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CARBON MITIGATION EFFECTS OF GLOBAL ENERGY INTERCONNECTION : THE CASE STUDY OF CONNECTING THE CANADA-US-MEXICO POWER GRIDS

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ABSTRACT

Widely known as the largest contributor to global carbon emissions, electricity sector has always been considered as a top priority for carbon emission reduction. Global energy interconnection (or, connecting power grids in different nations) could be one of the important measures to maximize the use of renewable/clean energy in different nations. However, its effects in carbon emission reduction have not well studied in a quantitative way. Taking North America as an example, this study uses a bottom-up energy system optimization model to study the carbon emission reduction effects of different interconnection scenarios. To capture the multiple possibilities of energy interconnection, we set up two scenarios for electricity demand: high and low; and two scenarios for power grid interconnection, weak connection and strong connection. The power electricity supply in different nations will change because of the different interconnection scenarios, which will make the CO_2 emission generated by electricity go up or down. When considering the power substitution and strong connection scenario, carbon dioxide emissions can be reduced by as much as 48% compared with the weak connection scenario.

Keywords: Global Energy Interconnection, CO_2 emission, North America,

1. INTRODUCTION

In order to address the climate change, resource shortage and other environmental problems, renewable energy, as a “clean energy” with no carbon emission, will take a significant place in future energy production to achieve sustainable development. Considering the trend of world energy development and global resource endowment, electricity will become the main form of energy supply in future, and "Two Substitutions", which means clean substitution and electrical substitution, would be the major solutions provided by this sector [1]. Clean substitution means electricity could replace other forms of “dirty” energy, such as coal and oil, at the supply side. And electrical substitution means electricity could replace other forms of dirty energy at the demand side, and therefore increasing the electricity demand. However, the mismatch of renewable electricity supply and electricity demand in spatial and temporal dimension is a huge barrier to maximize the use of renewable electricity. One of the key solutions is building global energy interconnection (GEI), which is a transmission plan of energies, relying on UHV (Ultra-high Voltage) power grid as its backbone. Also, the global energy interconnection is a key plan to embody the "Two Substitutions"[1].

Although most continents have the conditions to build large-scale renewable energy power plants, North America is considered to be more likely and easier to build the interconnection grids for four reasons, mature economic development system, rich renewable resources, high energy consumption and relatively simple geopolitical relations. What’s more, there are also super-grid plans in North America before [2,3]. A better understanding of the construction of global energy interconnection in Canada-US-Mexico will help the future development of the global energy internet.

Therefore, this study builds an energy system model for Canada-US-Mexico, and further discusses the future carbon emission reduction effects in different scenarios considering the GEI building.

2. METHOD

2.1 Electricity Demand Scenarios

Electrical substitution is defined as the substitution of electrical energy to coal, petroleum, natural gas and other fossil fuel to increase the proportion of electricity in the final energy demand.

To calculation the electricity demand in different electrical substitution scenario, the study simulates the future electricity demand using a grey economics model [4]. The equation is shown below:

$$D_{pr} = GDP_{pr} \times unitIE_{pr} + UPOP_{pr} \times unitUE_{pr} + RPOP_{pr} \times unitRE_{pr}$$

In the equation, *D* is the electricity demand; *GDP* means the gross domestic product (US Dollar). *unitIE* represent industrial electricity consumption per unit GDP. *UPOP* and *RPOP* represent urban and rural population. *unitUE* and *unitRE* mean per capita electricity consumption of the urban and rural household respectively. *pr* represents the country of the data.

