Open and Accessible Renewable Electricity System Modelling for Prince Edward Island

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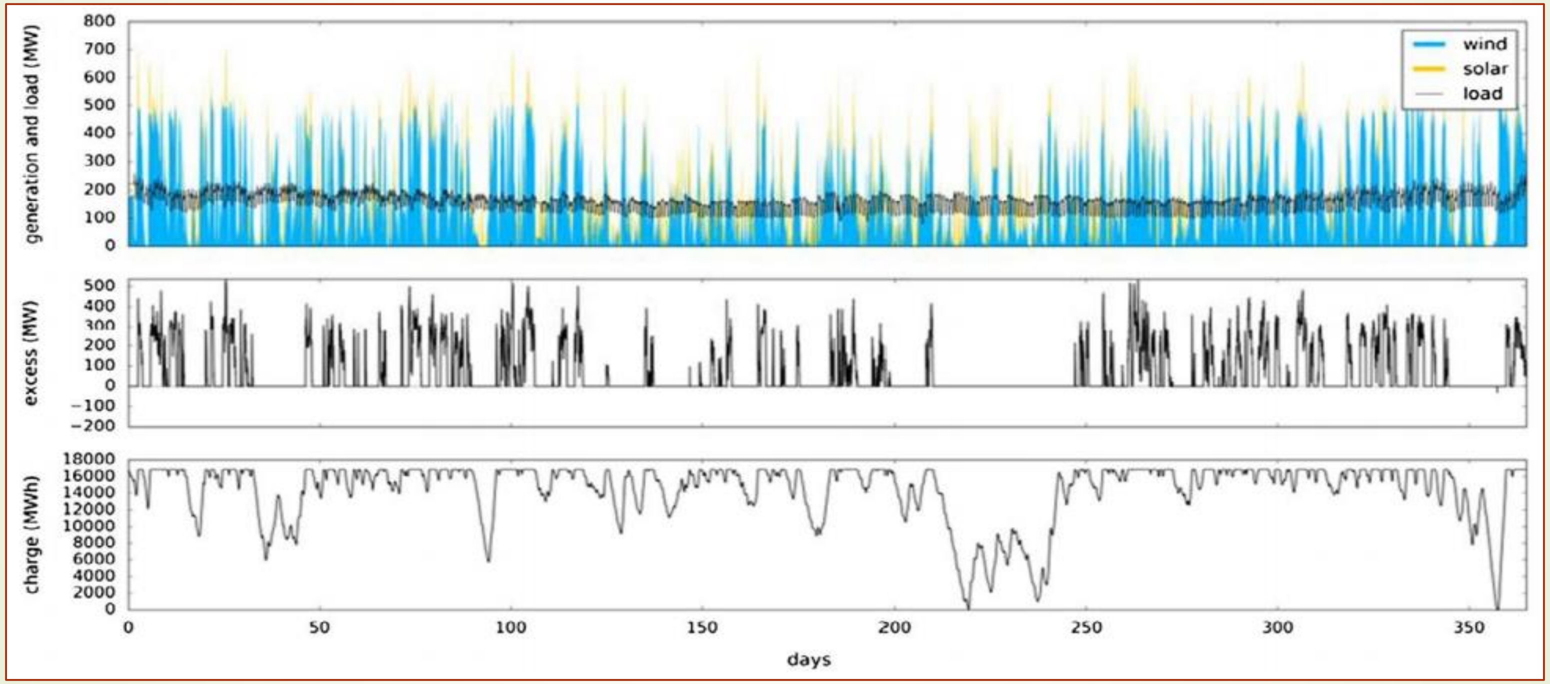
Prior Research Examined 100% Renewable Electricity on PEI for the Existing Electricity Sector



M. Hall and A. Swingler, "Initial Perspective on a 100% Renewable Electricity Supply for Prince Edward Island," *International Journal of Environmental Studies*, vol. 75, no. 1, pp. 135–153, 2018.

Main Research Objective

Extend existing energy modelling capabilities on Prince Edward Island to include electrification across other carbon-intensive sectors – namely transportation and heating

"Achieving decarbonisation of the Canadian economy will require a profound transformation … it is already clear that extended electrification of the economy will be at the core of this transformation." – Energy Modelling Initiative, 2019

Model Composition

In response to a void in modelling tools that can be applied to small-scale highly-renewable energy systems, that are open source, and that are easy to use, a new electricity system model has been created.

- ***Highly customizable and open-source model***
  - **Python backend** → allows customization by advanced users
  - **Excel frontend** → hides backend and is designed for anyone with basic spreadsheet proficiency and energy knowledge

Alignment with Open Data and Standard Data Sources

The open data sets include the following:

- Sub-hourly electricity load and wind data for PEI
- Environment and Climate Change Canada weather data
- Solar data accessible through the NREL System Advisor Model

Spreadsheet-Based User Interface
Model Overview

	A	B	C	D	E	F	G	H	I	J	K
1	**EMI-PEI Renewable Electricity System Model**										
2	This page gives an overview of the active model components.										
3											
4	CLICK TO RUN MODEL										
5											
6											
7	**Load**		**Generation**		**Storage**		**BEVs**		**Settings**		
8											
9	Main Load		Wind North Cape		Batteries				import energy cost	$/MWh	80
10	Heat Pump Heating		Wind Summerside		0				import capacity cost	$/MW	80,000
11	Domestic Hot Water		Wind East Point		0				GHGs of imports	kgCO2e/MWh	565
12	Commercial Hot Water		Wind Existing		0				export capacity	MW	560
13	Heat Pump Cooling		Solar								
14	BEVs 25000		0								
15	0		0								

