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THE ECONOMIC AND CLIMATE IMPACTS OF REDUCING CHINA'S RENEWABLE ELECTRICITY CURTAILMENT

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ABSTRACT

This study use a dynamic multi-sectoral CGE model with different nested structure and substitution elasticity for electricity sectors with different power sources to capture the effects of reducing renewable electricity curtailment across all economic sectors. We found that the reduction of renewable electricity curtailment would lead to a significant increase in renewable electricity generation, and a moderate decrease in non-renewable electricity generation. Among the renewable powers, wind power has the largest increase in activity level. Secondly, the reduction of renewable electricity curtailment would bring green co-benefits that carbon dioxide and air pollutant emissions from power sectors fall significantly, meantime national GDP and employment have slight increases. Third, without the cost-neutrality assumption, the impacts of reducing electricity curtailment would be largely over-estimated with CGE model. Fourth, if with multi-value simulations of CES substitution elasticity, the disparity on nested structure of power sectors would not cause serious disagreement on simulation results.

Keywords: Renewable power; Curtailment; Water-energy nexus; Environmental implications

1. INTRODUCTION

In order to mitigate climate change impacts and alleviate air pollution, China has accelerated the development of renewable electric power including hydropower, wind power, and solar power in the recent decade. However, the development of China's renewable energy is experiencing several challenges, and the most serious one is the renewable power curtailment [1-6]. The serious curtailment of renewable power would adversely affect the development of renewable energy industry by reducing enterprises' profit and lowering down investors' confidence [7-8]. Moreover, due to much smaller emission factors for renewable electric power, the curtailed renewable electric power may imply seriously incremental emission of carbon dioxide and air pollutants (such as SOx and NOx).

Based on the review of the literature, we found three research gap which will be addressed in this study. Firstly, in the economic studies, the methodology to explicitly simulate the changes in renewable electricity curtailment with economic models has not been developed. Secondly, the previous studies have not analyzed the actual replacement of non-renewable electricity by renewable powers in the economic model affected by reducing renewable electricity curtailment. Thirdly, different nested structures of electricity sectors with various substitution elasticities have been used to empirically evaluate the development of renewable electricity, which leads to the large disparity on research results.

Since the development of renewable electricity plays a vital role in China's low-carbon transformation and has widespread effects across the whole economic system, we use a dynamic multi-sectoral CGE model with differentiate nested structures and different substitution elasticities for electricity sectors to capture the economic and environmental effects of reducing renewable electricity curtailment in China.

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2. CHINA'S RENEWABLE ELECTRIC POWER CURTAILMENT

Table 1. The renewable power curtailment in China and selected regions in 2015-2017

	2015		2016		2017	
	Curtailment (TWh)	Curtailment rate (%)	Curtailment (TWh)	Curtailment rate (%)	Curtailment (TWh)	Curtailment rate (%)
Hydropower	53.70	4.90	52.90	4.31	51.50	4.13
Wind power	33.90	15.40	49.70	12.68	41.90	12.05
Solar power	4.90	11.22	7.40	9.89	7.30	5.82

Source: data on renewable power curtailment from National Energy Agent, China, 2016-2018

Note: Curtailment rate: Curtailment rate = curtailed power/ (curtailed power + grid-accommodated power); data on power generation from China Electric Power Yearbook, 2016-2017.

Accompanying with the rapidly increasing installed capacity and generation of wind power in the past years, China's curtailed wind power reached its peak in 2016 nearly 50 TWh. The regions with severe wind power curtailment mostly are mostly located in northwest, north, and northeast China. Similar to wind power, the serious curtailment of solar power has emerged accompanying with large-scale investment since early 2010s. China's curtailed solar power reached its peak in 2016 of nearly 7.40 TWh, and mostly located in northwest China. Hydropower has much lower curtailment rate but larger curtailed volume than wind and solar power, the curtailment sill exceeded 50 TWh in 2017, due to large installed capacity and generation of hydropower. Hydropower resources are mainly located in Yunnan and Sichuan [1; 6], accounting for over 70% of national hydropower curtailment in 2016 and 2017.

