Electrical Energy Needs for Canadian Remote Communities

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Acknowledgements

Outline

- Motivation
- Canadian remote community (RC) survey:
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  - Scope
  - Results
- Kasabonika Lake First Nation (KLFN) community microgrid:
  - Overview
  - Data collection campaign
- Optimal planning:
  - Overview
  - Planning model
  - Examples
- Conclusions

Motivation

- Many communities in Canada and remote communities in the rest of the world (e.g. India, Chile) are not connected to the grid and depend on local microgrids for their electrical energy supply.
- The dominant source of electrical energy for these communities is through diesel gen. sets:
  - Diesel fuel must be supplied to these communities.
  - All of the community supply comes from brief winter road access or by air, as many remote communities have no road access.

Motivation

- There is a need for:
  - Clean, reliable renewable electricity in Canadian remote communities and in other parts of the world.
  - Reduce energy costs and cost uncertainty (fuel and transportation), as energy costs in remote Canadian communities can be many times greater than at grid connected communities.
  - Reduce potential damage to the environment from fuel transportation and emissions (gases and other emissions).

RC Survey Objectives

- Obtain a representative sample of Canada's Remote Communities (RCs) microgrids' status, including solar and wind energy resources.
- Collect economic, technical and social data relevant to Renewable Energy (RE) in RCs.
- Create a database with the information collected.
- Generate data to inform other research projects.

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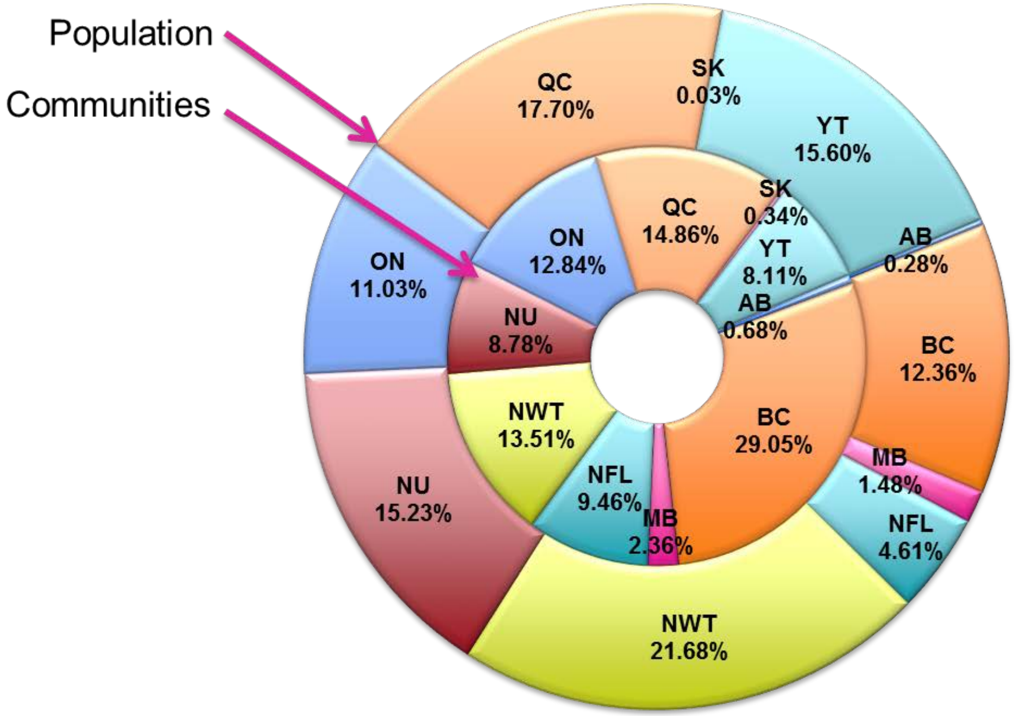
RC Survey Scope

- Sample off-grid communities in all provinces and territories in Canada.
- Covers communities operated by provincial and independent utilities.
- RE resource data limited to wind and solar.

RC Survey Results

- M. Arriaga, C. A. Cañizares, and M. Kazerani, “Northern Lights,” *IEEE Power and Energy Magazine*, invited paper, vol. 12, no. 4, July-August 2014, pp. 50-59.
- Community and population distribution:



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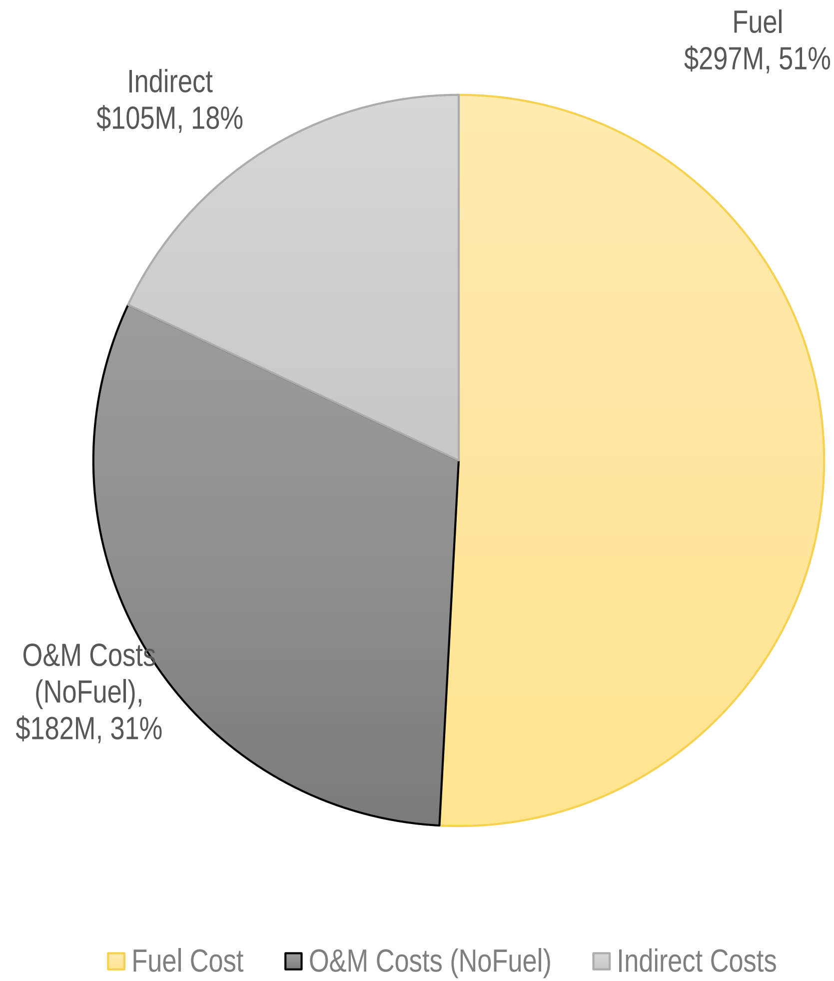
RC Survey Results

- Fuel consumption: 129 million lt./year
- CO_2 emissions: 368,000 ton/year
- Total cost: $583M/year
- Energy: 459 TWh/year
- Avg. LUEC: $1.2/kWh
- Subsidies: Provincial and federal.
- Operation/owner: Provincial utilities, community utilities.