Example

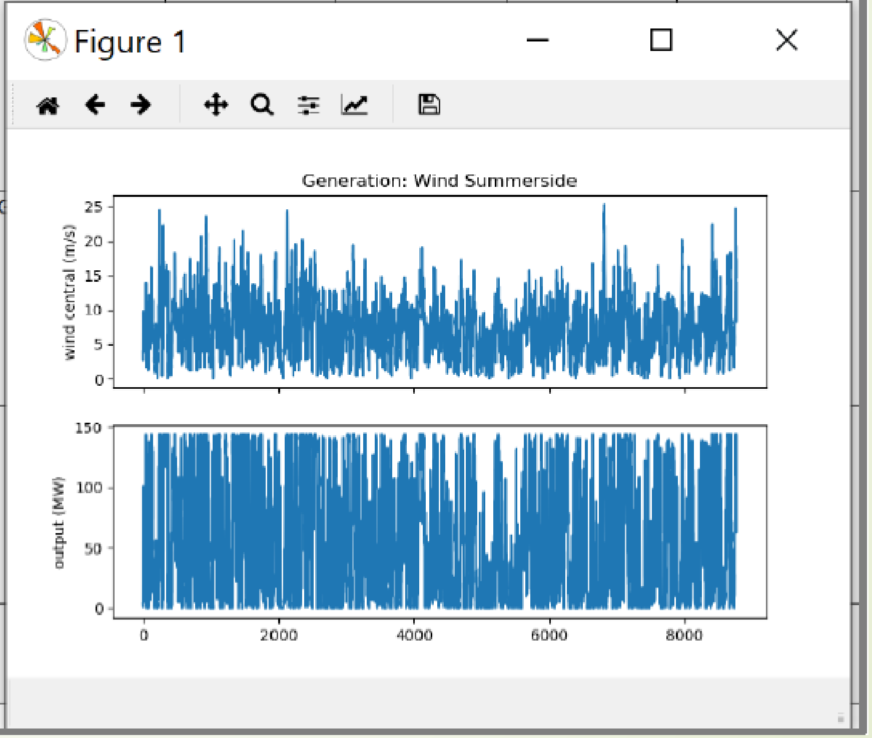
Loads Including Flexible Loads

	A	B	C	D	E	F	G	H
1	**Loads**							
2	List all fixed and flexible loads here.							
3			PREVIEW	PREVIEW	PREVIEW	PREVIEW	PREVIEW	PREVIEW
4	**Name**		Main Load	Heat Pump Heating	Heat Pump Cooling	Domestic Hot Water	Commercial Hot Water	BEVs 25000
5								
6	**Load time series**							
7	year long	select header	main load	HDH	CDH			BEVs 25000
8	week long	select header				Domestic Hot Wa	Commercial Hot Water	
9	day	select header						
10	week end day	select header						
11	seasonal adjustment							
12	seasonal scale	select header						
13	seasonal shift	select header						
14	**Conversion**							
15	performance curve	select header		ASHP Heating Mo	ASHP Cooling Mode COP Bins 21˚C Setpoint			
16	year long	select header		temperature	temperature			
17	week long	select header						
18	day	select header						
19	week end day	select header						
20	**Load shaping/scaling**							
21	energy	MWh						
22	peak power	MW		68.82	7.50			
23	**Demand response**							
24	flexload model	1 or 2	1	1	1	1	1	1
25	flexload fixed	MW	10					
26	flexload fraction	%		10%	10%			
27	fraction time series	select header						
28	***flexload model 1***							
29	nominal storage capaci	MWh				152	23.1	1500
30	max charge rate	MW				113.9	17.3	250
31	max discharge rate	MW				15.62	2.6	35.2
32	self discharge	%/hour				0.0%	0.0%	0.0%
33	charge efficiency	%				100%	100%	100%
34	discharge efficiency	%				100%	100%	100%
35	***flexload model 2***							
36	load shift type	0,1,2	0	0	1	1	1	
37	max time shift fwd	hr	4	2	2	4	4	
38	max time shift back	hr	4	2	2	4	4	

Example

Generation Sheet with Preview

	A	B	C	D	E	F	G	H	I
1	**Generation**								
2	List all sources of power here.								
3			PREVIEW	PREVIEW	PREVIEW	PREVIEW	PREVIEW	PREVIEW	PREVIEW
4	**Name**		**Wind North Cape**	**Wind Summerside**	**Wind East Point**	**Wind Existing**	**Solar**		
5									
6	**Input time series**								
7	year long	select header	wind west	wind central	wind east	wind existing	solar		
8	week long	select header							
9	day	select header							
10	week end day	select header							
11	seasonal adjustment								
12	seasonal scale	select header							
13	seasonal shift	select header							
14	**Power curve**								
15	performance curve	select header	G132-5MW Powe	G132-5MW Powe	G				
20	**Shaping/scaling**								
21	energy	MWh							
22	peak power	MW	150	150					
23	efficiency scaler	%	0.96	0.96					
24	**Financial**								
25	lifetime	years	25	25					
26	discount rate	(%/yr)	0.05	0.05					
27	CAPEX	$/W	1.59	1.59					
28	OPEX fixed	$/W/yr	0.021	0.021					
29	OPEX variable	$/Wh	0	0					
30	**GHGs**								
31	Up-front emissions	kg/W	1	1					
32	Fixed emissions	kg/W/yr	0	0					
33	Variable emissions	kg/Wh	0%	0%					
34									



Example

Storage Technologies

	A	B	C	D	E
1	**Storage**				
2	List all energy storage capacities that are not flexible loads here.				
3			PREVIEW	PREVIEW	PREVIEW
4	**Name**		**Batteries**		
5	energy capacity	MWh	800		
6	max charge rate	MW	200		
7	max discharge rate	MW	200		
8	self discharge	%/hour	0.01		
9	charge efficinecy		0.95		
10	discharge efficiency		0.95		
11	**Variability**				
12	variation time series	select header			
13					
16	**Financial**				
17	lifetime cycles		7500		
18	lifetime	years	25		
19	discount rate	(%/yr)	0.05		
20	CAPEX	$/Wh	0.23		
21	OPEX fixed	$/Wh/yr	0.015		
22	OPEX variable	$/Wh	0		
23	**GHGs**				
24	Up-front emissions	kg/Wh	0.65		
25	Fixed emissions	kg/Wh/yr	0		
26	Variable emissions	kg/Wh	0%		

Example

Electric Vehicles

	A	B	C	D	E
1	**BEVs**				
2	List all groups of BEVs that will be modelled based on distinct plug/unplug periods here. (Use multiple groups to separate very different use patterns, since the model is based on an average SOC within the group.)				
3			PREVIEW	PREVIEW	PREVIEW
4	name		Commuter group 1	Commuter group 2	Light Duty
5	total battery capacity	MWh	200	750	375
6	minimum state of charge	%	50%	30%	50%
7	max charge rate	MW	12	100	50
8	max discharge rate	MW	10	0	50
9	self discharge	%/hour	0	0	0
10	charge efficinecy	%	1	1	1
11	discharge efficiency	%	1	1	1
12	annual energy consumption	GWh	200		
13	seasonal variation timeseries	select header			
14	BEV model	1 or 2	2	1	1
15	**BEV Model 1 (ubiquitous chargers)**				
16	**usage TS (add to 1 over time period)**				
17	year long	select header			
18	week long	select header			
19	day	select header	BEV Category 3 - weekday		
20	week end day	select header			
21	unavailable fraction%	%	5%		
22					
23	**BEV Model 2 (limited chargers)**				
24	**plug/unplug time series**				
25	year long	select header			
26	week long	select header			
27	day	select header	BEV Category 1 - weekday	BEV Category 2 - weekday	BEV Category 3 - weekday
28	week end day	select header	BEV Category 1 - weekend day	BEV Category 2 - weekend day	BEV Category 3 - weekend day