Table 1 the Electricity demand parameters setting, under two scenarios

	USA & Canada			Mexico		
Electrical Substitution Scenario	Growth Rates of Industry Electricity Consumption per Unit GDP	Growth Rate of Urban Household Electricity Consumption	Growth Rate of Rural Household Electricity Consumption	G.th Rates of Industrial Electricity Consumption per Unit GDP	Growth Rate of Urban Household Electricity Consumption	Growth Rate of Rural Household Electricity Consumption
High	1%	1%	0	2%	3%	0
Low	0	0	0	0	0	0

Based on the population structure and rural/urban electricity consumption of Canada, America and Mexico, two electrical substitution scenarios are defined: low scenario and high scenario. Since US and Canada are the developed countries but Mexico is a developing one, the growth rates of industrial electricity consumption per unit GDP every year are set differently. For the developed countries, it is 0 in high scenario and 1% in low. For the developing country, it is 0 in high and 2% in low. The difference is distinguished while setting the growth rate of urban household electricity consumption as well: 0 in high scenario and 1% in low for developed countries, 1% in high scenario and 3% in low for the developing country. For the change of rural household electricity consumption, the difference is insignificant.

Based on the projection of population[5], GDP[6] and electricity demand scenario above, we can obtain the High Electricity Demand scenario and Low Electricity Demand scenario of Canada, USA, Mexico in 2050.

2.2 Energy Interconnection Scenarios

Global Energy Interconnection Development and Cooperation Organization (GEIDCO) did a research on Global Energy Interconnection backbone grid planning [7,8]. In our scenario assumption, Canada and Mexico are two completely independent grid, while US is partitioned into three parts: West USA, Texas, and East USA, as shown below[7].

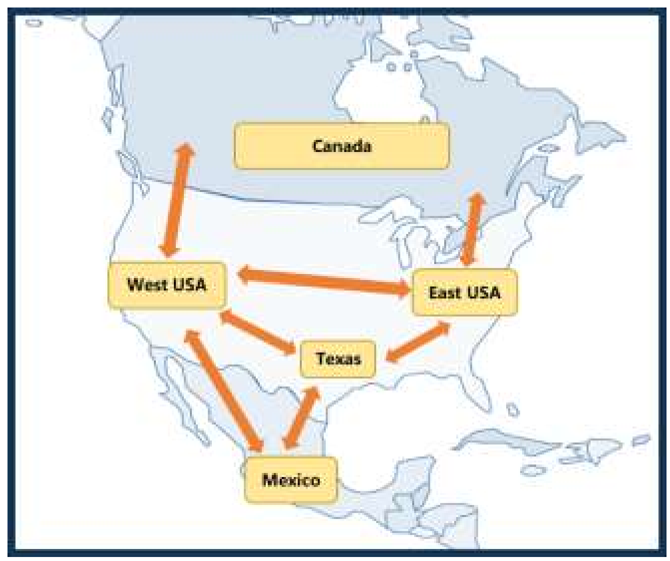

Fig1 Diagram of interconnection of Canada-US-Mexico

According to the reference [8], the two scenarios of energy interconnection are weak connection scenario(WC) and strong connection scenario(SC). Weak connection is considered as the same as the current connection in future. In the contrast, the strong connection scenario shows that the construction of backbone grid will be completed in 2050.

Considering the mutual promoted effects of electrical substitution and energy interconnection, the three scenarios are “High Electricity Demand (HED)+ Strong Connection(SC)”, “High Electricity Demand

(HED)+ Weak Connection(WC)”, and “Low Electricity Demand (LED)+ Weak Connection(WC)”.

2.3 Model Introduction

We developed a bottom-up energy technology optimization model for 5 regions to project the electricity supply of each technology in each region under different scenarios. The model could identify 24 technologies (including 13 coal-fired technologies, 3 other fossil energy technologies, 6 renewable energy technologies and 3 other technologies). The CO_2 emission of the electrical system is calculated using the emission factor method. The model could achieve the simulation of power structure under future power demand, with the optimization objective of minimized cost of the power system, considering the constraints of resources, construction speed and technological progress, etc. The model is based on the year of 2015, with some parameters from references[3,9], Other data sets of the model refer to many data sources.

3. RESULTS

3.1 Electricity demand

In the high electrical substitution scenario (HED), the electrical demand Canada, US and Mexico will increase up to 1174 TWh, 9394 TWh, and 1343TWh respectively. In the low electrical substitution scenario (LED), the electrical demand of US, Canada, and Mexico will increase up to to 1053 TWh, 7296 TWh, and 1062 TWh respectively (Fig 2).

