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Impact of electrical intertie capacity on carbon policy effectiveness

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ABSTRACT

This study investigates the potential cost and emissions reductions that result from an increase in electricity transmission capacity between Canada's two westernmost provinces: Alberta, a fossil fuel dominated jurisdiction, and British Columbia, a predominantly hydroelectric jurisdiction. A bottom-up model is used to find the least cost electricity generation mix in Alberta and British Columbia under different carbon policies. The long-term evolution of the electricity system is determined by minimizing net present cost of electricity generation for the time span of 2010–2060. Different levels of intertie capacity expansion are considered together with a variety of carbon tax and carbon cap scenarios. Results indicate that increased intertie capacity reduces the cost of electricity and emissions under carbon pricing policies. However, the expandable intertie does not encourage greater adoption of variable renewable generation. Instead, it is used to move low-cost energy from the United States to Alberta. The optimal intertie capacity and cost reduction of increased interconnectivity increases with more restrictive carbon policies.

1. Introduction

Variable renewable generation such as wind and solar is frequently lauded as a key element of future low-carbon energy systems. However, to enable widespread adoption, the variable output of these technologies must be reconciled with relatively unresponsive energy demand. Increased interregional transmission has been proposed as a method to facilitate greater penetration of variable renewables (Holttinen, 2005). This study investigates the impacts of greater integration between a hydroelectricity-dominated jurisdiction (British Columbia) and a fossil fuel dominated jurisdiction (Alberta) on the cost and emissions of electricity generation.

Hydroelectric reservoirs provide operational flexibility which is becoming an increasingly valuable characteristic of systems where temporal variations in renewable generation need to be managed (Ulbig and Andersson, 2015). In Alberta, the small share of hydroelectric generation limits flexibility; however, there is potential to increase the capacity of the BC-Alberta intertie to enable utilization of BC's reservoir generation to facilitate greater penetration of variable renewable generation in the Alberta system.

Other studies have investigated the use of hydroelectric generation with storage reservoirs to support variable renewable generation in California (Chang et al., 2013) and the Western Electricity Coordinating Council (WECC) regions (Ibanez et al., 2014). Both of these studies focus on a single year, rather than the long-term evolution of the electricity system, and show that system-wide cost and emissions are reduced by integrating storage hydro power and wind power resources. These studies also find that dispatching hydroelectricity to support renewable generation enables higher penetrations of renewables and reduces the frequency of curtailment events. These findings suggest that BC's existing hydroelectric resources could be used to support new renewable generation in Alberta, lowering the combined emissions of the two provinces.

The current study compares the evolution of electricity generation mixtures in BC and Alberta from 2010 to 2060 under alternative carbon policy scenarios, with and without expanded intertie capacity. The combined electricity system is optimized for lowest net present cost using a technology explicit model for generation in both provinces. The net present cost and cumulative emissions of the combined system are compared to determine the impact of greater integration on the adoption and operation of future low-carbon electricity systems. The study does not consider how the costs and benefits of increased intertie capacity are divided between the two provinces.

The timeframe for this study is much longer than the operational life of most electricity generating technologies. As a result, current generation units, with the exception of hydroelectric facilities, are retired within the model period. This allows modelling of the transition from the current generation mixture to future low-carbon mixtures.

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Previous studies have used similar methods to explore the transition to renewable generation in electricity systems under the influence of a range of factors. Among the factors previously examined are environmental performance uncertainty (Parkinson and Djilali, 2015a), climate and hydrological change (Parkinson and Djilali, 2015b), grid flexibility requirements (Welsch et al., 2014), fossil fuel price volatility (Wu and Huang, 2014), and combined environmental-economic optimization (Groissböck and Pickl, 2016). This study expands on these methods to examine the role of carbon policies and regional integration in decarbonizing electricity generation.

A previous single-year study of BC and Alberta, found that increased intertie capacity with no increase in wind capacity leads to a slight increase in combined annual emissions for the two provinces due to increased thermal generation in Alberta to supply increased exports to BC. These exports, which are primarily from coal-fired generators, offset domestic natural gas-fired generation in BC. However, with expanded wind generation and intertie capacity, emissions decrease as hydroelectric power substitutes for fossil fuel generation to provide grid flexibility in Alberta (Scorah et al., 2012). A second study by the same group finds that a carbon tax in excess of $100/tonne of carbon dioxide is required to trigger widespread wind power development and, again, that additional wind power development is enabled by increased intertie capacity (van Kooten et al., 2013).

A similar study examined the potential of increased transmission capacity to increase the penetration of variable renewables in northern Asia (Otsuki et al., 2016). This study, which models a single year with defined generating capacities, found that increased transmission capacity can reduce emissions from electricity generation by increasing the penetration of variable renewables. Optimal interconnection levels were also determined in (Lynch et al., 2012). Here the authors use a series of single-year optimizations to find the cost-optimal generation portfolio in individual countries in northern Europe considering only coal, gas, nuclear, and wind power. They found that intertie expansion only occurs when renewable energy targets are applied.