Example

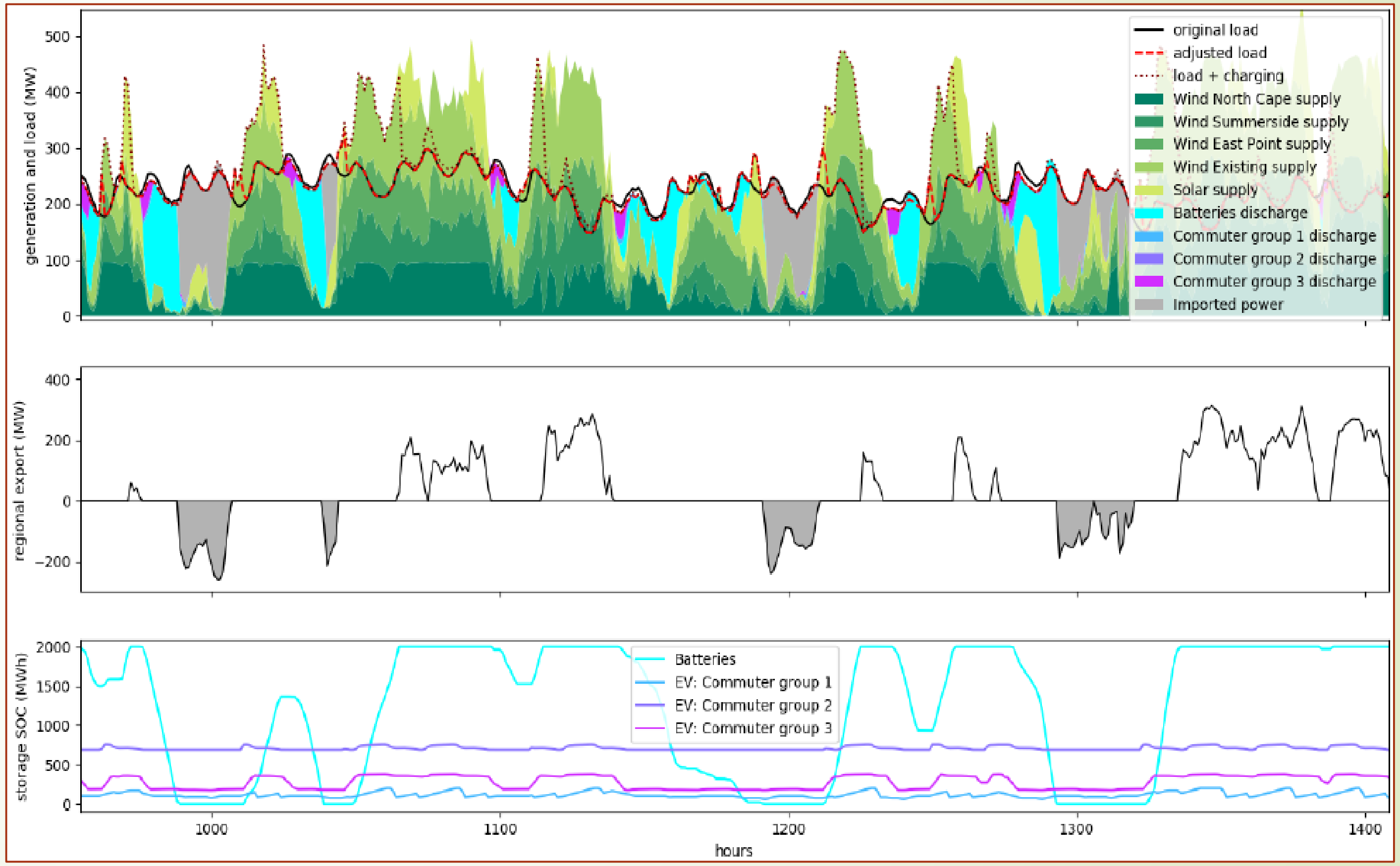
Python-Based Model Backend

- Object-oriented programming automatically processes various energy system elements specified in columns of spreadsheet interface
- A class exists for each system element type (load, generation, storage, and EV fleet) and an object is made for each element specified by the user
- Makes model operation modular and efficient to change
- Model behaviours can easily be modified, or a new component type could be added by following the structure of the existing spreadsheet pages and corresponding Python classes
- The code is relatively simple and navigable, making it well suited for expansion to suit others' needs
- Time-marching trial-and-error model with some characteristics of optimization in the handling of demand response