By reviewing the existing studies, renewable electricity curtailment could be mainly attributed to the problems of planning and policy more than those of resource and technology. Therefore, it is technically and economically feasible to reduce renewable power curtailment in China by improving power planning and policies to facilitate power accommodation by power grid.

3. SIMULATION MODEL AND METHODOLOGY

3.1 Simulation model and data source

To simulate the changes in renewable electricity curtailment, we have improved the electricity module of CHINAGEM model, and split the electricity sector to eight sectors for electricity generation with different power sources, including coal-fired power, oil-fired power, gas-fired power, nuclear power, hydropower, wind power, solar power, and biomass and geothermal power, and one sector for electricity transmission and distribution.

With different nested structures, electric power sectors would have much different substitution relationship, which determines the changes in electricity generation with power sources affected by reducing China's renewable electric power curtailment. Given the total utilization of electricity for each producing sector, then two types of nested structure of electricity generation sectors with the CGE model are introduced to reflect the substitution relationship between electricity with different power sources (Figure 1).

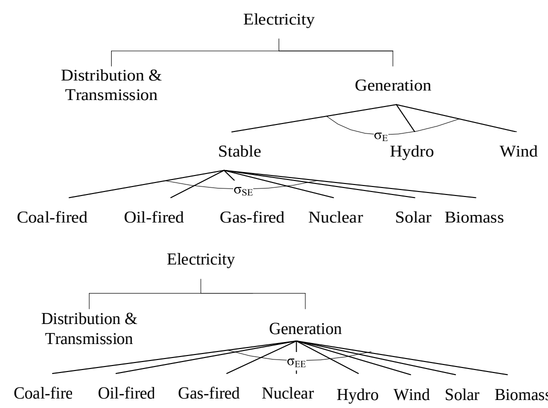


Figure 1. The nested structures of electricity sectors in Model A (above Panel) and Model B (below Panel)

To establish the database of CHINAGEM model, we make use of China's 2012 input-output table with 139 original producing sectors. As there is only one electricity sector in the original input-output table, the original electricity sector is split to 9 sectors with different power sources including 8 generation sectors and 1 sector of power transmission and distribution with the data from China Statistics Yearbook and China Electric Power Statistics Yearbook. Similarly, the crude oil and gas sector is spitted to two sectors: crude oil and crude gas. Thus the 146 producing sectors are obtained. The Armington elasticities of commodities are transferred from the GTAP V10 database by mapping the CHINAGEM 146 sectors to GTAP 57 sectors. Other elasticities of demand and supply equations are from the previous studies.

3.2 Scenario

As China's renewable electric power generation is projected to increase rapidly in the coming decades stimulated by incentive policies [9], a baseline scenario from 2013 to 2030 is established based on the projection by IEA (2018) to reflect different changing trends of electricity generation with different power sources [10].

Then to evaluate the impacts of reducing renewable electric power curtailment, the policy scenario is designed with the assumption that China's renewable electricity curtailment will be completely depleted before the end of 2020s. During 2021-2030, the curtailment rate of renewable powers would gradually decline from the average level of 2015-2017 with annually equal changing rates. As a result, by 2030 renewable electricity capacity will be fully utilized. The utilization of renewable electric power capacity could be improved by technology and management progress related to renewable energy, such as accelerating the construction of power grid, improving power peaking capacity, and reforming the local power market. This type of technological progress could be simulated by raising total production efficiency (*a1tot*) of renewable electricity sectors in the equation (1) - (3).