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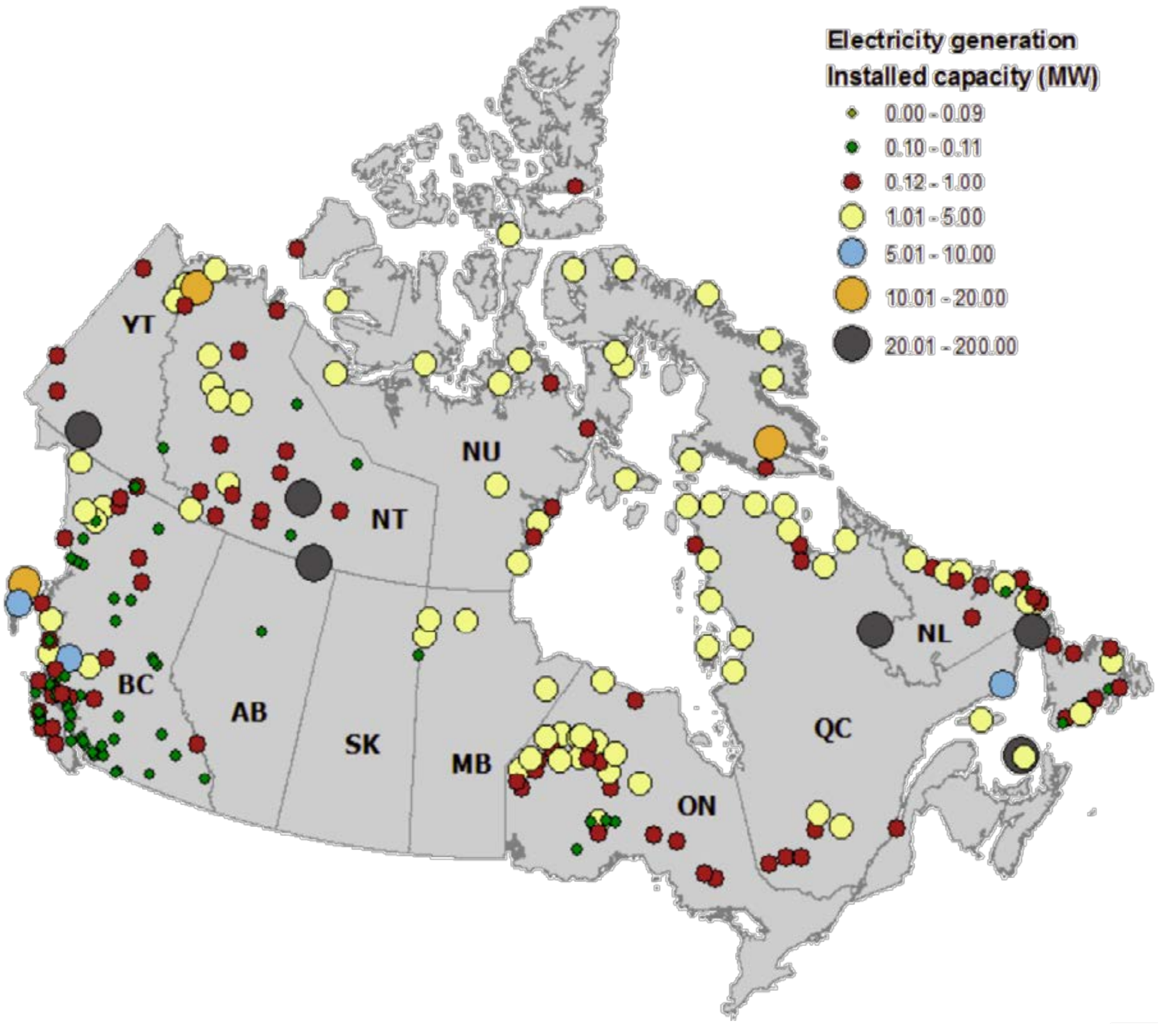
RC Survey Results

- Grid:
  - The most encountered distribution level has been 25kV.
  - Technical and non-technical losses: 1.3% - 9%.
  - Power factor > 0.90.
- Generation:
  - Most locations run on diesel engines and a few sites have micro-hydro units.
  - Typically 3-4 engines installed on each site.
  - 176 diesel engines adding up to 146MW installed capacity.
  - 70% of diesel generators are Caterpillar.
  - Diesel engines sizes: 60kW – 5.1MW.
  - Generation voltage: 600V – 6.9kV.
  - Net heat rate: 3.2 – 3.8L/kWh.

RC Survey Results

- Electricity economics:
  - Cost: \$0.08/kWh - \$0.89/kWh.
  - Electricity rates:
    - Residential energy rates: \$0.03/kWh - \$0.12/kWh.
    - Government energy rates: \$0.13/kWh - \$2.34/kWh.
  - The rates in all surveyed provinces increase by blocks to discourage heating loads.
- Subsidies:
  - Most provinces give a subsidy to set the residential rate equal to the on-grid equivalent rate.
  - Typically government customers pay the full cost of energy, in some cases even more.

RC Survey Results



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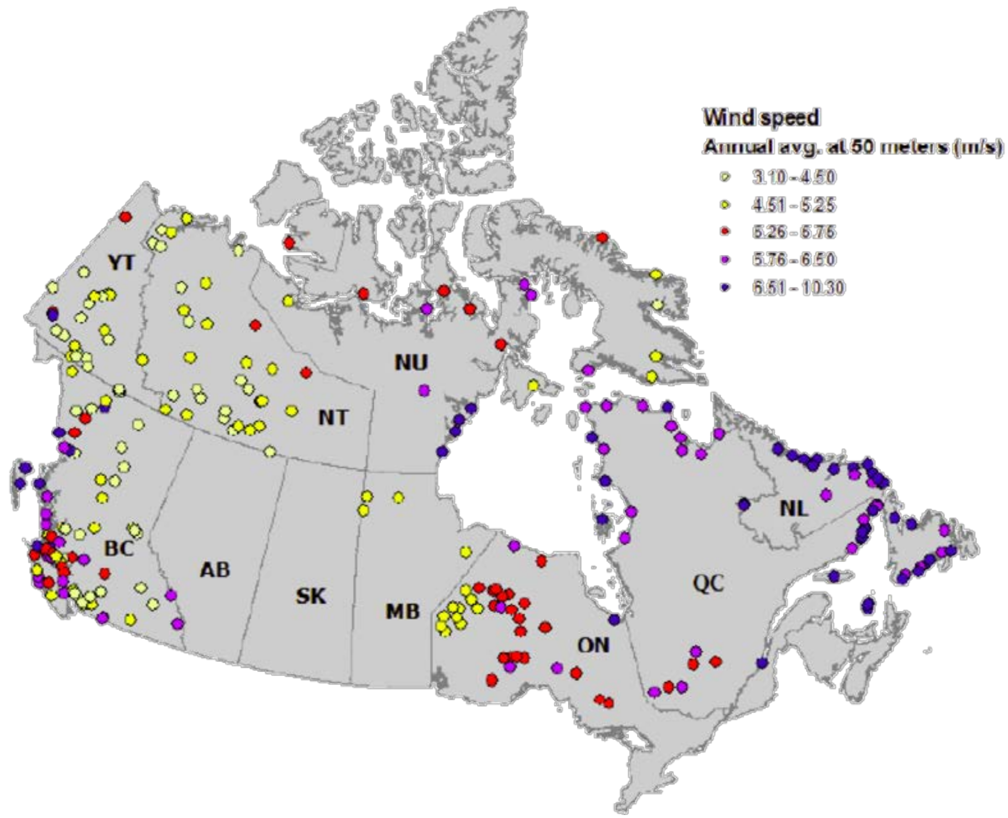
RC Survey Results

- Wind resources:
  - Potential sites can achieve 20%-35% capacity factor.
  - Difficult to set a fixed federal incentive; a provincial approach is required.
  - Small wind relies on local wind currents difficult to capture in mesoscale models.



