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ANALYSIS

Decarbonising the Alberta power system with carbon pricing

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A B S T R A C T

The Alberta power system, like many systems in the world, faces a supply gap and pressure to reduce CO_2 emissions. A techno-economic optimisation model of the Alberta power system is developed in the Open Source Energy Modelling System (OSeMOSYS) to explore the impact of carbon pricing to 2060. Costs, emissions, and generation mixes are compared for thirteen scenarios. Carbon pricing accelerates the decarbonisation process, although with decreasing effectiveness. The most cost-effective reductions come via the transition from coal to natural gas. Coal with CCS becomes economic in most scenarios, indicating that low-carbon baseload generation is valuable. Natural gas plants provide valuable dispatchable generation, whether or not extensive build-out of wind and solar power occurs.

1. Introduction

Although Canada, as a whole, has a low-carbon electricity mix, with nearly 80% of generation provided by hydro and nuclear, generation mixes and carbon intensities vary widely from province to province. The Alberta system is based on abundant coal and natural gas resources and, hence, the carbon intensity of electricity generated in the province is the highest of any province in Canada, and higher than the global average. For decades power generation in the province has been the principal source of carbon dioxide (CO_2) emissions and was only recently surpassed by oil sands as the highest emitting sector [1].

In Alberta, high load growth and an aging coal fleet are projected to require development of approximately 14 GW of new electricity generating capacity by 2034, nearly doubling the current system capacity [2]. Alberta possesses some of Canada's best wind and solar resources, there is potential for additional hydropower, and there is government support for carbon capture and sequestration [3]. As seen in Fig. 1, many jurisdictions face challenges that mirror the Alberta situation, namely, a fossil fuel dominated generation mix, pending capacity shortage and pressures to reduce carbon emissions. Therefore the results of this study are of interest to a wide audience.

Long ignored by energy systems, the external costs of carbon emissions can be accounted for by carbon pricing in the form of taxes or a cap-and-trade system. Both of these mechanisms can decarbonise a system by making carbon-intensive energy more costly. First pioneered by Finland in 1990, many nations and regions have implemented carbon taxes under a range of structures that encompass various fuels, sectors, and rates. Analyses of the impacts of these policies over nearly two decades have found mixed results [7,8]. For example, despite having one of the highest carbon tax rates, Norway's policy has not reduced *per capita* CO_2 emissions because of exemptions for certain sectors, rapid growth of oil and gas exports, and inelastic demand [9]. Successful policies, like that of Finland, were found to cover a greater range of fuels and sectors, with flexibility in the system to shift to lower carbon alternatives [8,9]. Europe's emissions trading system (EU ETS) is the world's first and largest cap-and-trade system. Recession, overlapping policies, and other challenges have impacted its effectiveness at reducing CO_2 [10–12]. China has been experimenting with emissions trading through several pilot projects and intends to implement a national trading system [13].

Energy models are frequently used to provide insight into how future demands can be met. For example, a partial equilibrium model was used to compare the impacts of carbon taxes and energy taxes on Japan's energy system [14]. These researchers found the carbon tax to be an effective option, but details of the system preference for

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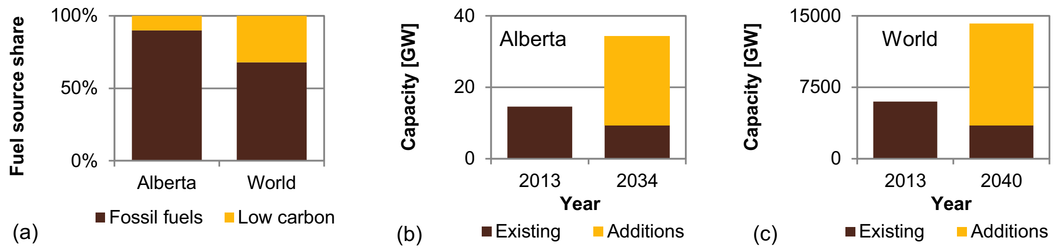

Fig. 1. (a) Share of annual electricity generation by fuel source [4,5]. Expected generation capacity additions for (b) Alberta [2], and (c) World [6].

generation technologies to meet the emission target were not reported. More recently, a CA-TIMES (The Integrated MARKAL-EFOM System,[1] California system) model was used to study how the California energy system could achieve an 80% reduction in greenhouse gases by 2050 [15]. Results indicate that meeting the emission target requires electrification of industry and transportation sectors, enabled by an expansion of wind and solar power after 2030, or carbon capture and sequestration (CCS) and nuclear if permitted. This comprehensive study shows that ambitious emission targets can be met, but the Alberta power system is currently much more carbon intensive than California's and, therefore, requires different policy measures, at least in the near-term. Carbon taxes were applied previously in a basic model of the Alberta power system, indicating that nuclear and large hydro power, if permitted, provide the greatest emission reductions [16].