$$x1prim(i)-\{a1prim(i)+a1primgen+a1tot(i)\}=x1tot(i) \qquad (1)$$

$$x1energy(i)-\{a1energy(i)+a1tot(i)\}=x1tot(i) \qquad (2)$$

$$x1(c,i)\_s-\{a1(c,i)\_s+a1tot(i)\}=x1tot(i) \qquad (3)$$

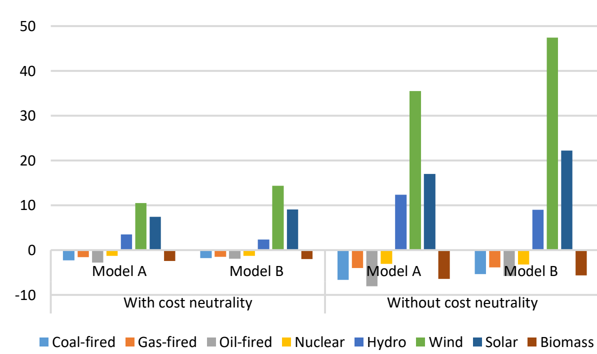
For each sector *i*, *x1prim(i)* and *x1energy(i)* are the percentage changes in total inputs of primary factor and energy commodities respectively, and *x1(c, i)_s* is the percentage change in non-energy intermediate input of commodity *c*. *a1prim(i)*, *a1primgen*, *a1energy(i)* and *a1(c, i)_s* are the percentage changes in input-augmented technology relating to primary factors, energy commodities, and non-energy intermediate inputs. *x1tot(i)* is the percentage change in i^{th} sector 's output. *a1tot(i)* is the percentage change in total production efficiency of sector *i*, which represents the total production efficiency. From the equation (1) - (3), it's obvious that the decrease in *a1tot(i)* representing technological progress could raise the output of sector *i* and lower down the utilization of primary factors, energy commodities and non-energy intermediate inputs.

However, the default of this method is that total generation cost of renewable electric power sectors would simultaneously be reduced, for the progress in total production efficiency could save the intermediate and endowment inputs for the same level of power generation. But the technology and policy progress to reduce renewable electricity curtailment should not cut down the production costs of renewable powers but only facilitate its utilization by power grid. Therefore the simulation results would over-estimate the changes in renewable power generation caused by raising total production efficiency of renewable powers unless total generation cost is unchanged. So we introduce the cost-neutrality assumption to make up the reduced total generation costs for renewable electricity sectors which is equal to the change in total production efficiency multiplying total generation cost. Then we compare the results for changes in electric power generation between the simulation with and without cost neutrality assumption.

The substitution between electricity sectors with different power sources not only depend on the nested structure of electricity sectors in CGE model, but also on the calibration of CES substitution elasticities. The previous studies have specified different values for CES substitution elasticities of electric powers. The nested structure in Model A is employed in Dai et al. (2016) who set σSE and σE to be +∞ and 3 respectively, which indicates indefinite substitution among stable powers, and definite substitution between stable and intermittent powers [9]. However, Liang et al. (2014) has employed the same nested structure, but calibrated σSE and σE to be 10 and 3 respectively [11]. To obtain the robust results for the impacts of reducing renewable electricity curtailment, a series of simulations specifying different CES substitution elasticities should be implemented. In this study σSE and σE of model A are calibrated to be 10 and 3 respectively following Liang et al. (2014) [11], and σEE of model B to be 5 following Chateau et al. (2015) [12]. Then two different simulations for each model are conducted raising CES substitution elasticities by 50% or decreasing by 50% respectively, which could generate different simulation results for power generation and economic variables.

4. RESULTS FOR REDUCING RENEWABLE ELECTRICITY CURTAILMENT

4.1 The changes in electricity generation



Source: CHINAGEM model

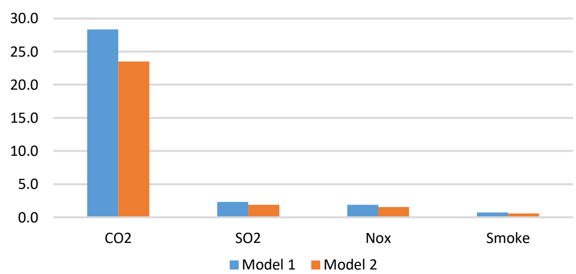
Figure 2. The impacts of reducing renewable electric power curtailment on activity level of electric power sectors (%)

Among the renewable powers, wind power would have the largest increase in activity level by over 10% affected by reducing renewable power curtailment; Solar power would has smaller increase in power generation, as it has a relatively smaller curtailment rate (9.0%);

Hydropower would have a slighter positive impact on its power generation (3.5% in Model A and 2.4% in Model B). But the changes in renewable power generation is much different between the two models. In contrast to renewable electricity, the electric power generated with fossil fuel, nuclear, and biomass would have a moderate decrease affected by reducing renewable electricity curtailment.