Model Outputs

Console Printout

- Wind North Cape - generation COE: 30 $/MWh
- Wind Summerside - generation COE: 42 $/MWh
- Wind East Point - generation COE: 33 $/MWh
- Wind Existing - generation COE: 62 $/MWh
- Solar - generation COE: 47 $/MWh
- Batteries - storage COE: 382 $/MWh
- ~~~~~~
- Total generation: 2003.2 GWh
- Total annual load: 1654.0 GWh
- Integrated generation: 1596.0 GWh, 79.7%
- Peak export (MW): 406.2 MW
- Peak import (MW): 266.7 MW
- Net import (GWh): -296.5 GWh
- Total (exports only): 407229.4 MWh
- Total (imports only): 110739.4 MWh
- Imports energy cost: $ 8.9M
- Imports capacity cost: $ 21.3M
- Elec. import GHGs: 33221.8 tCO2e
- Local renewable energy: 93.5%
- LCOE: 105.0 $/MWh
- Overall GHG intensity: 20.1 kgCO2e/MWh



Example

Model Demonstration on PEI Scenarios

Installed capacity and capacity factors in each scenario

		Scenario 0	Scenario 1	Scenario 2
Installed capacity (MW)	Wind	204	384	624
	Solar	0	225	550
	Import	232	267	311
Capacity factor	Wind	34.6%	38.7%	41.0%
	Solar	n/a	14.7%	14.7%
	Import	41.1%	13.4%	4.2%

- *Scenario 0: Baseline Case, 2016*
- *Scenario 1: Low Electrification Case, 2030*
- *Scenario 2: High Electrification Case, 2030*

Electrification amounts modelled for each scenario

	Scenario 1	Scenario 2
Electric cars, trucks and SUVs		
Number of BEVs	25,000	75,000
Typical km/year/vehicle	16,500	16,500
L gasoline avoided	41,250,000	123,750,000
tCO_2e avoided	94,463	283,388
Air-source heat pumps		
L oil avoided	45,000,000	90,000,000
tCO_2e avoided	123,075	246,150
Domestic hot water		
Number of hot water heaters	25,300	50,600
L oil avoided	12,250,000	24,500,000
tCO_2e avoided	33,504	67,008
Commercial hot water		
L oil avoided	1,950,000	3,900,000
tCO_2e avoided	5,333	10,667
Total GHGs avoided from displaced fuels listed above		
