Optimization of the Western Canada Power Grid

Incorporation of Renewable Energy

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Overview

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Introduction

Motivation

In order to improve the environmental quality, many countries are phasing out coal-fired power plants and integrate **renewable** energy into **power grid**.

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

The **goal** of current research is

- understand the economic consequences of integrating renewable energy
- design policies to achieve an optimal generation mix
- determine the costs and benefits of using renewable energy sources(RES) to reduce greenhouse gas emissions

Research Context

The capacity of renewables such as wind and solar energy have been grown rapidly along with that the cost decreased continuously

It is challenging the stability and reliability of power system.

- Intermittency of renewables:
  - rely on other dispatchable power sources as backup
  - huge amount of capacity payments
- Disrupt electricity system:
  - almost zero marginal production cost
  - the investment of conventional assets decline

Research Context

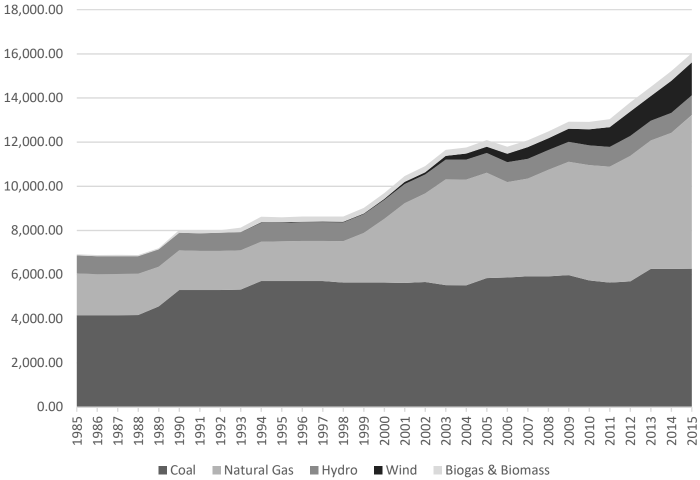


Figure 1: Alberta Generation Sources MW

Research Context

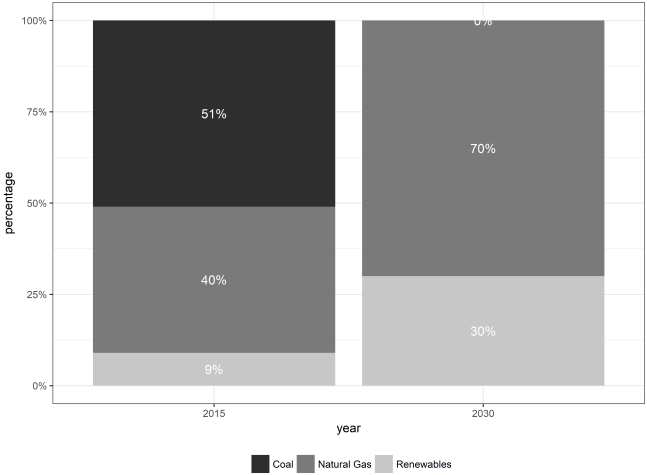


Figure 2: Change in Alberta Capacity

Research Context

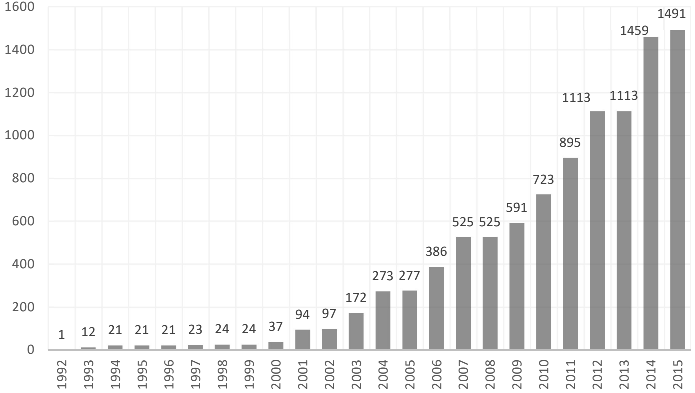


Figure 3: Alberta Wind Installed Capacity MW

Research Context

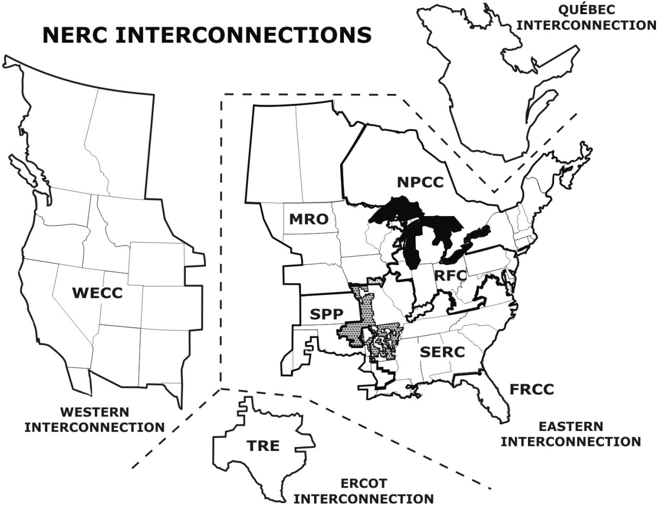


Figure 4: Interconnections of Alberta and other jurisdictions

Research Questions

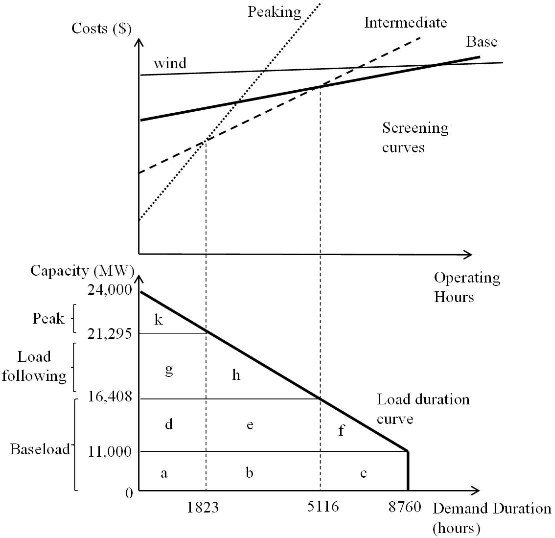
- Explore the viability of relying on wind power to replace upwards of 60% of electricity generation in Alberta that would be lost if coal-fired generation is phased out
- Examine the effect of flexible storage of electricity in Alberta power system with wind and solar sources
- Investigate economic cost of electricity source by calibration

Research Methods

Load Duration Curve and Screening Curves

- The load duration curve captures the structure of the load
- The screening curves are the cost curves for generation assets
  - Intercept represents fix cost/capital cost
  - Slope represents the variable operating cost/marginal cost
  - Total costs (capital plus operating) per unit of generating capacity vary with the number of hours that the capacity is utilized to produce electricity each year.
