Long Term Optimization of BC-Alberta Interconnected Energy System: Hydro-Wind Combined Case Study

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In 2008, the Province of British Columbia recognized the urgent need to act:

- North America’s first legislated broad-application carbon tax (currently $20 per ton of CO$_2$ emitted, increasing $5 per year to 2012), revenue neutral

- A comprehensive Climate Action Plan for greenhouse-gas abatement (33% decrease from 2007 levels by 2020, legislated)

- Endowed the Pacific Institute for Climate Solutions at the University of Victoria
An interdisciplinary Canadian example, (one that PICS is now actively pursuing):

**Key question:**
As a first step to reduce CO$_2$ emissions, can we remove coal from the Canadian energy diet?

**Possible strategy:**
Couple wind power with Hydro in an integrated Canadian (or North American) electrical grid.
Why is this an interdisciplinary issue with respect to Canadian policy (and politics)?

• Electricity supply is a provincial responsibility (thus, constitutional issues).

• Electricity exports to the US can be lucrative (thus, an economic issue).

• Future hydro supply in the face of a changing climate? (thus, a climatology/hydrology issue).

• Transmission corridors have impacts and distances are immense (thus, ecological and engineering issues).

• Carbon emissions must be reduced (thus, a political/sociological/psychological issue).
~12 GW grid
~95% hydro

~12 GW grid
~90% coal/gas

~3.2 GW grid
~60% coal/gas

~5 GW grid
~98% hydro

~33 GW grid
~93% hydro

Lines shown are ≥345 kV
Lake Williston and the W.A.C. Bennett Dam, one of the world’s largest batteries.
Canadian Wind Resources:
The World’s Second Largest

Mean Wind Speed at 50 m above ground
Vitesse moyenne du vent à 50 m au dessus du sol

Horizontal resolution of 5 km
Resolution horizontale de 5 km
Wind Power Production, Alberta, February 2011

Day Ahead Wind Power Forecast vs. Actual Wind Production for the Month of February 2011

This figure is intended to illustrate the correlation between the wind power forecast received from WEPROG and actual wind production.

Accuracy Statistics:
- Mean absolute percent error (MAPE) = 14.4%
- Average range between the maximum and minimum forecast = 361 MW

Installed maximum capacity

Actual

Forecast

Prepared on 01-Mar-2011
Wind energy is now a big economic driver: Global Statistics, 2009

- $63 B in installations ($60.5 B in 2010); 37.5 GW added globally
- 500,000 employees worldwide
- Growing globally 31% per year
- Now becoming cost competitive with new hydro and coal
The Integrated North American Transmission Grid

~12 GW grid
~95% hydro

~12 GW grid
~90% coal/gas

Map copyright CEA. Lines shown are 345kV and above. There are numerous interconnections between Canada and the U.S. under 345kV that do not appear on this map.
BC and Alberta Reference Energy System

Resources
- Wind (104 sites BC and 8 Alberta)
- River Systems (Peace, Columbia, Pend D’Orielle, Bridge, Kootenay, Campbell, Nechako)
- Natural Gas
- Coal
- Biomass Resources

Reservoirs
- Related Reservoirs (Williston, ...)
- Dinosaur, Site C, ...

Conversion
- Wind Farms
- Hydroelectric
- Gas Turbine, Combined Cycle, Cogeneration
- Coal Power Plant
- Biomass and others

Transmission
- HVDC
- HVAC
- Import-Export

Distribution
- Residential
- Commercial
- Industry
- Agriculture
- Transportation