tCO_2e avoided	256,375	607,212

Please note – Numbers shown of domestic water heaters to be electrified in modelling includes wood and propane-based water heaters but their fuel/GHG quantities are small and excluded in the table. Heat pumps add some new cooling load, excluded from the table.

Energy and power storage capacities modelled

Types of Storage	Energy Capacity	Power Capacity
Scenario 1	MWh	MW
Batteries	500	125
BEVs	1500	250
Thermal	1006	222
Scenario 2	MWh	MW
Batteries	1000	250
BEVs	4500	750
Thermal	1931	383

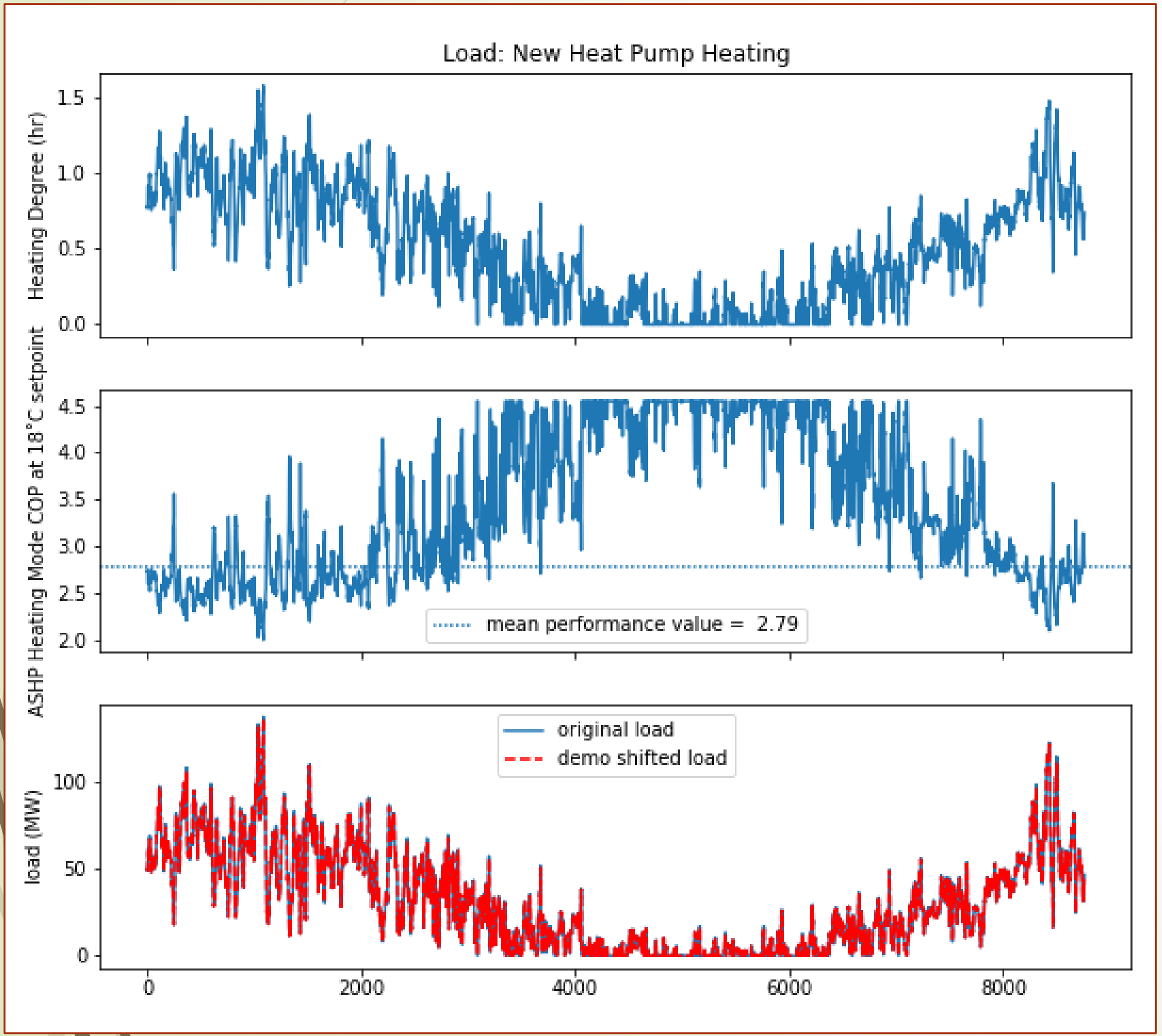
Financial parameters of selected energy and storage technologies

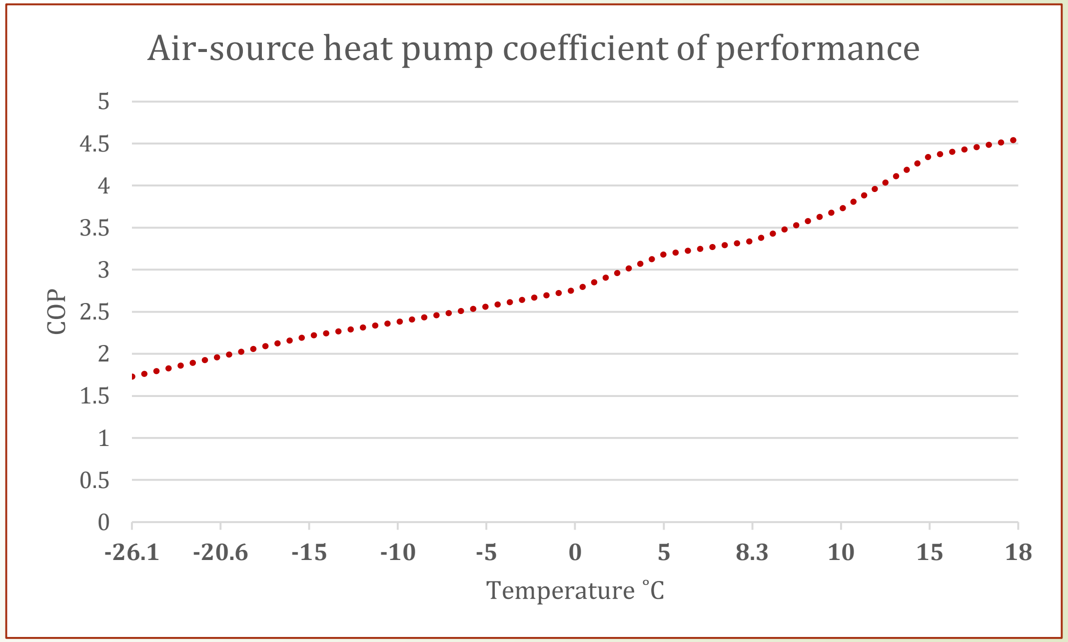
Technologies		Units	2025
Solar PV optimally tilted	Capex	$/kW	699
	Opex fixed	$/kW/yr	17.7
	Opex var	$/kWh/yr	0
	Lifetime	years	35
Wind onshore	Capex	$/kW	1590
	Opex fixed	$/kW/yr	21.0
	Opex var	$/kWh/yr	0
	Lifetime	years	25
Batteries	Capex	$/kWh	175
	Opex fixed	$/kW/yr	8.5
	Opex var	$/kWh/yr	0
	Lifetime	years	30
thermal energy storage	Capex	$/kWh	50
	Opex fixed	$/kW/yr	0.65
	Opex var	$/kWh/yr	0
	Lifetime	years	30

Import-export parameters

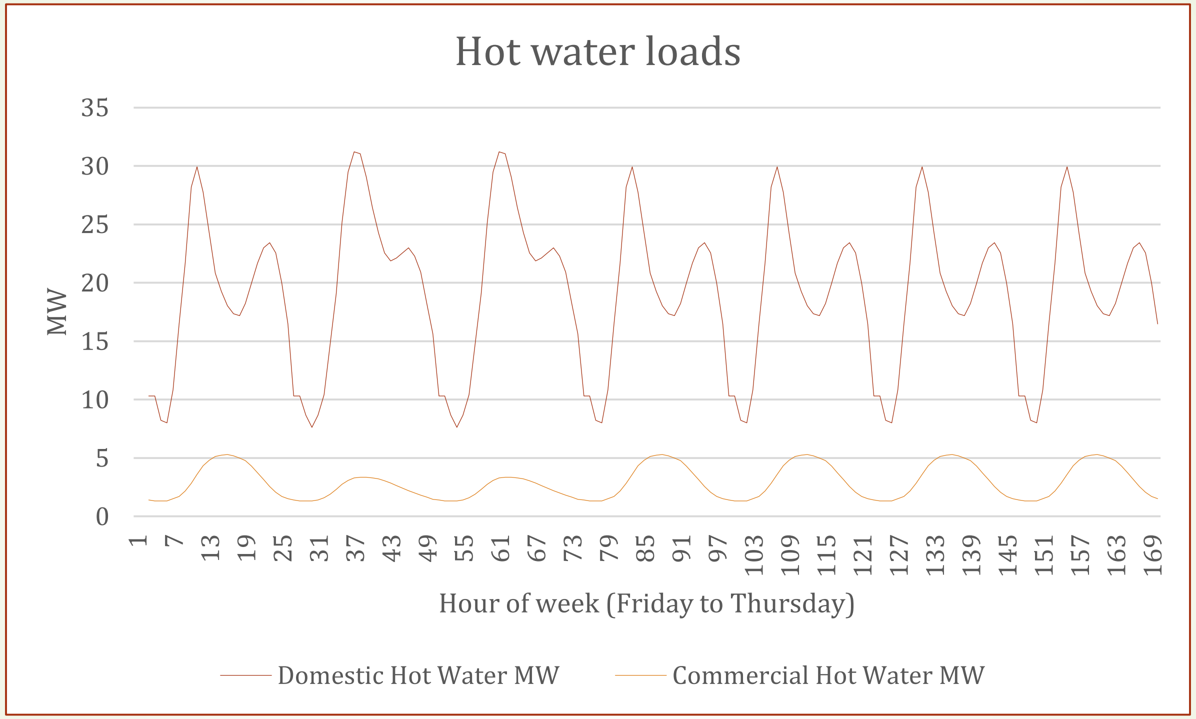
Cost of imports	80	\$/MWh
Capacity cost	80	\$/kW
GHGs of imports	300	kg CO_2e/MWh
Transmission capacity	560	MW export/import

Heat pump loads are modelled by applying temperature-dependent coefficient of performance to air-source heat pumps





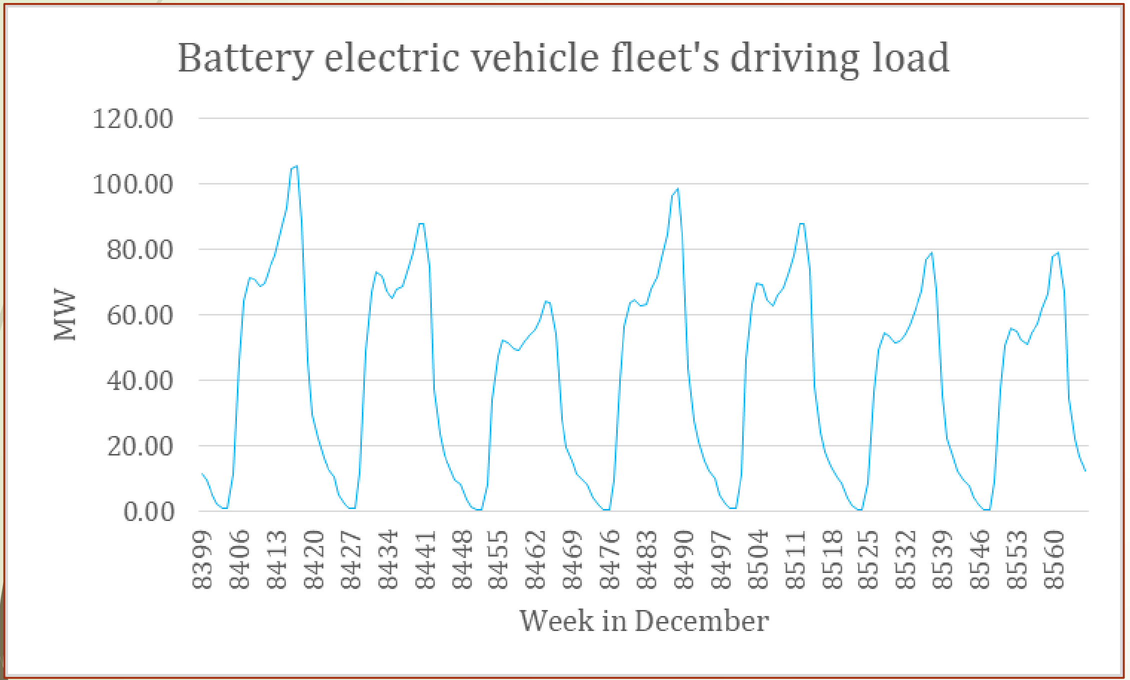
Sample of domestic and commercial hot water load profiles



Aggregate hot water loads have inherent thermal energy storage, thus are flexible and subject to demand response, but when hot water temperatures reach a minimum (e.g. – 110-120˚F) hot water loads become inflexible

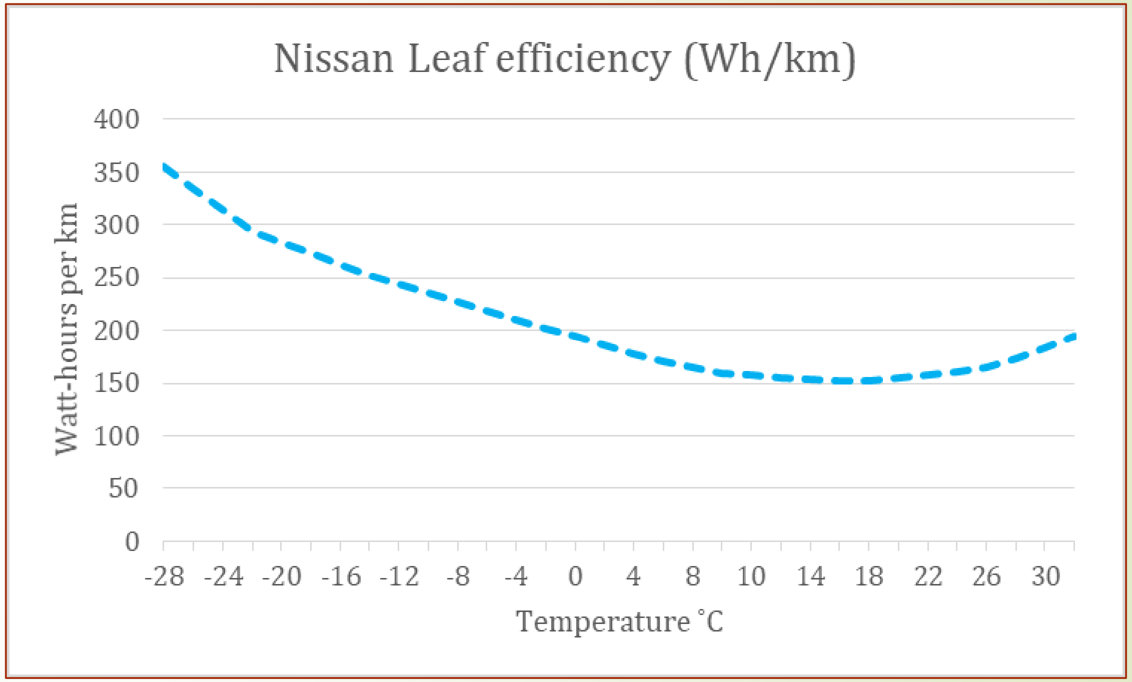