The current study adds to the literature by considering the impacts of increasing intertie capacity between two regions over the long term. Increased interconnectivity has been shown to increase the value of intermittent renewables (Hirth, 2013; Schaber et al., 2012) and to decrease emissions from wind-thermal systems (Otsuki et al., 2016; Göransson and Johnsson, 2011) in the short term. The paper examines the extent to which these benefits impact the long-term evolution of the electricity system. The additional value to intermittent renewables afforded by the intertie may reduce the policy incentive required to achieve high penetrations. Additionally, differences in resource characteristics, such as cost and availability, between regions could also lead to large expansion of generation in one jurisdiction for export to another. Although this study focuses on BC and Alberta the conclusions could be applicable to other regions as well.

In the following sections, modelling details are described, including the optimization algorithm, economic and technical assumptions, and carbon policy scenarios. Results are then presented for the least and most carbon intense of the scenarios examined. Finally, trends across scenarios such as carbon mitigation cost and intertie utilization rates are discussed.

2. Methods

The system structure assumed for this study is shown schematically in Fig. 1, where BC and Alberta are treated as distinct nodes with no internal resolution of the transmission structure.

Combined, British Columbia and Alberta host 22% of Canada's electricity generation (Canadian Electricity Association, 2012). British Columbia's electrical system is dominated by hydroelectric generation, with small contributions from biomass, and natural gas (Fig. 2(a)). In contrast, Alberta's generation mix is dominated by large shares of coal and natural gas with small shares of wind, hydro, and biomass

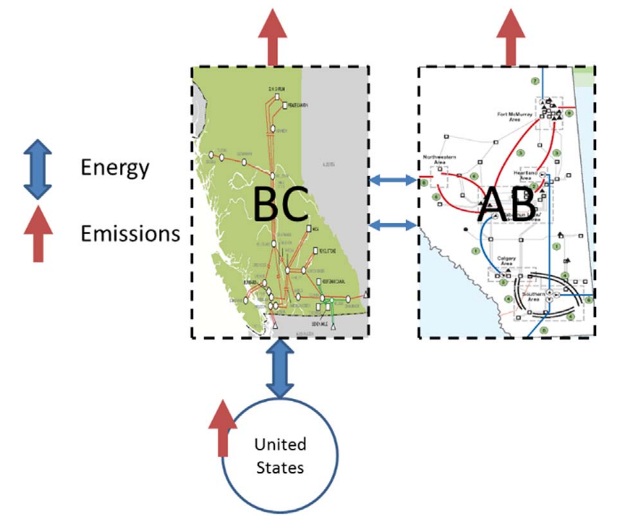

Fig. 1. Diagram of the modelled area and connections between regions. Energy can flow between BC and both Alberta and the United States. Emissions are accounted for in all three regions.

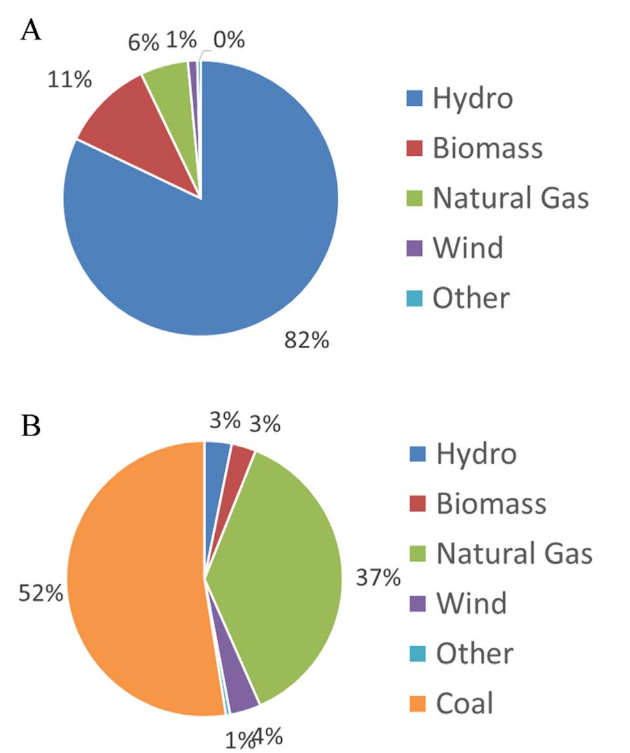

Fig. 2. Electrical energy generation mixes in British Columbia (a) and Alberta (b) for 2012 (Alberta Energy, 2014; British Columbia Ministry of Energy and Mines).

(Fig. 2(b)).

The initial (i.e. 2010) supply mixtures for BC and Alberta are defined to represent the existing infrastructure, the capacities of each technology are listed in Table A-3. The United States is represented by the Mid-Columbia (Mid-C) electricity market, which has a 3.5 GW interconnection with BC. The intertie at Mid-C is constrained to its current capacity which is assumed constant for the duration of the study. The physical constraint that is central to this study is the link between BC and Alberta, which is represented as a single intertie. Electricity trade is driven by cost minimization for the combined BC and Alberta jurisdictions. Supply scenarios for BC and Alberta reflect current estimates of available quantities and costs.

Initial generation capacities are taken from the 2013 Electricity