End-Use Demand
MAIN ASSUMPTIONS

• THE LONG TERM MIXED-INTEGER OPTIMIZATION MODEL IS CONSTRUCTED WITH A TIME FRAME UP TO YEAR 2050.
• EACH YEAR IS DIVided INTO SIX SEASONS
• TWO TYPES OF DAY, WEEKDAYS AND WEEKENDS (INCLUDING HOLIDAYS) ARE DEFINED IN THE MODEL.
• EACH DAY IS DIVided INTO SEVERAL HOURS, INCLUDING PEAK HOURS, NIGHT TIME AND BASE LOAD DURING DAYTIME.
• GAS PRICES ARE BEING CONSIDERED ACCORDING TO NATURAL GAS PRICE FORECASTS OF BC HYDRO
• LOAD DEMAND FORECAST FOR BC AND ALBERTA IS INCLUDED ACCORDING TO BC HYDRO AND AESO DEMAND FORECAST REPORTS
Four wind power regions in BC with a total of 15,000mw estimation of wind potential

<table>
<thead>
<tr>
<th>Category</th>
<th>Number of Projects</th>
<th>Total Installed Capacity (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vancouver Island</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Readily Available</td>
<td>11</td>
<td>1283</td>
</tr>
<tr>
<td>Ambitious</td>
<td>3</td>
<td>138</td>
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<tr>
<td>Total</td>
<td>14</td>
<td>1421</td>
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<tr>
<td><strong>North Coast</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Readily Available</td>
<td>7</td>
<td>922</td>
</tr>
<tr>
<td>Ambitious</td>
<td>5</td>
<td>3288</td>
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<tr>
<td>Total</td>
<td>12</td>
<td>4211</td>
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<tr>
<td><strong>Southern Interior</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Readily Available</td>
<td>24</td>
<td>3554</td>
</tr>
<tr>
<td>Ambitious</td>
<td>6</td>
<td>600</td>
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<tr>
<td>Total</td>
<td>30</td>
<td>4154</td>
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<tr>
<td><strong>Peace</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Readily Available</td>
<td>27</td>
<td>3410</td>
</tr>
<tr>
<td>Ambitious</td>
<td>21</td>
<td>2703</td>
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<tr>
<td>Total</td>
<td>48</td>
<td>6113</td>
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## Major river systems defined in the model

<table>
<thead>
<tr>
<th>River System</th>
<th>Plants</th>
<th>Generation Capacity (MW)</th>
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</thead>
<tbody>
<tr>
<td>The Peace</td>
<td>G.M. Shrum (GMS)</td>
<td>3430</td>
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<tr>
<td></td>
<td>Peace Canyon (PCN)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Site C</td>
<td>1100</td>
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<tr>
<td>The Columbia</td>
<td>Mics (MCA)</td>
<td>3840</td>
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<tr>
<td></td>
<td>Revelstoke (REV)</td>
<td></td>
</tr>
<tr>
<td>The Pend D’Oreille</td>
<td>Seven Mile (SEV)</td>
<td>954</td>
</tr>
<tr>
<td></td>
<td>Waneta (WAN)</td>
<td></td>
</tr>
<tr>
<td>The Bridge</td>
<td>Lajoie (LAJ)</td>
<td>548</td>
</tr>
<tr>
<td></td>
<td>Bridge (BR)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Seton (SON)</td>
<td></td>
</tr>
<tr>
<td>The Kootenay</td>
<td>Kootenay Canal</td>
<td>570</td>
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<tr>
<td>The Campbell</td>
<td>Strathcona (SCA)</td>
<td>229</td>
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<tr>
<td></td>
<td>Ladore (LDR)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>John Hart (JHT)</td>
<td></td>
</tr>
<tr>
<td>Nechako</td>
<td>Alcan Co.</td>
<td>960 (mostly for aluminum plant)</td>
</tr>
</tbody>
</table>
Seasonal inflow variations for one of the major reservoirs
Optimization results
Scenario 1 - BC Optimal Generation Mix
(BC-AB grid expansion and BC gas expansion not allowed)
Scenario 1 - Alberta Optimal Generation Mix (BC-AB grid expansion and BC gas expansion not allowed)