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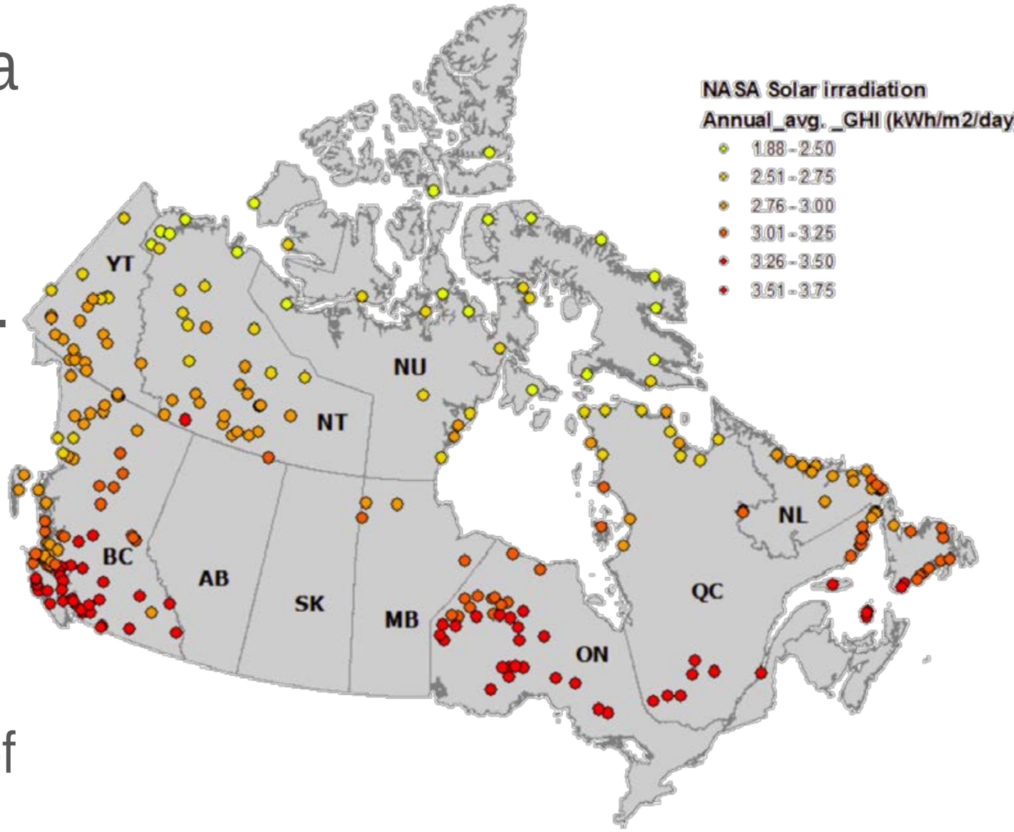
RC Survey Results

- Solar resources:
  - Potential sites can achieve a capacity factor of 8-10%.
  - Even distribution of solar resource across the country.
  - Comparison with wind resource:
    - Simpler installation and maintenance in remote communities.
    - Higher prediction accuracy of expected energy.



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KLFN Microgrid Data Collection

Kasabonika Lake

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KLFN Microgrid Data Collection

- Kasabonika Lake First Nation:
  - Community:
    - 914 people.
    - 500 km north of Thunder Bay.
    - Winter-road access.
  - Electricity generation:
    - 0.4 MW, 0.6MW, and 1 MW diesel generator in operation.
    - 1.5 MW diesel generator replacing 0.4 MW generator is being installed.
    - 3x10 kW Bergey WTs.
    - 1x30 kW Wenvor WT.
    - 10 kW solar PV array.

KLFN Microgrid Data Collection

Local grid dataloggers:

1. Diesel generator plant.
2. 3x Bergey WTs.
3. Store.
4. Water treatment plant.

Dent meters:

5. Sewage plant.
6. School.
7. Police station.
8. Nursing station.
9. Wenvor WT.

Laptop dataloggers:

10. 13 Houses across the community.

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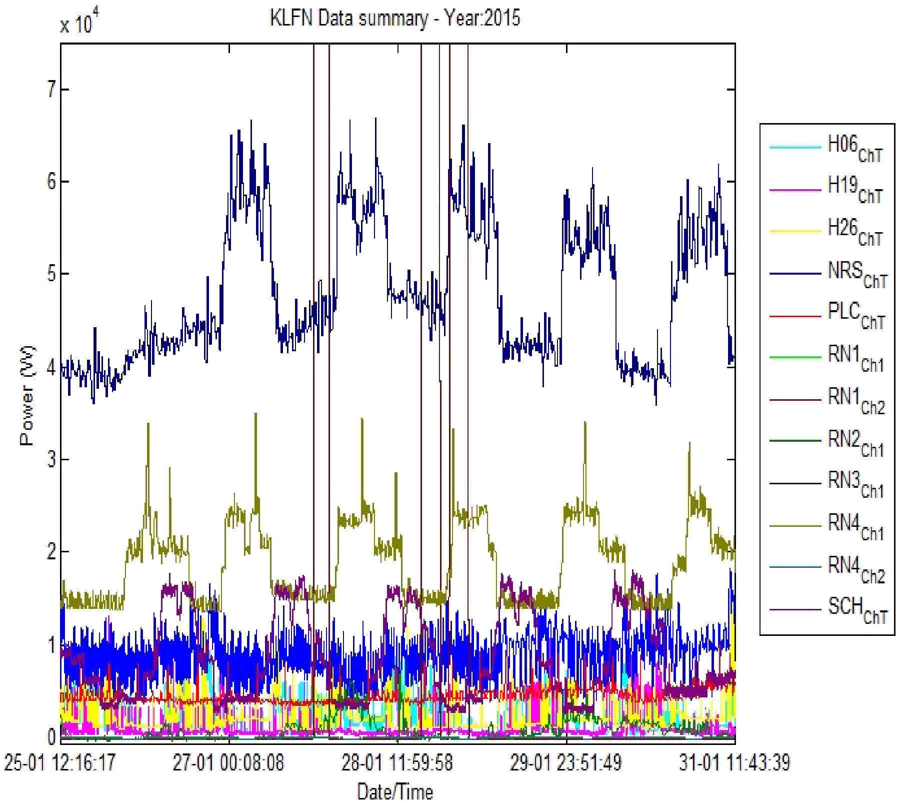
KLFN Microgrid Data Collection

- Data summary:
  - Dataloggers collected information for approximately one year.
  - Some information missing but a representative sample for all locations has been collected.