Electric vehicles are modelled using intraday and seasonal driving patterns, and by including an efficiency-based temperature dependence

EVs participate in smart charging without vehicle-to-grid (for now)



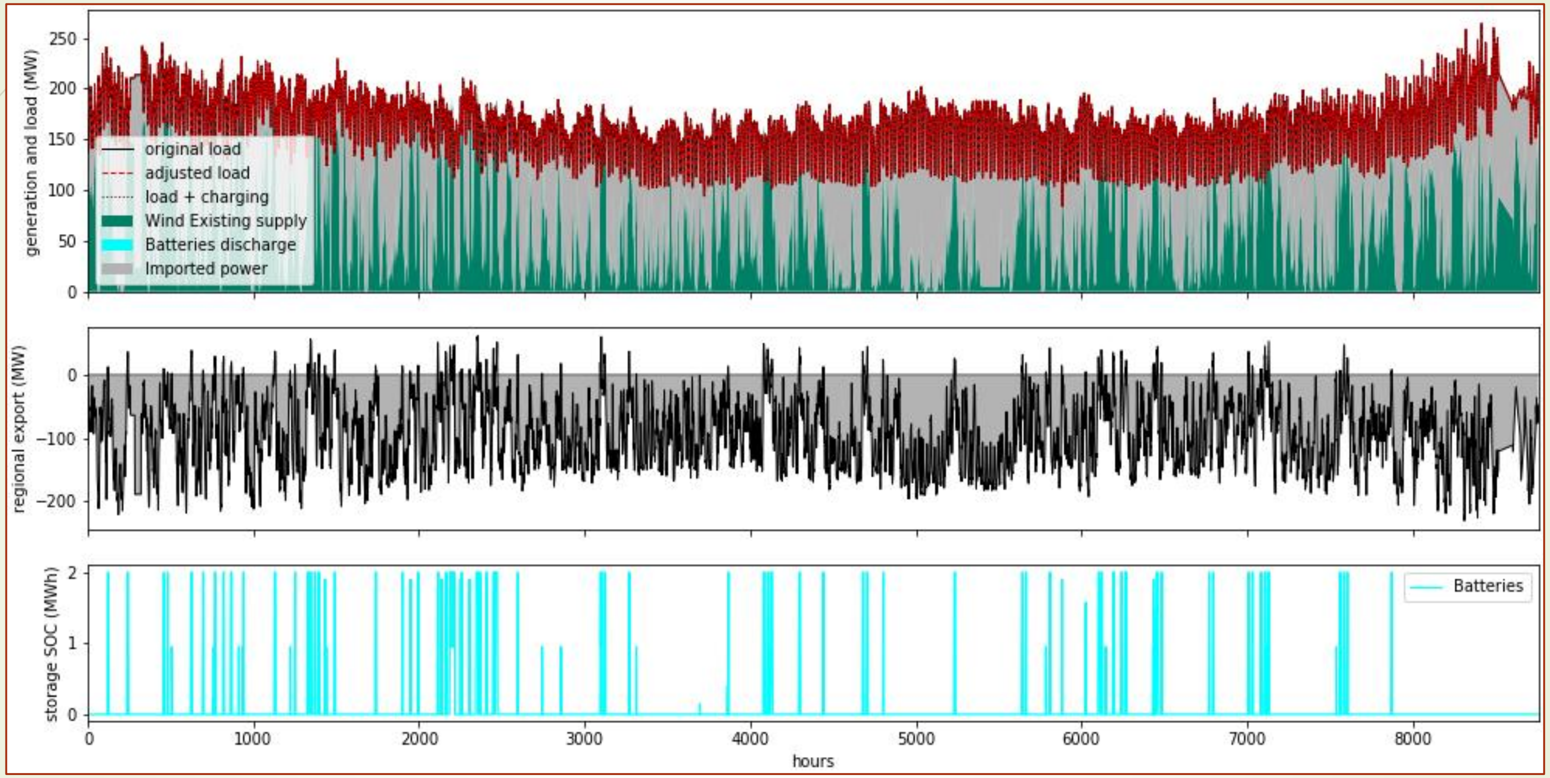
Sample BEV fleet load showing temperature dependence

Note – above is BEV power consumption while driving (unplugged)



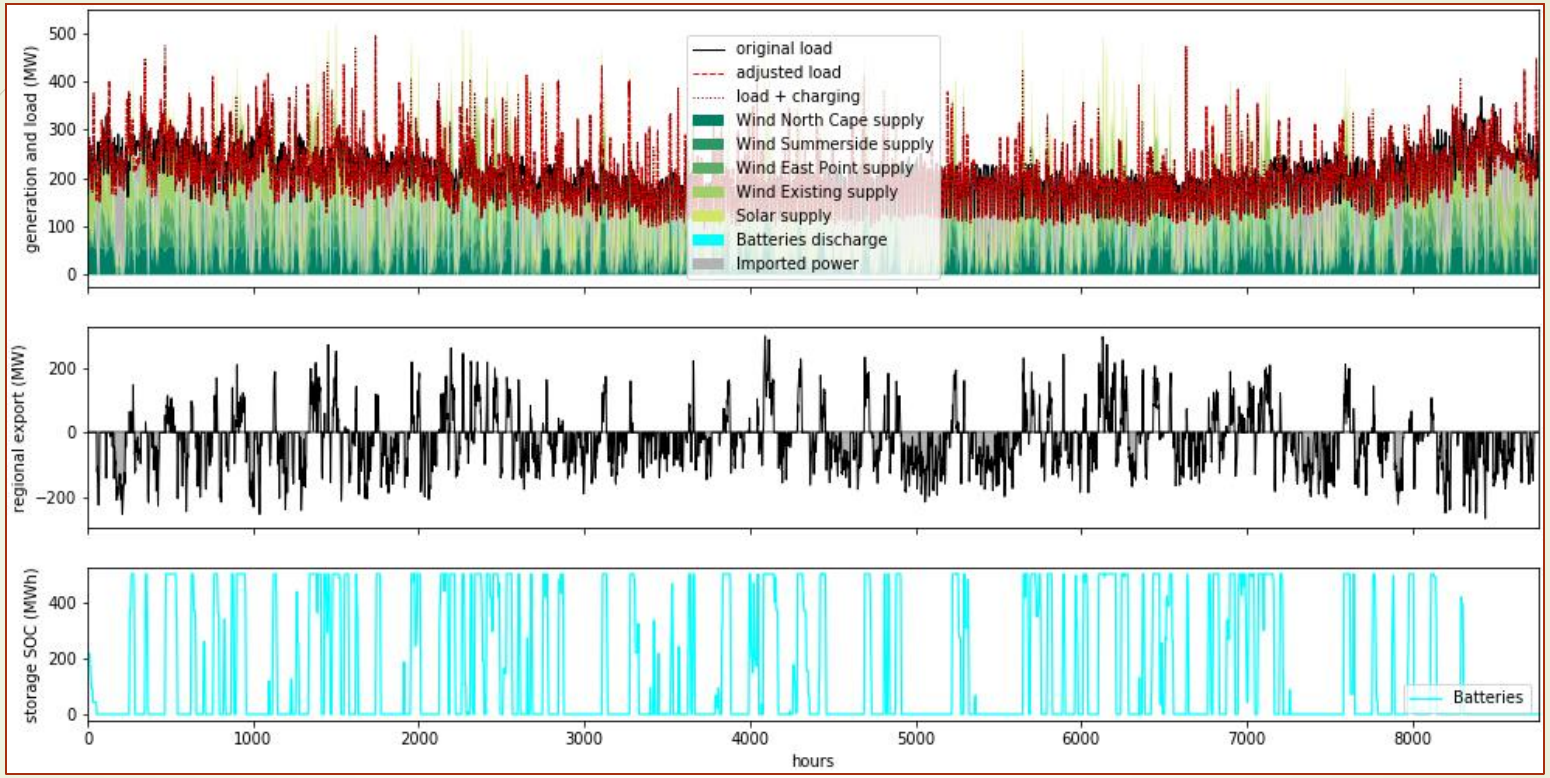
Nissan Leaf efficiency with temperature

Baseline Scenario - Results



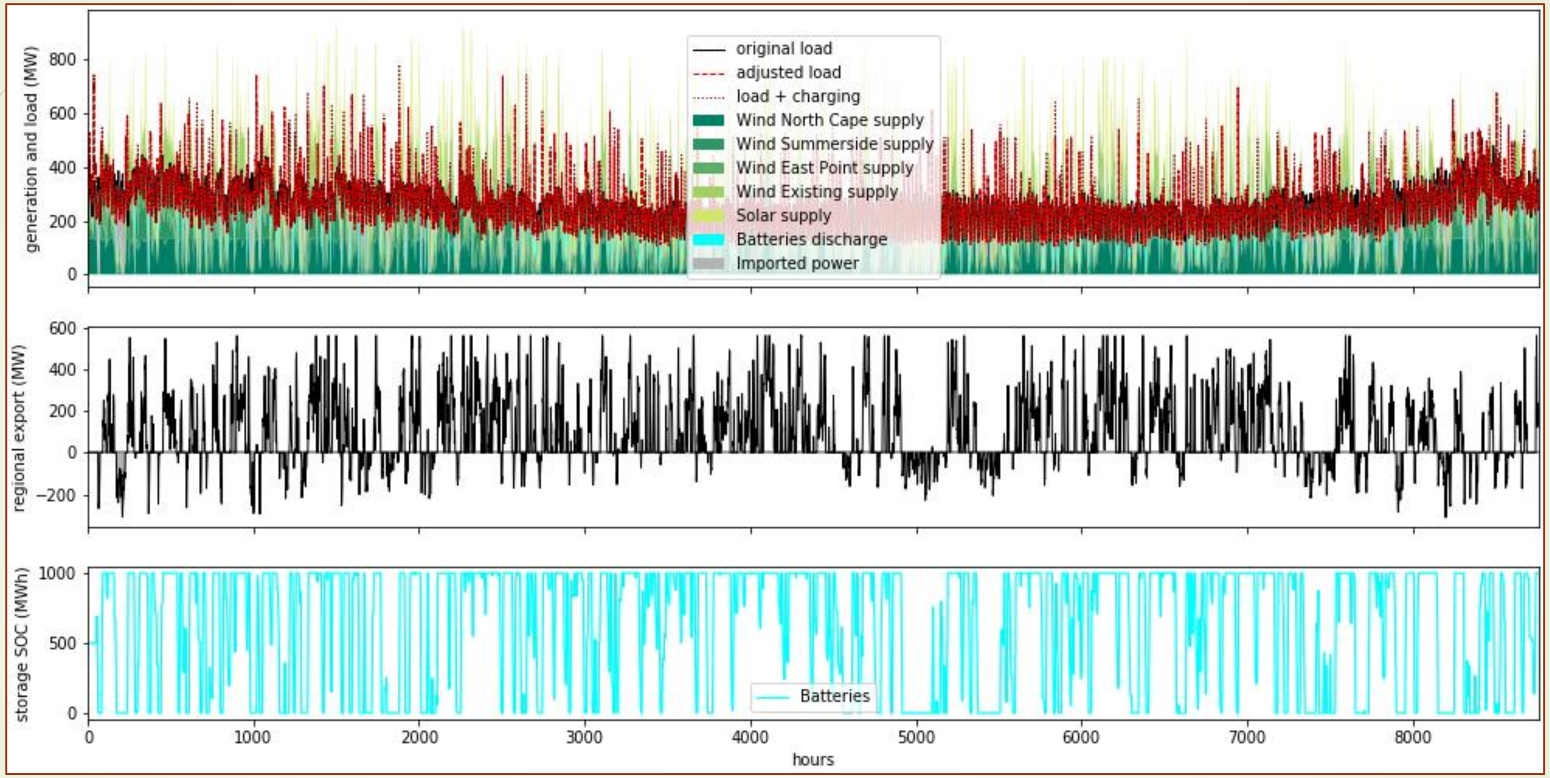
- Total annual load: 1420 GWh
- Local renewable energy: 41%
- Overall LCOE: 85 $/MWh (current CAD)
- Overall GHG intensity: 177 $kgCO_2e/MWh$

Moderate Scenario – 2030 Results



- Total annual load: 1753 GWh
- Local renewable energy: 82%
- Overall LCOE: 74 $/MWh (current CAD)
- Overall GHG intensity: 54 $kgCO_2e/MWh$

Ambitious Scenario – 2030 Results



- Total annual load: 2186 GWh
- Local renewable energy: 95%
- Overall LCOE: 81 $/MWh (current CAD)
- Overall GHG intensity: 16 kgCO_2e/MWh

End-use energy reductions due to electrification of transportation and heating

		Scenario 1	Scenario 2
Cars, trucks and SUVs to battery electric vehicles			
Displaced gasoline fuel use	MWh/yr	401,042	1,203,125
New electrified load	MWh/yr	100,260	300,781
Net energy use reduction	%	75.0%	75.0%
Oil space heating to air-source heat pumps			
Displaced light fuel oil use	MWh/yr	483,500	967,000
New electrified load	MWh/yr	134,504	269,007
Net energy use reduction	%	72.2%	72.2%
Oil domestic hot water to joule heat			
Displaced light fuel oil use	MWh/yr	131,619	263,239
New electrified load	MWh/yr	80,434	160,868
Net energy use reduction	%	38.9%	38.9%
Oil commercial hot water to joule heat			
Displaced light fuel oil use	MWh/yr	20,952	41,903
New electrified load	MWh/yr	12,804	25,608
Net energy use reduction	%	38.9%	38.9%