Interestingly, compared with Model A, the Model B has larger percentage increases in wind and solar power generation, which is highly dependent on alternative nested structures specified in these models.

4.2 The changes in carbon and pollutant emission



Source: CHINAGEM model

Figure 2. The reductions of carbon dioxide and air pollutant emissions from power sectors affected by reducing renewable electricity curtailment (million tons)

As the fossil-fuel electric powers have much higher emission intensity of carbon dioxide and air pollutants, the replacement of fossil-fuel electricity by renewable powers affected by reducing renewable electricity curtailment would reduce carbon dioxide and air pollutant emissions of electric power sectors. The reduction in carbon and air pollutant emission are mainly resulted from the substitution of renewable electricity to coal-fired electricity.

Furthermore, the Model A would have the larger decreases in carbon dioxide and air pollutant emissions from power sectors than Model B.

4.3 The changes in macro-economic variables

The reduction of renewable electricity curtailment would raise the national GDP by 0.03% in Model A and 0.02% in Model B respectively during the period of 2021-2030. Meantime, China's total export would also increase by 0.05% in Model A and 0.04% in Model B respectively, while the total import would decline by 0.02% in Model A and 0.01% in Model B respectively. From the expenditure decomposition of national GDP, the changes in total export and import account over 70% of GDP increase both for Model A and Model B. At the same time, the reduction of renewable electricity curtailment would also have positive impacts on China's total employment in 2021-2030.

The results is consistent with the previous studies that the expansion of renewable electricity would bring green co-benefits with the changes in power generations by raising GDP and employment [9].

4.4 The major winner and loser sectors

Table 2. The most positively and negatively affected producing sectors by different models (%)

Model A		Model B	
The most positively affected sectors			
Basic Chemistry	0.089	Basic Chemistry	0.059
Non-Ferrer Cast	0.057	Non-Ferrer Cast	0.041
Non-Ferrer Ore	0.055	Electrical Machinery	0.041
Synthetic material	0.051	Non-Ferrer Ore	0.040
Synth Mate	0.050	Electrical Comp	0.035
Ferrer Production	0.047	Ferrer Production	0.034
The most negatively affected sectors			
Coal mineral product	-0.35	Water service	-0.284
Water service	-0.13	Coal mineral product	-0.243
Electricity Distribution	-0.04	Machine Repair	-0.025
Machine Repair	-0.02	Financial Service	-0.015
Financial Service	-0.01	Gas Supply	-0.015
Gas Supply	-0.01		

Source: CHINAGEM simulation

Determined by the input-output relationship, the upstream and downstream sectors along the production chain of renewable sectors would benefit from the reduction of renewable electricity curtailment. Other positively affected sectors are mostly the downstream sectors of renewable electricity sectors consuming a large amount of renewable powers, and have increases in activity level by over 0.03% in 2021-2030. Those sectors negatively affected are mostly along the production chain of non-renewable powers.

5. CONCLUSIONS AND DISCUSSION

The major findings of this paper are summarized as following. First, the reduction of renewable electricity curtailment would lead to a significant increase in renewable electricity generation, and a moderate decrease in non-renewable electricity generation. Second, the reduction of renewable electricity curtailment would bring green co-benefits that accompanying with changes in power generation, carbon dioxide and air pollutant emissions from power sectors decline significantly, meantime national GDP and employment increase slightly. Third, without the cost-neutrality assumption, the impacts of reducing electricity curtailment would be largely over-estimated with CGE model. Fourth, with multi-simulations of CES substitution elasticities, the disparity on nested structure of power sectors would not cause serious disagreement on simulation results.

This study contributes to the existing literature in the following perspectives: 1) the method to simulate renewable electricity curtailment with CGE model is developed. 2) The actual displacement of non-renewable electricity by renewable powers affected by reducing renewable electricity curtailment is examined. 3) The relative importance of nested structure and substitution elasticity for power sectors is assessed.

This paper examine the complete depletion of renewable electricity curtailment by the end of 2020s, however, the curtailment depletion needs a great amount of investment and policy effort. Specifically, accelerate the power grid construction to establish trans-regional power transmission

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