- By allocating the lower cost dispatchable generating unit, grid operator can achieve the **least cost** generating mix

Load Duration Curve and Screening Curves



Mathematical Programming

- A grid model is developed to examine the allocation of renewable and non-renewable generating sources
- The objective of optimization is to maximize the total operation profit or minimize total operation cost
- Optimization is subjected to load conditions, technological constraints, decarbonization requirement and tax/subsidy policy

Mathematical Programming: Objective

$$\Pi = \sum_{t=1}^{T}[P_{A,t}D_t - \sum_{i=1}^{I}(OM_i + b_i + \tau\phi_i)Q_{i,t} + \sum_{k=1}^{K}[(P_{k,t} - \delta)X_{k,t} - (P_{k,t} + \delta)M_{k,t}]] - \sum_{i=1}^{I}(a_i - d_i)\Delta C_i, \tag{1}$$

$$i \in \{coal, CTgas, wind, etc\},$$

$$k \in \{BC, MID, SK\},$$

$$t \in \{1:8760\},$$

Mathematical Programming: Constraints

$$\sum_{i=1}^{I} Q_{i,t} + \sum_{k=1}^{K}[M_{k,t} - X_{k,t}] \geq D_t, \quad \forall t = 1, ..., T; k \in \{BC, MID, SK\}, \tag{2}$$

$$Q_{i,t} - Q_{i,t-1} \leq C_I \times R_i, \quad \forall i, t = 2, ..., T; \tag{3}$$

$$Q_{i,t} - Q_{i,t-1} \geq C_I \times R_i, \quad \forall i, t = 2, ..., T; \tag{4}$$

$$Q_{i,t} - Q_{i,t-1} \geq C_I \times R_i, \quad \forall i, t = 2, ..., T; \tag{5}$$

$$M_{k,t} \leq TRM_{k,t}, \quad \forall k, t = 1, ..., T; \tag{6}$$

$$X_{k,t} \leq TRX_{k,t}, \quad \forall k, t = 1, ..., T; \tag{7}$$

$$Q_{i,t}, M_{k,t}, X_{k,t} \geq 0, \quad \forall k, i, t = 1, ..., T; \tag{8}$$

Mathematical Programming: Result

- Resulting model is used for policy analysis in different scenarios
  - Different wind speed profiles
  - Different intertie capacity/storage potential
  - Different nuclear capacity level
  - Different level of carbon tax/feed-in tariff
- Results
  - Green gas emission
  - Phasing out coal plants
  - Penetration of renewables
  - Average costs of reducing carbon emissions

Cost Calibration of Electricity

- **Missing money problem**: the whole market price doesn't reflect the average cost of generating capacity, then doesn't provide enough incentive for investment of generating assets.
- **Levelized costs of electricity (LCOE)** fails to take into account the timing of available power from intermittent sources and how this impacts other assets providing power to the grid at the time.
- To understand the true **economic cost of electricity**, a comprehensive evaluation should consider the life time cost and expected profitability of the generating technologies.