Total energy reductions due to modelled electrification of transportation and heating			
Displaced gasoline and oil use	MWh/yr	1,037,113	2,475,267
New electrified load	MWh/yr	328,002	756,264
Net energy end-use reduction	MWh/yr	709,111	1,719,003
Reduction in electrified end-use	%	68.4%	69.4%

GHG Emissions

- **2016 GHG emissions in PEI's inventory totaled 1,830,000 tCO_2e** of which energy accounted for 1,310,000 tCO_2e [1]
- **Scenario 1 reduces annual GHG emissions to ~1,574,000 tCO_2e**

  Decrease of ~256,000 tCO_2e in PEI's GHG inventory
- **Scenario 2 reduces annual GHG emissions to ~1,223,000 tCO_2e (~1.2 MT CO_2e)**

  Decrease of ~607,000 tCO_2e in PEI's GHG inventory (meets PEI's latest 2030 target)
- Additionally, modelled import electricity GHGs [2] are reduced
  - 251,135 tCO_2e in baseline year
  - 94,946 tCO_2e with moderate electrification and RE scale-up

    Decrease of ~156,000 tCO_2e in import electricity GHGs relative to baseline year
  - 34,739 tCO_2e with ambitious electrification and RE scale-up

    Decrease of ~216,000 tCO_2e in import electricity GHGs relative to baseline year

[1] Environment and Climate Change Canada, National Inventory Report 1990–2017: Greenhouse Gas Sources and Sinks in Canada, 2019.
[2] Import electricity GHGs are excluded in PEI's GHG inventory. See methodology in reference 1. Although, these GHG reductions are relevant in the regional, Canadian, and global contexts.

Value to Informing Policy

Modelling can inform energy policy and emission reduction strategy decisions. In 2019 the Legislative Assembly of PEI adopted a new target to reduce GHGs to 1.2 MT CO_2e in 2030. This will be challenging as PEI's population is expected to grow from 147,000 in 2016 to 181,000 in 2030.