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KLFN Microgrid Data Collection

- Observations:
  - Current imbalances:
    - Significant (up to 100% on average), particularly in the summer.
    - Seasonal changes do not allow to change transformer connections at generation plant to correct them.
  - Voltage profiles:
    - Flat: 3-phase averages of 600.5 V at the gen. plant and 117.3 V (586.6 V) at the water treatment plant at the end of the feeder, i.e. ~2 % drop.
  - Frequency:
    - Small variations: in a 59.95-60.15 Hz range practically all the time.
    - Renewable sources' impact is small, given the relatively low capacity penetration level of 7% at peak load (70/1000 kW).

Optimal Planning

- M. Arriaga (Student), C. A. Cañizares, and M. Kazerani, “Long-Term Renewable Energy Planning Model for Remote Communities,” *IEEE Transactions on Sustainable Energy*, vol. 7, no. 1, January 2016, pp. 221-231.
- M. Arriaga (Student), C. A. Cañizares, and M. Kazerani, “Renewable Energy Alternatives for Remote Communities in Northern Ontario, Canada,” *IEEE Transactions on Sustainable Energy*, vol. 4, no. 3, July 2013, pp. 661-670.
- Determine best microgrid design technically and economically considering:
  - Local resources.
  - Type of equipment.
  - Sizes.
  - Costs: purchase, installation, operation and maintenance.
  - Social and community issues.

Optimal Planning

- Feasibility of installing RE capacity:
  - Decide most appropriate location(s).
    - Start with the location(s) with high wind/solar energy resources (high capacity factors).
    - Move then to sites with “less” RE resources.
  - Optimize for overall project and O&M costs.
  - Constraints:
    - Sites with capacity factor above certain level.
    - Maximum allowed RE penetration level.

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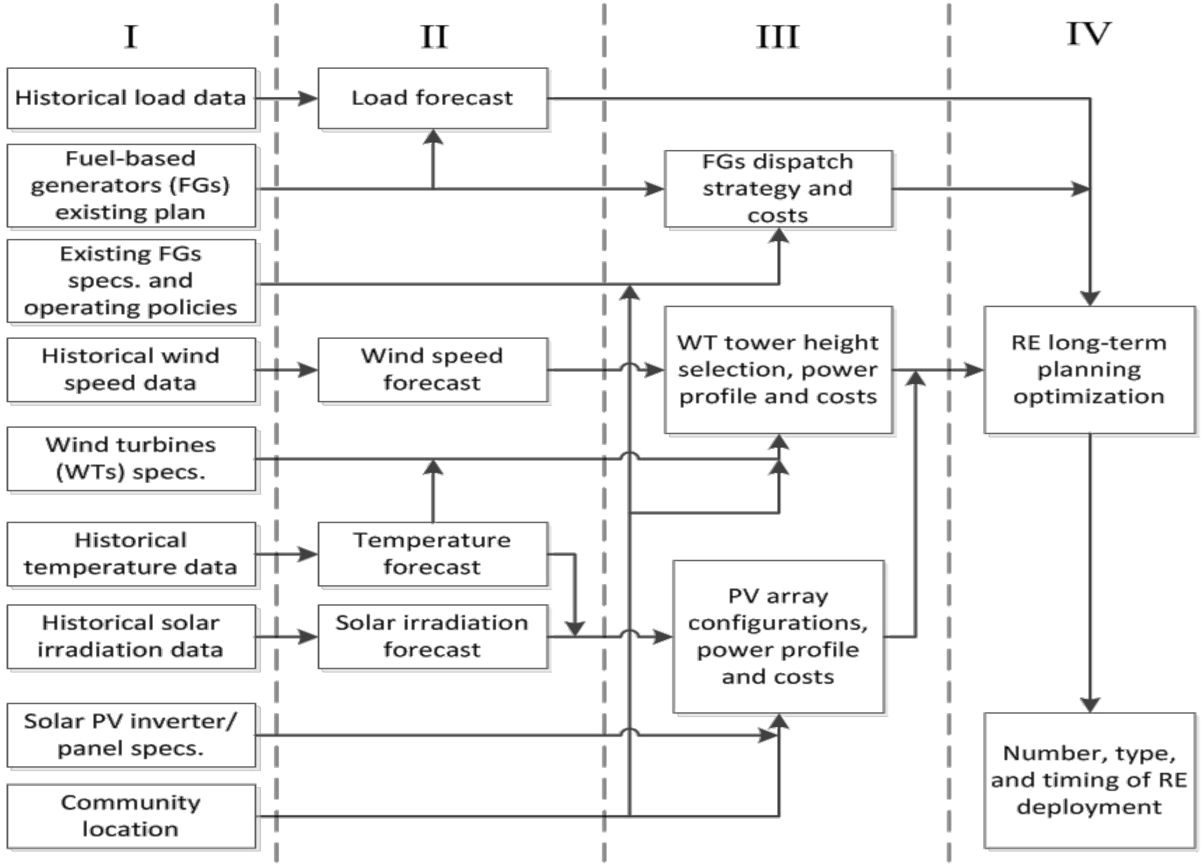
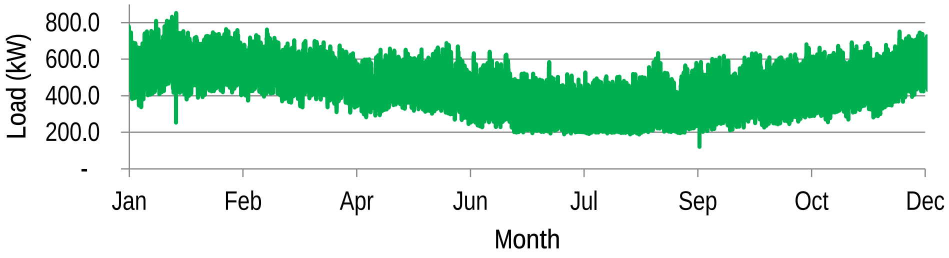
Optimal Planning

- Long-term renewable energy planning:

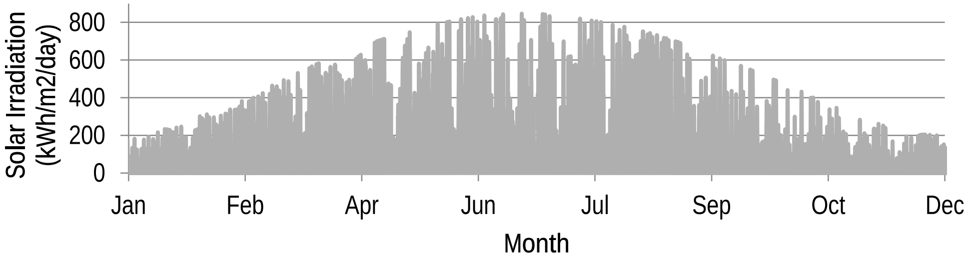


Optimal Planning Example

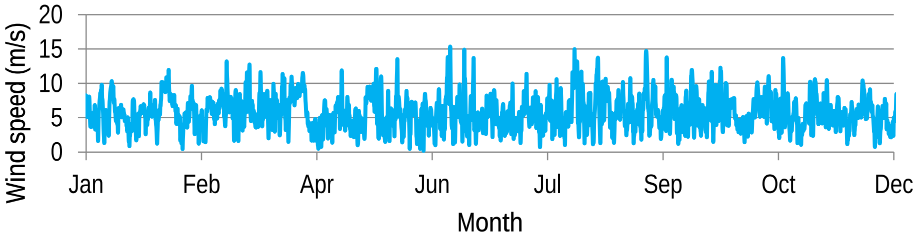
- KLFN electric energy demand:



