hour of each month in MW.

Nova Scotia

Hour \ Month	1	2	3	4	5	6	7	8	9	10	11	12
0	1476	1442	1360	1187	983	913	960	992	922	1029	1245	1467
1	1452	1417	1336	1170	968	902	940	968	902	1011	1223	1440
2	1436	1396	1323	1172	967	897	931	957	897	1007	1202	1423
3	1428	1389	1315	1181	981	906	929	954	898	1011	1200	1420
4	1435	1399	1338	1224	1008	926	941	979	924	1046	1213	1430
5	1469	1436	1402	1307	1072	996	987	1022	993	1141	1256	1468
6	1554	1529	1478	1379	1153	1085	1079	1100	1068	1229	1351	1558
7	1627	1601	1521	1396	1184	1120	1142	1166	1102	1249	1427	1635
8	1661	1621	1533	1391	1188	1137	1186	1210	1130	1256	1460	1671
9	1671	1611	1518	1375	1174	1143	1212	1230	1143	1249	1463	1675
10	1663	1587	1503	1364	1174	1149	1231	1248	1157	1248	1452	1660
11	1658	1579	1487	1350	1167	1144	1238	1259	1159	1235	1443	1647
12	1661	1566	1463	1311	1145	1129	1231	1257	1152	1215	1435	1637
13	1631	1538	1432	1294	1124	1114	1217	1251	1139	1196	1417	1605
14	1609	1515	1426	1289	1128	1120	1217	1257	1145	1205	1409	1589
15	1623	1524	1448	1307	1152	1144	1230	1269	1172	1232	1432	1608
16	1676	1568	1474	1322	1159	1153	1231	1263	1178	1251	1500	1691
17	1755	1633	1481	1312	1138	1127	1199	1225	1151	1262	1561	1777
18	1734	1657	1518	1330	1130	1117	1179	1194	1160	1274	1527	1749
19	1708	1641	1529	1373	1155	1110	1166	1206	1170	1246	1502	1726
20	1675	1610	1498	1340	1167	1115	1176	1198	1120	1203	1463	1696
21	1618	1567	1446	1269	1108	1059	1123	1145	1062	1145	1407	1643
22	1542	1495	1397	1225	1052	990	1058	1088	1009	1098	1335	1564
23	1506	1464	1374	1206	1011	937	999	1031	956	1061	1290	1509

Figure 10. Average electrical load Nova Scotia by hour of each month in MW

The sections below are reproduced, with permission and with some changes, from RMI's publications.[25]

A.3 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/SMR in each case. The model includes four components:

[25] *The Growing Market for Clean Energy Portfolios; The Economics of Clean Energy Portfolios.*

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 the contribution of renewables in meeting peak load, also known as the effective load carrying capacity (ELCC).
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 and the business-as-usual plant (gas plant or SMR). Data for this is included in Section A.4.
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.

A.3.1 Service requirement model

The RMI model calculates the composition of least-cost portfolios of clean energy resources that can provide the same grid services as a proposed natural gas-fired power plant/SMR. The model requires that the clean energy portfolio meet three key service requirements:

Monthly energy: The portfolio must produce at least as much energy each month as the gas plant/SMR. We estimate the gas plant's monthly capacity factor by assuming operators will run the plant similarly to other comparable plants in the region.

Peak-hour capacity: The total power output (in megawatts) of the portfolio must match or exceed the gas plant's seasonally adjusted nameplate capacity during the region's top 50 hours of peak net load in a year. These hours can be, but are not necessarily, sequential. To calculate peak net load, we start with the predicted total regional hourly load and subtract projected wind and solar (distinct from the clean energy portfolio).

Flexibility: The total power output (in megawatts) of the clean energy portfolio must match or exceed the gas plant's seasonally adjusted nameplate capacity during the hour when the region experiences its greatest one-hour increase in net load. Further, the model requires that the clean energy portfolio not exacerbate ramping issues (i.e., the "duck curve"), by requiring that during the largest four-hour ramp-down of solar generation, total power output must be able to remain constant or increase (e.g., by charging storage during peak solar photovoltaic output and discharging as power output drops).

A.3.2 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 plant-level energy efficiency constraint limits the amount of energy that can be provided by energy efficiency to a specific proportion (in this case, 50%) 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).

A.3.3 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/SMR, 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 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.

A.4 Data sources

Data	Source
Hourly load profile	2018 data from New Brunswick Power and Nova Scotia Power.[26, 27]
Hourly energy consumption by end use	Based on U.S. data.[28]
Energy efficiency and demand response potential	Estimated using data from NB Power's Demand Side Management Plan. Cost data is from the same source, along with estimates of lighting costs from U.S. data.[29, 30] The number of devices that energy efficiency and demand response measure can impact is estimated from end-use energy consumption data from the NRCan Comprehensive Energy Use Database and data from the Energy Information Agency for residential and commercial lighting.[31, 32, 33]

[26] NB Power, *Hourly Load Data for 2018*. https://tso.nbpower.com/Public/en/system_information_archive.aspx

[27] Nova Scotia Power, "Hourly Total Net Nova Scotia Load." https://www.nspower.ca/oasis/monthly-reports/hourly-total-net-nova-scotia-load

[28] Amory Lovins, *Reinventing Fire* (RMI, 2014). https://rmi.org/insight/reinventing-fire/

[29] Megan Billingsley, Ian Hoffman, Elizabeth Stuart et al, *The Program Administrator Cost of Saved Energy for Utility Customer-Funded Energy Efficiency Programs* (Berkeley Lab, 2014). https://emp.lbl.gov/publications/program-administrator-cost-saved