Scenario 1 - AB Generation Mix

MW


2036

2041

2046

2051

Wind
Gas
Coal
Load_AB
Scenario 2 - BC Optimal Generation Mix (Grid expansion allowed between BC-ab)
Scenario 2 - AB Optimal Generation Mix (Grid expansion allowed between BC-ab)
Scenario 2 - BC-AB Grid Expansion
<table>
<thead>
<tr>
<th></th>
<th>Base Year (2009)</th>
<th>Scen1 (2050)</th>
<th>Scen2 (2050)</th>
<th>Scen3 (2050)</th>
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</thead>
<tbody>
<tr>
<td>Hydro_BC</td>
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<td>10353</td>
<td>11452</td>
<td>11434</td>
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<tr>
<td>Wind_BC</td>
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<td>15400</td>
<td>15400</td>
<td>0</td>
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<tr>
<td>Gas_BC</td>
<td>912</td>
<td>910</td>
<td>0</td>
<td>6424</td>
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</tbody>
</table>

**BC Installed Capacities Year 2050 Compared to Base Year (MW)**
### Alberta Installed Capacities Year 2050 Compared to Base Year (MW)

<table>
<thead>
<tr>
<th></th>
<th>Base Year (2009)</th>
<th>Scen1 (2050)</th>
<th>Scen2 (2050)</th>
<th>Scen3 (2050)</th>
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</thead>
<tbody>
<tr>
<td>Coal_AB</td>
<td>6000</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Wind_AB</td>
<td>780</td>
<td>11000</td>
<td>11000</td>
<td>0</td>
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<tr>
<td>Gas_AB</td>
<td>1376</td>
<td>20969</td>
<td>19356</td>
<td>20436</td>
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<tr>
<td></td>
<td>Base Year (2009)</td>
<td>Scen1 (2050)</td>
<td>Scen2 (2050)</td>
<td>Scen3 (2050)</td>
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<tr>
<td>----------------</td>
<td>------------------</td>
<td>--------------</td>
<td>--------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Coal</td>
<td>6000</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gas</td>
<td>2288</td>
<td>21879</td>
<td>19356</td>
<td>26860</td>
</tr>
<tr>
<td>Wind</td>
<td>780</td>
<td>26400</td>
<td>26400</td>
<td>0</td>
</tr>
<tr>
<td>Hydro</td>
<td>10332</td>
<td>10353</td>
<td>11452</td>
<td>11434</td>
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<tr>
<td><strong>Total System Capacity</strong></td>
<td>19400</td>
<td>58632</td>
<td>57208</td>
<td>38294</td>
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Tie Line Capacities in Three Scenarios

<table>
<thead>
<tr>
<th></th>
<th>Scen1</th>
<th>Scen2</th>
<th>Scen3</th>
</tr>
</thead>
<tbody>
<tr>
<td>US-BC</td>
<td>1300</td>
<td>1300</td>
<td>1300</td>
</tr>
<tr>
<td>AB-BC</td>
<td>780</td>
<td>5343</td>
<td>1658</td>
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</table>
BC-Alberta Generation Mix in 2050

- Gas: 53%
- Hydro: 24%
- Wind: 23%
Marginal Costs of Electricity at the Final Level in Second Scenario ($/MWh)
CO2 Emissions from BC-AB Energy System (kton/yr)

- Allow BC-AB transmission expansion
- No wind expansion allowed
- Gas expansion allowed in BC as well

- Wind penetration allowed
- No BC-AB transmission expansion
- No Gas allowed in BC

- Wind penetration allowed
- Allow BC-AB transmission expansion
- No Gas expansion allowed in BC

Scen1  Scen2  Scen3
Conclusions

- Installing new transmission lines between BC and Alberta would be more cost effective with or without wind capacity expansion.
- By penetration of wind energy up to year 2050, final electricity marginal cost would reach about $40/MWh which is still affordable comparing to current electricity prices.
- Wind energy penetration can result into 42% CO2 emission reduction in year 2050 compared to no wind scenario.
Thank you

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