- Solar resources:



- Wind resources:



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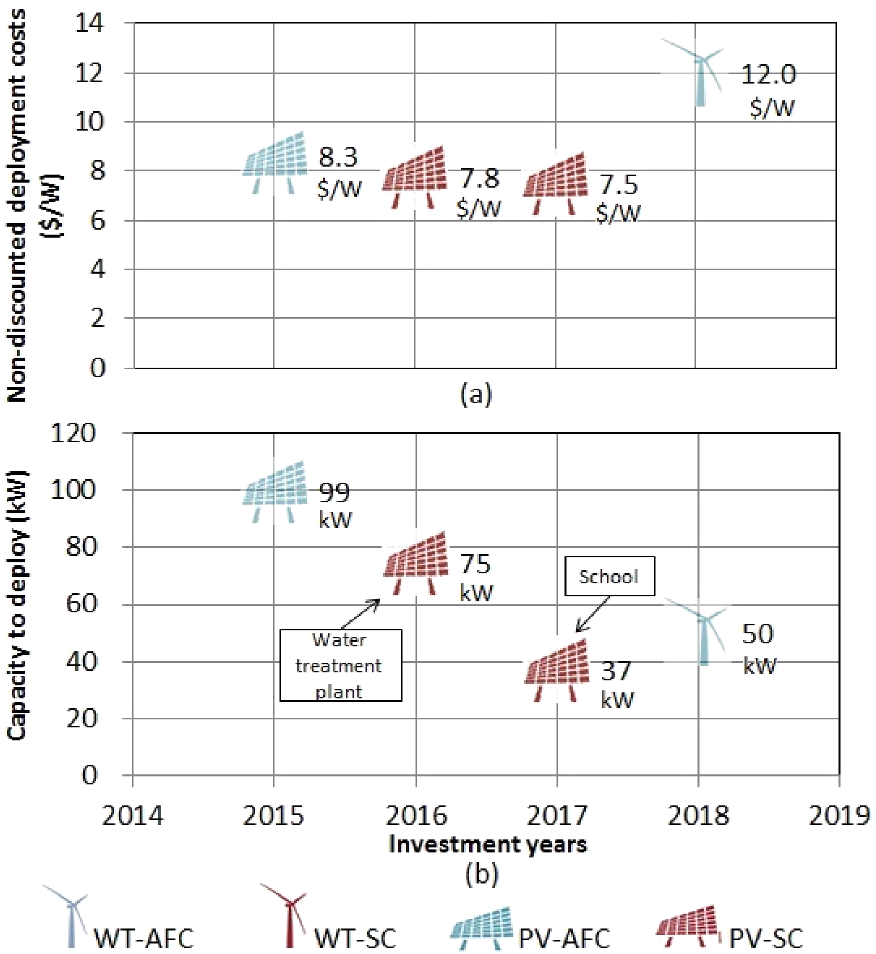
Optimal Planning Example

- Results:
  - RE equipment type and capacity.
  - RE operation schemes.
  - RE installation time-frame.
  - RE Location for selected customers.



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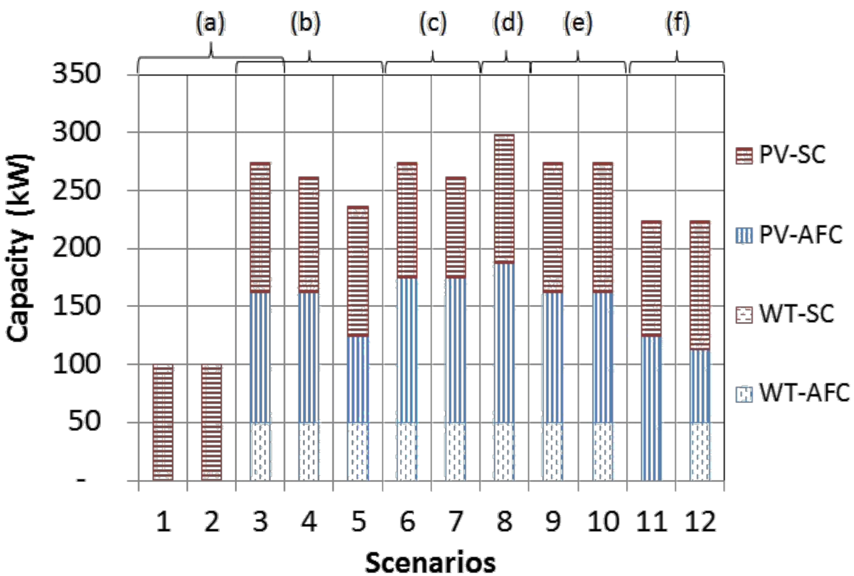
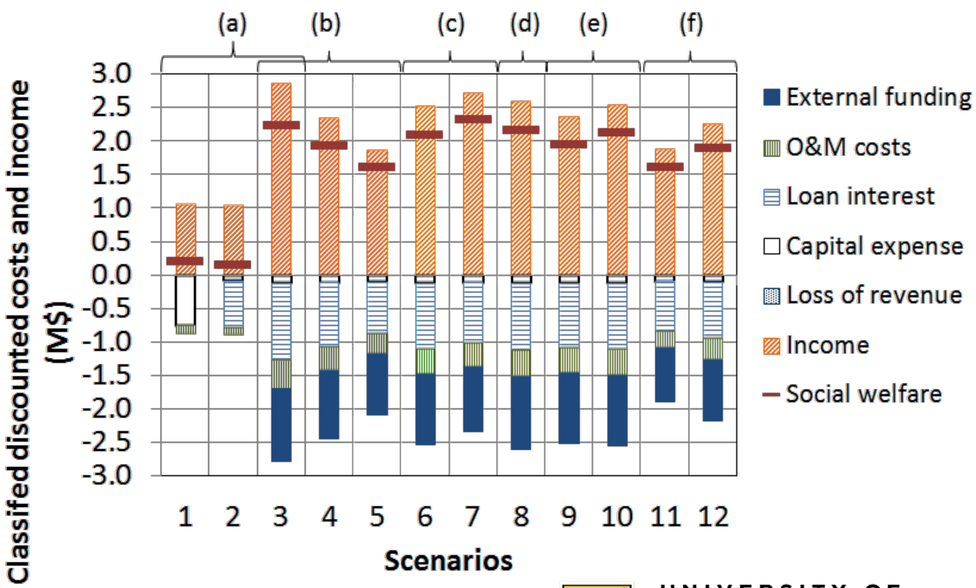
Optimal Planning Example