This new model allows exploration of various policy-relevant considerations:

- The electrification of carbon-intensive transportation and heating sectors
- The effects of both population growth and energy conservation measures beyond electrification;
- the use of vehicle-to-grid technology to leverage EV-based energy storage;
- distributed thermal energy storage for heating and cooling;
- centralized large-scale thermal energy storage systems; and
- electrification of additional sectors (e.g. manufacturing, agriculture, fishing).

High-level metrics provided by the model, such as energy costs and GHG emissions changes, can be useful to policymaking in areas of both general sizing of energy system components, and examining trade-offs and cost-benefit comparison of energy transition alternatives.

Conclusions

- Model is demonstrated on three scenarios based in PEI, illustrating data sources available and how they can be used to evaluate energy alternatives
- Low electrification case: clear quantification shows that a lot will be needed to reduce energy-related emissions in line with the province's stated targets
- High electrification case (rapid electrification of transportation and heating): overall energy costs may be slightly lower while benefits of climate and health damage costs avoidance will be significant
- Results suggest costs do not change significantly with high renewables and electrification
- These results should be verified in terms of both the model's calculations, and the assumptions and inputs used in formulating the scenarios

The open-source model should provide a new level of accessibility for engaging with energy system alternatives while maintaining the rigour necessary to give trustworthy and informative results

Thank you!

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