Renewable Energy Systems with Battery Storage: An Alberta Case Study

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Objectives

To investigate the potential to use battery storage to meet Alberta's goal of eliminating reliance on coal power and replacing coal with renewables.

- Integrate wind and solar energy into grid
- Two levels of carbon tax are considered
- All coal-fired plants are phased out
- Combined-cycle natural gas (CC gas) for base load
- Li-ion batteries use cases for the transmission system or peak-replacement applications

Introduction

Alberta will phase out all coal-fired power plants and replace two-thirds of the lost electricity production with renewables by 2030.

1. The investment of renewables is incentivized by a **carbon tax** of \$20/t CO_2 beginning January 2017, followed by an increase to \$30/t CO_2 a year later.
2. The renewables such as wind and solar are **intermittent**. The wind may stop quickly, the sun may not shine suddenly, and the energy from renewables is not stable and reliable.
3. With the 30% penetrate rate of intermittent renewables, some form of energy storage technology will be needed to maintain a reliable power supply throughout the province.
4. This paper investigates the relative costs and benefits of various types of policies aimed at eliminating coal-fired power and incentivizing the integration of renewables into the Alberta grid.

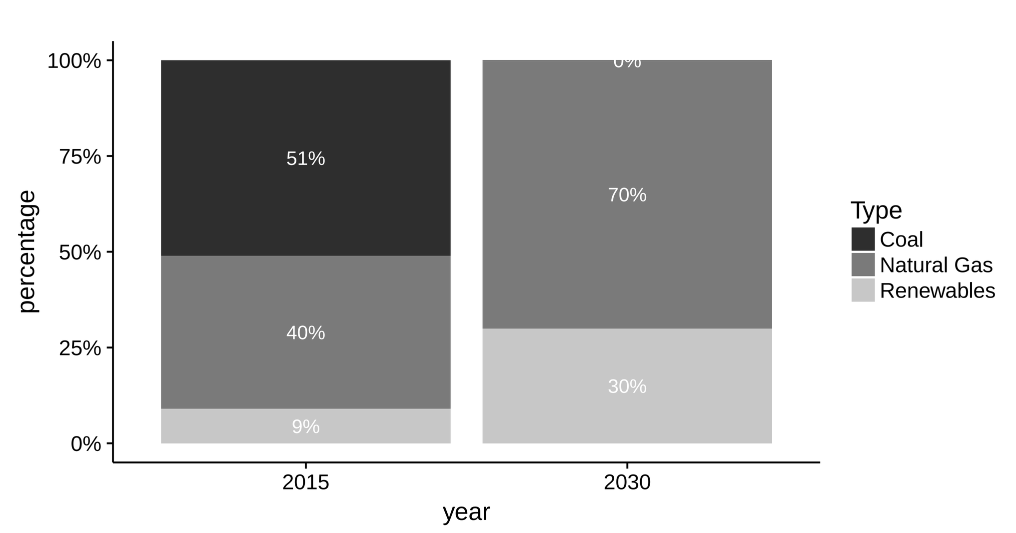

Figure 1: Alberta's goal

Data

The following materials were required to complete the research:

- Hourly load data from 2005 to 2016 from Alberta Electric System Operator (**AESO**)
- Hourly wind speed data for 17 locations 2006 to 2015 from Government of Canada
  - used to simulate the output of a 3.5 MW turbine
- Hourly solar data for 28 locations 1996 to 2005 from Canadian Weather Energy and Engineering Datasets (**CWEEDS**)
  - used to simulate the output of a Solar Module