Calibration by Positive mathematical programming

- Construct economic cost functions or production function of energy resources for grid optimization modeling
- Actual observed base-year operating levels can be recovered with calibrated cost functions in optimization
- Resulting nonlinear model is used for policy analysis

Data

Data

- Alberta's hourly load data from 2005 to 2016 from Alberta Electric System Operator (AESO)
- Hourly wind speed data for 17 locations 2006 to 2015 from Statistic Canada
- Hourly solar data for 28 locations 1996 to 2005 from Canadian Weather Energy and Engineering Datasets (CWEEDS)

Load Data

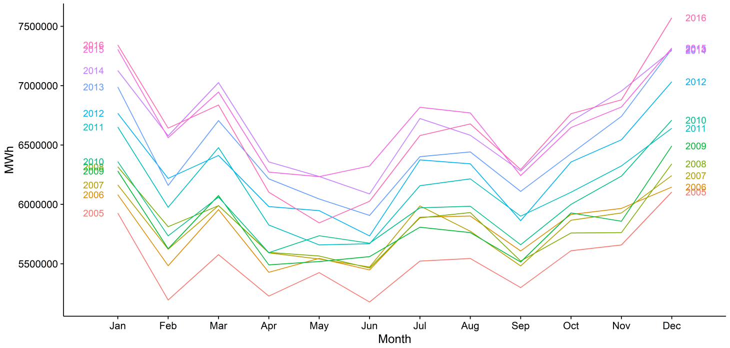


Figure 5: Alberta's Monthly Load 2005 to 2016 from AESO

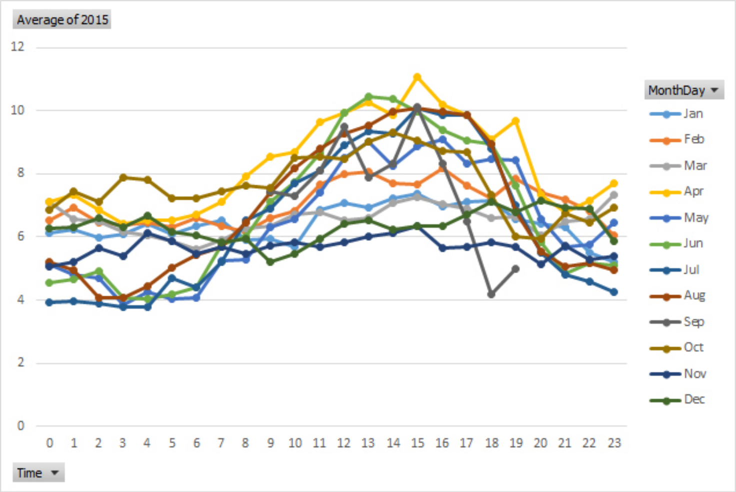


Figure 6: Alberta's Fort Vermilion Average Wind Speed 2015 from Government of Canada

Solar Data

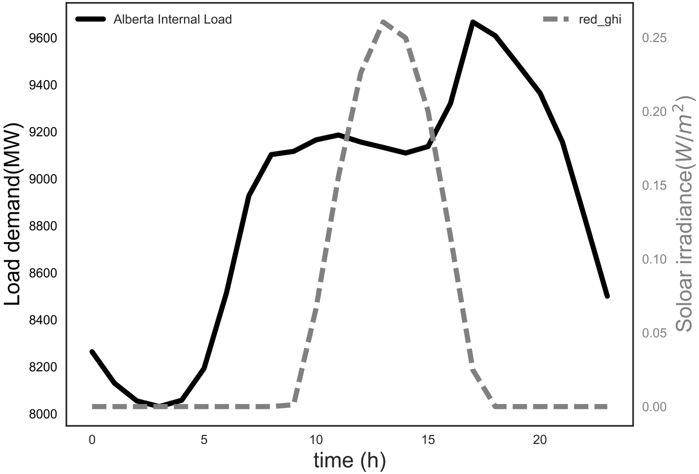


Figure 7: Average Load and Solar Irradiance in January

Dissertation Outline

Dissertation Outline

- **Chapter 1** Background
- **Chapter 2** General method of MP, PMP, Simulation
- **Chapter 3** Load Duration Curve and Screening Curves: A Framework for Analysis
- **Chapter 4** Wind and Emission Reduction Targets
- **Chapter 5** Hybrid Renewable Energy Systems with Battery Storage
- **Chapter 6** Calibration of Electricity Cost for Power System Optimization
- **Chapter 7** Conclusion

Time Line

Time Line

Time	Chapter
2017 Summer	Chapters one
2017 Winter	Chapter two: General methods of MP, PMP, and simulation
2017 Winter	Chapter three: Load Duration Curve and Screening Curves
2018 Spring	Chapter four is based on an existing paper
2018 Spring	Chapter five is under the second stage of research
2018 Summer	Chapter six is at its early stage
2018 Winter	Chapter seven

THANK
YOU