Other previous research has a broader scope, modelling multiple jurisdictions or energy sectors. Nelson et al. apply carbon pricing in a high-resolution model of the power system in western North America to explore future low-carbon futures [17]. The research presents results showing what is possible in a system with cooperation among dozens of jurisdictions, but does not provide clear insight for the evolution of a sub-system in the absence of such regional integration. Capros et al. apply an emissions cap in a partial equilibrium hybrid model to explore the decarbonisation of multi-sector energy systems in the European Union until 2050 [18]. Results indicate that renewable energy (electricity and biofuels) and low carbon baseload electricity (nuclear and CCS) each contribute significantly to emission reductions, but the timing and relative difficulty of the transitions that occur in the system are not explicitly reported.

In this study, potential pathways to a low-carbon power system for Alberta are explored using a long-term, techno-economic, optimisation supply model. Simulations to 2060 are conducted for scenarios based on various carbon prices. The resulting energy mixes, system costs, and CO_2 reductions are evaluated, including sensitivity to fuel prices, technology costs, and load growth.

In Section 2, relevant background for the Alberta power system is provided, as well as key model characteristics and a description of the scenarios modelled. Results and discussion (Section 3) are presented in terms of carbon intensity, generation mix, emissions by source and type, and the impacts of high gas prices. Conclusions and implications of the research are in Section 4.

2. Methods

2.1. Background: the Alberta power system

Alberta has a deregulated energy-only electricity market, managed by the Alberta Electric System Operator (AESO), with 16 GW of capacity delivering 75 TWh annually. In mid-2014 there were nearly 100 generators offering into the Alberta market. Small gas-fired units under 100 MW are the most common, but the bulk of capacity is held by large coal-fired plants rated over 400 MW. Coal-fired thermal generation plants have been the system backbone since its inception, but cogeneration units sited for oil sands projects and fuelled by inexpensive natural gas have met most of the load growth since 2000. Over this same time frame, many new wind farms have been commissioned, resulting in a tenfold increase in wind generation between 2002 and 2012. Impressive as this growth is, wind generation met only 3.9% of demand in 2013, while coal and natural gas plants contributed 55% and 35% respectively [19].

Alberta is connected with interties to British Columbia (BC Hydro) at effectively ~700 MW, Saskatchewan (SaskPower) at 153 MW, and Montana (NorthWestern Energy) via a new ~300 MW merchant intertie. In Alberta's deregulated power market, imports may be purchased from external participants that offer in at $0/MWh, the pool price floor. Export bids to send electricity out of the province are set at $999.99/MWh, the pool price ceiling. Both import and export transactions ultimately occur at the final pool price for that trading block, a structure that prevents either imports or exports from controlling the pool price. Demand for power in Alberta has doubled over the last twenty years, and trade has shifted increasingly to imports, especially from hydro-rich BC during peak hours. Net imports in 2014 contributed 2.2% of demand, 62% of which came from BC [19,20].

2.2. OSeMOSYS energy model

The research presented here is conducted with the Open Source Energy Modelling System (OSeMOSYS), developed by the Royal Institute of Technology (KTH) in Sweden [21,22]. OSeMOSYS is a technology explicit, energy optimisation supply model well suited for analysis and planning purposes. OSeMOSYS is chosen for its open and accessible nature, which are extremely valuable when informing public policy by allowing third parties to independently reproduce results [23,24]. Although not as complex as some other models, OSeMOSYS results have been validated with MARKAL [21] and a TIMES-PLEXOS pairing [25]. OSeMOSYS is used to research electricity systems in several regions, including Africa [26,27], and Saudi Arabia [28]. The "underlying methodology" of OSeMOSYS has even been applied to the development of other energy system models [29].

In OSeMOSYS, a system is represented by technologies and the energy carriers that they use and/or produce. For example, a coal fired power plant (technology) uses coal (energy carrier) to generate electricity (energy carrier) that contributes to meeting a specified electricity demand. The user defines technologies by costs (capital, fixed, and variable), efficiencies, emission rates, existing capacities, production constraints, discount rates, etc. Energy carriers must satisfy the constraint that production must be greater than or equal to the sum of time-specific use and exogenous demand. Fig. 2 illustrates the Alberta model used in this study, showing technologies and energy carriers.

[1] http://www.iea-etsap.org/web/Times.asp.