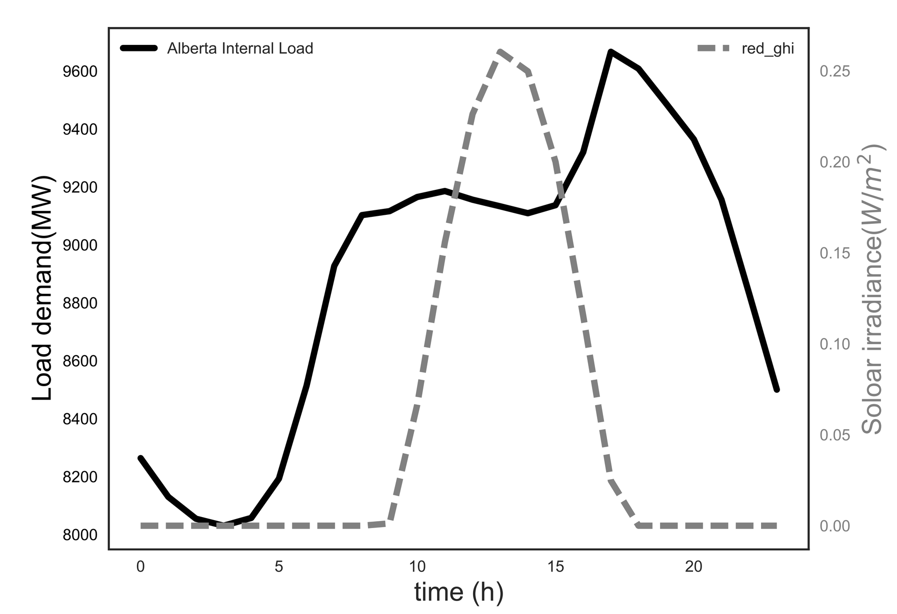

Figure 2: Average Load and Solar Irradiance in January

Methodology

Optimization:

AESO minimizes total cost by choosing:

- the amount of wind turbines and solar panels
- the size of lithium-ion battery and the flow of energy into and out of the battery in each hour
- the overall capacity of gas generation and the hourly production of electricity from natural gas

Scenarios:

- Different profiles wind and solar energy
  - each year of solar, wind and load data as a representative year
- Different levels of carbon tax
  - \$0/t CO_2; \$20/t CO_2 ; \$30/t CO_2
- Different use case of battery
  - Transmission system (provide voltage support and grid stabilization, etc) ; Peaker replacement(replace peaking gas turbine facilities)

Optimization

Objective:

$$TC = \sum_{r\in w,s}\sum_{t=1}^{T} C_r N_r P_{r,t} + \sum_{t=1}^{T} C_g P_{g,t} + C_b \times K_b \quad (1)$$

- TC refers to the total cost of the hybrid renewable energy system
- $C_i, \quad i \in w, s, g, b)$ refer to exogenous the levelized costs of electricity (LCOE) of renewable wind(w) and solar(s), natural gas(g) and battery storage(b)
- N_w and N_s refer to the number of wind turbines and solar modules to be installed
- $P_{r,t}$ refers to the amount of energy produced by each renewable unit $N_r, r \in w, s$
- b refers to the energy rating of the battery (MWh)

Constraints:

$$\sum_{r\in w,s} N_r P_{r,t} + P_{g,t} + b_t^- \geq D_t + b_t^+ \quad (2)$$

- b_t^- the discharge from the battery at time t to meet demand
- b_t^+ the flow of energy into the battery (charge) at time t if there is too much power available

$$V_{b,t} = V_{b,t+1} + \delta b_{t-1}^+ - b_{t-1}^- \quad (3)$$

- $\delta = 0.92$ is the round trip efficiency of the battery
- Dynamic equation that indicates the available energy in the battery at time t

$$b_t^- \leq V_{b,t} \quad (4)$$

- Discharge from the battery cannot exceed the current energy available in the battery

$$P_{g,t} \leq G \quad (5)$$

- Power produced by a gas turbine cannot exceed its capacity

Results

1. Without carbon levies, CC gas supplies electricity all of the time, as it has the **lowest LCOE**
2. With lower level of carbon levy, wind power is **integrated** into the system; however, the battery **utilization rate** remains low throughout, and only be used 0.5% of the time
3. With higher level of carbon levy, installed wind capacity **increases**; the battery utilization factor increases as well
4. Solar power was not found to be optimal in any of simulations; its relatively **higher LCOE** remains a barrier to entry
5. In many time periods, more energy was produced than needed; it would not be optimal for battery capacities to be so high as to capture all the wasted renewable energy, all the time.

Conclusion

As renewable and battery **cost** continue to drop, Alberta may see itself relying **more** on wind and natural gas in its generation mix, and batteries may be hypothesised to replace conventional gas turbines as peakers in the near future.

Additional Information

Our simulation merely captures the **monetary** aspects of renewable integration and energy storage, while ignoring many of the benefits that can accrue from such projects.

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