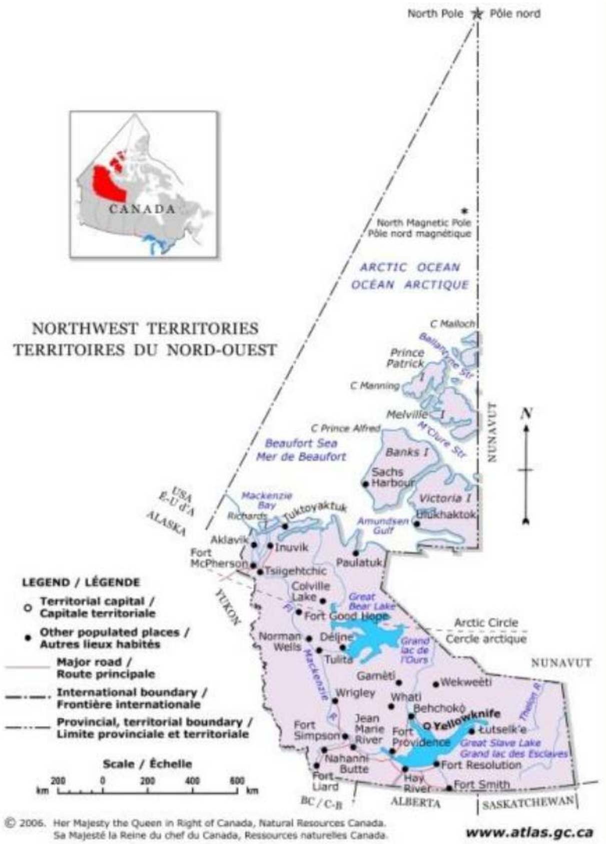
- Scenarios:
  - 1 – 3: With/without external funding, and bank loan alternatives.
  - 3 – 5: 4%, 6%, and 8% discount rates.
  - 6 – 7: 5% and 7% fuel cost annual growth.
  - 8: No RE installed capacity limit.
  - 9 – 10: ±6% solar irradiation.
  - 11 – 12: ±10% wind speed variation.

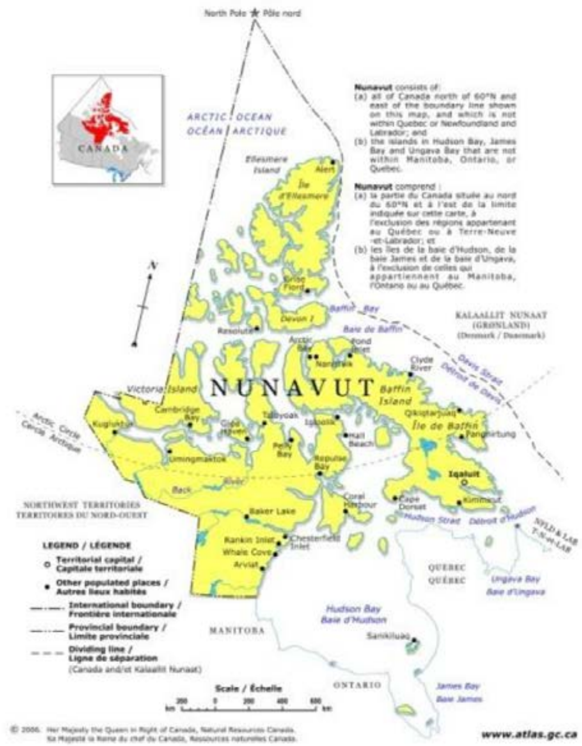




Optimal Planning Example

- Determine optimal RE penetration in Nunavut and NWT community microgrids:





Optimal Planning Example

- Nunavut pre-selection: I. Das and C. A. Cañizares, “Renewable Energy Deployment in Canadian Arctic-Phase I: Prefeasibility Studies and Community Engagement Report for Nunavut,” WWF Contract, WISE, University of Waterloo, June 2016, 68 pages (http://www.ctvnews.ca/sci-tech/study-suggests-wind-solar-power-options-in-arctic-1.2925208)

COMMUNITIES	OVERALL RANK	WIND SPEED	SOLAR ENERGY	Tr. COST SEA	Tr. COST AIR	COMM. SIZE	ENERGY DEMAND	GHG EMISSION	ELECTR. RATE	REGION
Rankin Inlet	1	H	H	ML	L	H	H	ML	L	Kivalliq
Iqaluit	2	MH	MH	L	ML	H	H	MH	L	Qikiqtaaluk
Arviat	3	H	H	ML	L	H	ML	ML	ML	Kivalliq
Cape Dorset	4	H	MH	L	L	H	ML	ML	L	Qikiqtaaluk
Baker Lake	5	H	H	ML	L	H	ML	L	L	Kivalliq
Repulse Bay	6	H	MH	ML	L	H	ML	L	ML	Kivalliq
Sanikiluaq	7	H	H	ML	L	MH	ML	L	ML	Qikiqtaaluk
Chesterfield Inlet	8	H	H	ML	L	L	MH	ML	MH	Kivalliq
Coral Harbour	9	MH	H	ML	L	MH	ML	L	MH	Kivalliq
Whale Cove	10	H	H	ML	L	L	ML	ML	H	Kivalliq
Pangnirtung	11	MH	MH	L	ML	H	ML	L	L	Qikiqtaaluk
Igloolik	12	H	MH	ML	H	H	ML	MH	L	Qikiqtaaluk
Qikiqtarjuaq	13	H	MH	MH	ML	ML	MH	ML	ML	Qikiqtaaluk
Hall Beach	14	H	MH	ML	H	MH	ML	L	MH	Qikiqtaaluk
Clyde River	15	H	ML	MH	H	H	ML	ML	ML	Qikiqtaaluk
Cambridge Bay	16	H	ML	H	H	H	MH	ML	ML	Kitikmeot
Kugaaruk	17	H	MH	MH	H	MH	ML	L	H	Kitikmeot
Gjoa Haven	18	MH	MH	H	MH	H	ML	L	MH	Kitikmeot
Kimmirut	19	MH	MH	L	H	L	ML	ML	H	Qikiqtaaluk
Grise Fiord	20--21	MH	L	MH	H	L	H	H	H	Qikiqtaaluk
Resolute Bay	20--21	MH	L	MH	H	L	H	H	H	Qikiqtaaluk
Kugluktuk	22--23	ML	ML	H	MH	H	ML	L	MH	Kitikmeot
Pond Inlet	22--23	ML	ML	MH	H	H	ML	L	MH	Qikiqtaaluk
Taloyoak	24	MH	ML	H	H	MH	ML	L	H	Kitikmeot
Arctic Bay	25	ML	ML	MH	H	MH	ML	L	MH	Qikiqtaaluk

Optimal Planning Example

- Nunavut pre-feasibility ranking based on HOMER: Optimal O&M savings vs RE installation costs