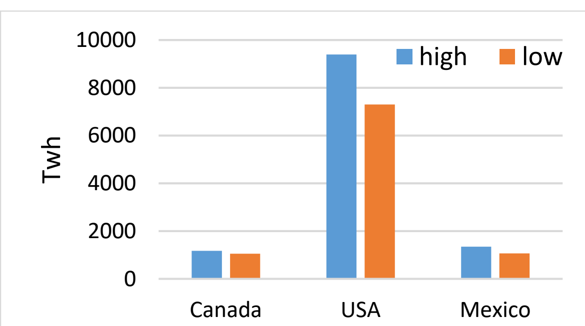

Fig 2 The electricity demand of Canada-USA-Mexico under 2 scenarios

3.2 The electricity supply structure and CO2 emission reduction under two interconnection scenarios.

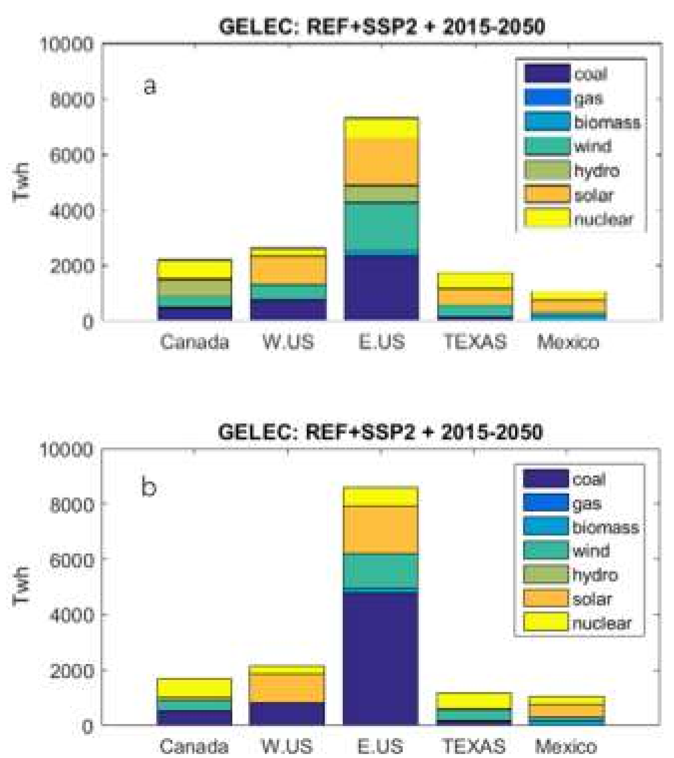

Fig 3 The electricity supply structure of Canada-USA-Mexico under 2 interconnection scenarios. (a, Weak Connection; b, Strong Connection)

In the “HED+SC” scenario, more clean energy like hydro-power in Canada and wind power will be produced in the west USA. The result shows that 24.8% energy will rely on coal. Especially for east US, the coal-power would produce about 32.6% of the total electricity demand.

If with the assumption of “HED+WC” scenario, the result would change a lot compared with HED+SC scenario. 42.3% of the electricity would rely on coal. For east US, the proportion of coal-power would increase to 55.6% of the total electricity demand.

Compared with the “HED+WC” scenario, the CO_2 emission from coal-power plants would be 92% more than the emission under the “HED + SC”, which means the CO_2 emission is nearly 2 times of that under “HED+SC” scenario.

4. DISCUSSION

The study uses bottom-up energy technology optimization model to stimulate the carbon emission reduction of Canada-US-Mexico in three mixed scenarios. The result shows that the construction of the Global Energy Interconnection can promote the development of local hydro power, wind power and solar power. The North America Global Energy Interconnection could also provide an accessible way to achieve the carbon emission goal in North America.

However, this study has several limitations. First, it has not taken the influence of inter-continent energy interconnection into consideration. Second, it would be meaningful to guide the renewable energy development if the benefit-cost analysis is included. Both of the topics will be studied in the future.

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