[30] Energy Information Administration, "Annual Electric Power Industry Report, Form EIA-861 detailed data files." https://www.eia.gov/electricity/data/eia861/

[31] NB Power, *DSM Plan 2018/19-2020/21* (2018). https://www.nbpower.com/media/1489275/dsm_plan-2019-2021-en.pdf

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

[33] 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/

Renewable energy potential	Hourly generation potential and capacity factors sourced from Renewables Ninja.[34]
Energy efficiency costs	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.[35]
Demand flexibility cost	Estimates are also program based, and calculated for each sector from the median annual demand response program costs reported by utilities on EIA's Form 861 (2019).[36]
Gas plant costs	Capital and operating costs are from New Brunswick and Nova Scotia Integrated Resource Plans and fuel costs are from the Canada Energy Regulator's 2020 Canada's Energy Future evolving case natural gas prices adjusted to remove the price on carbon, which is accounted elsewhere in the model.[37, 38, 39]
Solar costs	Based on cost of solar tracking costs from CER Economics of Solar Power in Canada scaled to real solar costs from an Alberta project based on relative difference between Atlantic and Alberta costs in CER study.[40, 41] Forecast declines in future costs are based on BNEF's LCOE Viewer.[42]
Wind costs	Based on onshore wind costs from 2018 CERI report scaled to real contract prices from Alberta Renewable Electricity Program based on relative difference between Atlantic and Alberta costs in CERI study.[43, 44] Forecast declines in future costs are based on BNEF's LCOE Viewer.[45]

[34] Stefan Pfenninger and Iain Staffell, "Renewables.ninja." https://www.renewables.ninja/

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

[36] Energy Information Administration, Annual Electric Power Industry Report, Form EIA-861 detailed data files (2019) https://www.eia.gov/electricity/data/eia861/

[37] Canada's Energy Future Data Appendices. https://apps.cer-rec.gc.ca/ftrppndc/dflt.aspx?GoCTemplateCulture=en-CA

[38] New Brunswick *Integrated Resource Plan*.

[39] Nova Scotia *Integrated Resource Plan*.

[40] Canada Energy Regulator, *The Economics of Solar Power in Canada* (2020), https://www.cer-rec.gc.ca/en/data-analysis/energy-commodities/electricity/report/solar-power-economics/economics-solar-power-in-canada-results.html

[41] Vincent Morales and Binnu Jeyakumar, *Renewable energy — what you need to know* (Pembina Institute, 2020), 2. https://www.pembina.org/reports/renewable-energy--what-you-need-to-know.pdf

[42] BloombergNEF, "LCOE Viewer," Accessed June 23, 2021. https://www.bnef.com/flagships/lcoe

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

[44] 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

[45] "LCOE Viewer."

Battery energy storage costs	Capital and operational costs and annual capital cost decline projections are taken from Levelized Cost of Storage Analysis – Version 6.0 and NREL Electricity Annual Technology Baseline.[46, 47] 2025: $335/kWh 2030: $272/kWh
Hydroelectricity import costs	Based on average New England wholesale price of $50/MWh from the last decade, which is representative of the cost of imported electricity.[48]
Small modular nuclear reactor costs	From SMR roadmap.[49] Low: $68/MWh Medium: $90/MWh High: $118/MWh
Transmission costs	Cost of transmission within the provinces is based on U.S. data and assumed to be C$101.6/kW in capital costs and C$3.8/kW-yr in fixed operating costs.[50] The additional cost of transmission for hydroelectricity from Quebec and Newfoundland was estimated to be C$20/MWh and was included in sensitivity analysis, but determined not to have an impact on the final outcome.[51]
Gas pipelines costs	Not included in analysis.
Carbon pricing	Provincial and federal regulations.[52,53, 54]

[46] Lazard, *Levelized Cost of Storage Analysis* (LCOS 6.0) (2020). https://www.lazard.com/media/451418/lazards-levelized-cost-of-storage-version-60.pdf

[47] NREL, Electricity Annual Technology Baseline (ATB) Data Download (2020). https://atb-archive.nrel.gov/electricity/2020/data.php

[48] ISO New England, "Key Grid and Market Stats." https://www.iso-ne.com/about/key-stats/markets/

[49] Canadian Small Modular Reactor Roadmap Steering Committee, *A Call to Action: A Canadian Roadmap for Small Modular Reactors* (2018). https://smrroadmap.ca/wp-content/uploads/2018/11/SMRroadmap_EN_nov6_Web-1.pdf

[50] XCEL Energy, *2016 Electric Resource Plan* (2016). http://www.dora.state.co.us/pls/efi/efi_p2_v2_demo.show_document?p_dms_document_id=887185

[51] *A Comprehensive Guide to Electricity Generation Options in Canada*

[52] New Brunswick Government*, New Brunswick Regulation 2021-43 under the Climate Change Act* (2021), 19. https://www2.gnb.ca/content/dam/gnb/Departments/ag-pg/PDF/RegulationsReglements/2021/2021-43.pdf

[53] Government of Canada, *Output-Based Pricing System Regulations* (2019). https://laws-lois.justice.gc.ca/eng/regulations/SOR-2019-266/index.html

[54] Nova Scotia Environment, *Nova Scotia's Cap and Trade Program Regulatory Framework* (2019). https://climatechange.novascotia.ca/sites/default/files/Nova-Scotia-Cap-and-Trade-Regulatory-Framework.pdf