Community (Alphabetical)	(NPV)O&M Savings	Installation Costs (NPV)	O&M Savings	RE and Associated CAPACITIES				RE Penetration	CO2 Reduction	Rankings based on	
				Battery	PV	Wind	Converter			O&M Savings %	Installation Costs of RE
	$	$	%	kWh	kW	kW	kW	%	%	(Descend)	(Ascend)
Arviat	837,705	907,600	1.70	0	0	100	0	2.6	2.46	16	3
Baker Lake	3,648,351	4,047,500	6.73	1,000	500	0	500	7.1	7.36	14	8
Cambridge Bay	6,198,906	5,879,400	7.39	1,500	600	100	700	8.3	9.07	13	9
Cape Dorset	580,989	591,400	1.21	0	100	0	100	0.6	1.41	18	1
Clyde River	3,053,834	3,087,000	9.92	800	200	100	200	11.3	13.49	8	7
Hall Beach	2,429,447	2,374,200	7.95	700	100	100	200	9.8	11.27	11	6
Hall Beach	8,332,737	7,940,400	27.25	1,500	400	400	500	36.2	37.25	3	12
Igloolik	735,488	721,800	1.50	100	100	0	100	1.7	1.66	17	2
Iqaluit	36,739,335	37,081,000	9.62	12,500	2,000	1,500	3,000	13.5	14.99	9	16
Iqaluit	96,285,121	84,714,992	25.21	21,500	2,000	6,000	5,500	39.3	40.08	4	17
Iqaluit	93,116,687	90,651,504	24.28	25,000	0	7,500	5,500	41.4	42.25	5	18
Kugaaruk	6,285,116	6,138,500	18.45	1,100	500	200	500	25.9	25.84	7	10
Kugaaruk	7,471,944	7,572,900	21.94	1,500	500	300	600	31.5	31.55	6	11
Pangnirtung	1,944,607	1,863,800	3.85	100	300	0	300	4.7	4.57	15	5
Qikiqtarjuaq	1,898,300	1,730,400	7.41	500	200	0	200	6.7	9.22	12	4
Rankin Inlet	11,197,390	12,392,600	9.43	4,000	500	600	800	13.8	14.79	10	14
Rankin Inlet	33,006,219	32,523,800	27.79	7,000	1,300	2,000	2,200	39.2	39.06	2	15
Sanikiluaq	11,292,466	11,537,900	33.99	10,000	400	600	700	52.1	53.06	1	13

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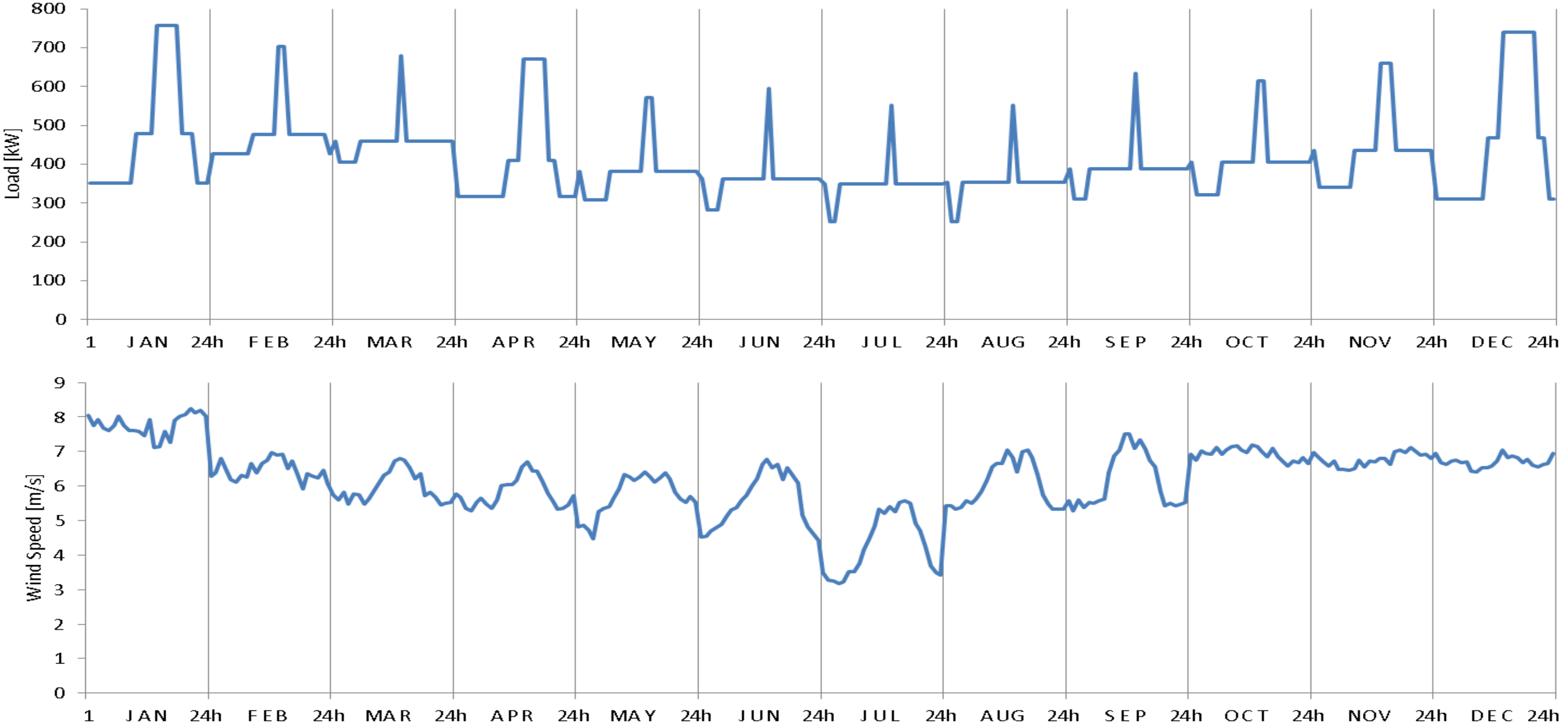
Optimal Planning Example

- Sanikiluaq hourly profiles daily averages per month for load (for the first year) and wind speed profile @21m height:



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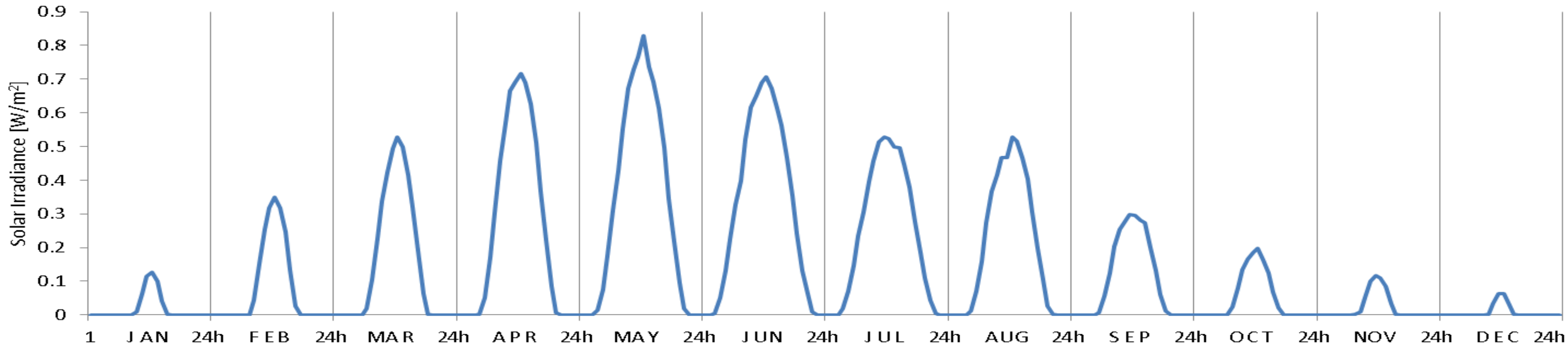
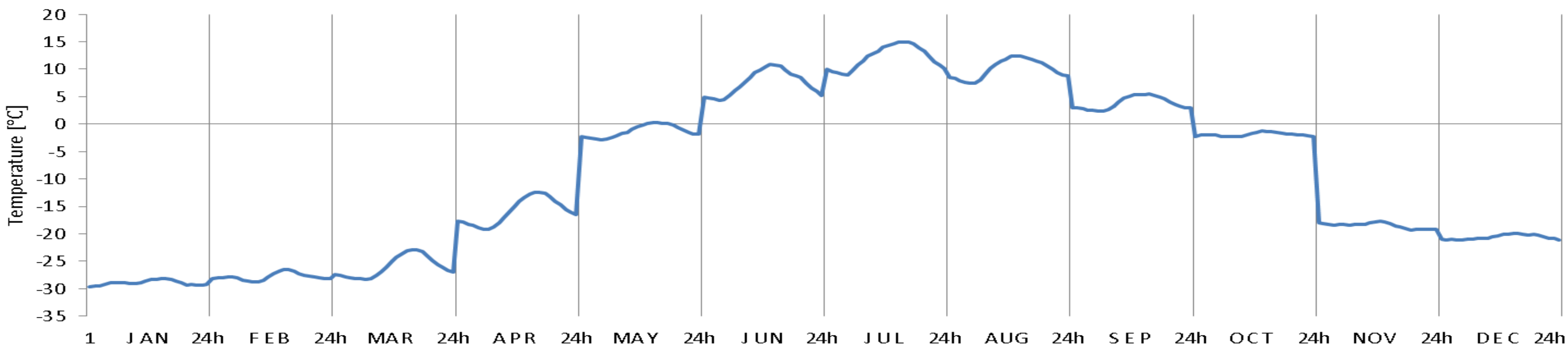
Optimal Planning Example

- Sanikiluaq hourly profiles daily averages per month for solar irradiation and temperature:





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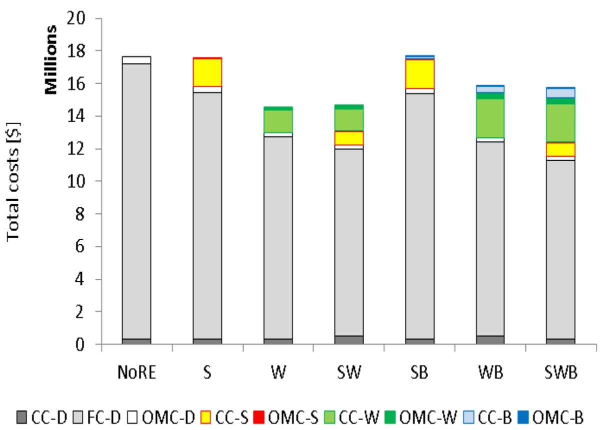
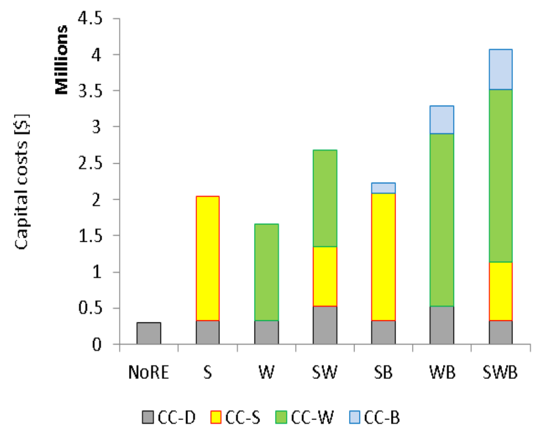
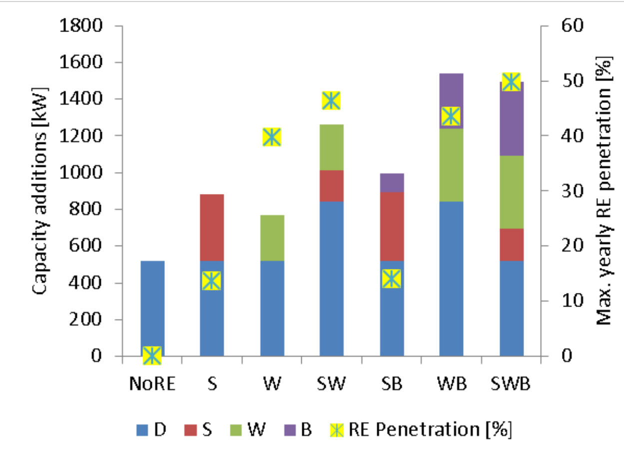
Optimal Planning Example

- Detailed feasibility studies for Sanikiluaq: optimal results for 10-year horizon:







  - Maximum reduction of fuel cost (FC) occurs when wind is deployed.
  - NPCs of optimal total costs for RE cases are less than BAU (NoRE) by ~$2 million (~10%), thus justifying RE deployment in all cases.
  - Maximum diesel use reduction of about 35% occurs for the SWB case with a maximum RE penetration of close to 50%.

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Conclusions

- There is a need to introduce RE in microgrids in Canada:
  - To reduce environmental impact.
  - To reduce operating costs.
  - To help address load growth restrictions.
- RE deployment reduces fuel consumption in many communities:
  - Fuel savings allow in some cases to not only pay for RE equipment but secure further costs savings, making business sense.
  - RE penetration is significant in several cases, helping reduce the environmental impact of diesel use.
- Wind is the preferable RE option for all communities, but solar is also an option for more southern communities.
- Battery addition reduces fuel use, but it is an overall more expensive solution for several communities.

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Conclusions and Next Steps

- In all communities, RE deployment reduces fuel consumption.
- For the best options:
  - Maximum yearly RE penetration from 22 to close to 60 %, which is higher than the pre-feasibility results obtained with HOMER due to approximations in diesel dispatch calculations.
  - Total cost savings from 3.5 to 15 %.
  - Fuel savings from 6 to 40 %.
- Wind is the preferable RE option for all communities.
- Battery addition reduces fuel use, but it is an overall more expensive solution than without it for some communities.
- Of all communities, Sanikiluaq is the only community where SWB is the best option.
- Final results for a 10-year project horizon were presented with reduced search spaces for all communities to meet workshop deadlines.
- In the feasibility report, results for a 20-year project horizon and a broader search space for each community will be presented.

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