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Energy structure change and carbon emission trends in China

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ABSTRACT

This article builds a hybrid energy model based on energy demand and energy supply equilibrium, along with the objective of minimizing costs. To estimate the differences between various energy technologies that impact the economy, efficiency and carbon emissions, we simulated the structure of China's future energy roadmap and trends of carbon emissions. The simulation results show that if international oil prices decline and China's economic growth appropriately deviates from the golden growth, carbon emissions can reach a peak in 2025, relying mainly on nuclear energy to substitute for coal. In other words, the peak of carbon emissions in China can technically be achieved by 2025, but certain economic losses will occur. With the objective of costs minimization, the results indicate that after 2025, the proportion of coal in the country's total energy supply will rapidly decline. However, in 2030 the proportion of non-fossil energy in the country's primary energy supply will remain slightly lower than 20%.

1. Introduction

The world's largest economies, China, the US and the European Union, recently announced ambitious targets for reducing emissions post-2020. In particular, in November 2014, China and the United States announced a joint statement regarding their post-2020 emissions reduction targets, in an effort to slow down climate change as a powerful force. The countries will strengthen cooperation in advanced coal technology, nuclear energy, shale gas and renewable energy, and thus promote bilateral energy structure optimization and reduction to include what is generated from coal emissions. To achieve this goal, China must make an achievable roadmap. On this issue, former vice minister of Chinese Ministry of Science and Technology Liu [1] proposed eight ways to cope with ever-increasing pressure to reduce CO_2 emissions in accordance with progress of China's national development planning and science and technology research, including improving energy structure, improving energy efficiency, nationwide campaign on energy conservation and emissions reduction, increasing carbon sinks on land and sea, attention transfer of production capacity, innovative engineering, participating in scientific discussions, increasing the share of emissions and so on. He pointed out that to improve the energy structure adjustment become the best way to reduce emissions of CO_2, but he did not make specific route to control energy use.

Although the route is still not clear, but the Chinese government has committed to achieving carbon emissions peak around 2030, and strive to advance. This commitment is actually in line with demand-side analysis, Chinese scholars have studied trends in carbon emissions from the demand side of economic development, found in the current rate of technological progress to protect the reduction and avoid the economic crisis, China's emissions peak is more appropriate shown in 2030. Zhu and Wang et al. suggested a model to estimate carbon emission demand under a balanced growth path [2] and Wang and Zhu et al. developed the model of economic growth with technological progress [3], their calculated results showed that China can achieve carbon emission control in 2031; however, they failed to control emissions from the supply side. Shi, Zhu and Wang [4] enriched the route structure of this reduction, but still found it difficult to determine the specific emission reduction route, and also excluded the uncertainty of technological progress. Therefore, Wu and Wang et al. [5] further developed an evolutionary economics model that was obtained under the condition of uncertain technological advances, determining that the peak of China's energy consumption will most likely occur in 2029, with a peak value of 5146 Mtce. Based on uncertain interference, the probability of reaching a peak in carbon emissions by 2030 is 91.79%; thus, it is likely that the commitment will be implemented. This paper tries to discuss emissions from the supply side, that is, under steady growth constraint, from the

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perspective of energy supplies for China to achieve the road map of optimal control of emissions and to reach carbon emissions peak as early as possible.

2. Model and data

Obviously, under the condition of steady growth, China wants to achieve its emission reduction commitments need to design an emission reduction roadmap which meet two constraints: 1) reduction path should meet the needs of steady economic growth, ensuring that no economic crisis will result from an emissions reduction; 2) emission reduction process can be technically achieved, controlling the alternative energy reduction process on a near-optimal route. Under optimal conditions for stable economic growth, these are the ideal results in consideration of the cost.

2.1. Energy demand model

Model constructed in this paper will balance energy demand and energy supply as a constraint, trying to achieve a "soft link" between macro-economic and micro energy technologies, namely energy demand is exogenously given. Energy demand data are from the work of Wu and Wang et al. [5] who calculated them based on input-output model and Agent-Based Simulation approach. In the energy demand model, they divided China's macro-economic system into 17 departments and integrate to micro-enterprise innovation behavior to achieve the simulation of Chinese energy consumption under the micro-enterprise innovation-driven. Such combination of methods in microscopic individual analog and macroscopic structure simulation preferably reflect the impact of the main consumer of macroscopic energy demand under the steady growth.

2.2. Energy supply model

In this paper, using examples of energy demand in the context of balanced economic growth, carbon emissions due to energy use are calculated based on the structure of the corresponding energy supply. Because technical and economic systems always seek the minimum cost, changes in the cost of energy will determine the structure of carbon emissions. Different energy sources have different carbon intensities, with the total cost of the minimum energy structure, which has been affected by changes in energy prices and technological progress, determining the resulting carbon emissions. From the above analysis, the key issue is to construct an energy model to respond to technical and economic processes, as opposed to the Wang and Zhu [3] approach of using empirical data to estimate energy structures and calculate emissions macroscopically.

An energy supply model was created based on minimizing the total cost of an energy system. The costs of different economic energy supplies (including investment, operations and maintenance costs) were compared after discounting. The optimal solution was the combination of the smallest total system costs. Ultimately, the choice of technology combination minimizes the premise that the whole energy supply system must meet the demand of energy costs, while at the same time provides a change in structure to the trends of energy technology and corresponding prices and cost changes. Each year, the energy consumption of economic activities must equal the energy supply, which will be presented as a constraint in the research model, namely, energy demand is exogenously given. Thus, we propose a specific configuration of the energy supply model, as shown in Fig. 1.

2.2.1. Energy technology category

In this paper, energy supply technologies been classified as electric energy and non-electric energy. The electric energy technologies, including hydropower, nuclear, wind, solar photovoltaic, biomass power generation and traditional thermal power, are subdivided into categories of coal-fired thermal power technology, oil and gas power generation. Coal-fired power is further categorized as traditional pulverized coal power generation (PC), supercritical and ultra-supercritical coal-fired power (USC) and integrated gasification combined cycle power generation (IGCC) technology. Non-electric energy mainly consists of coal, oil, natural gas and biomass. According to the characteristics of the different energy technologies and the mutual ease of alternatives, we use constant elasticity of substitution (CES) as a production function for each energy technology at multiple levels of a nested compound, as shown in Fig. 2.

Non-electric energy refers to the energy derived from the exploitation of nature, which can be used directly without a second conversion, so its price depends on mining costs. Nordhaus [6] considered fossil fuels to be expendable fossil energy resources with acertain total amount, and believed that as the yearly consumption of fossil fuels increases, the cost will continue to rise. Therefore, the price of fossil fuels is calculated endogenously using a reduced-form cost function that allows for non-linearity in both the depletion effect and in the rate of extraction:

$$P_f(t) = \chi_f + \pi_f\left[Q_f(t-1)\Big/\overline{Q}_f(t)\right]^{\psi_f} \quad f = coal, gas \tag{1}$$

χ_f is the current cost of energy extraction, transportation costs and distribution costs, π represents effects of resource depletion. The second term is a function of increasing costs, Q_f and $\overline{Q}_f$ represent the accumulation and exploitation of the remaining reserves, indicated as:

$$Q(t-1) = Q_f(0) + \sum\nolimits_0^{t-1} X_f(t) \quad f = coal, gas \tag{2}$$

$$\overline{Q}(t+1) = (1+\eta)\overline{Q}_f(0) - Q_f(t) \quad f = coal, gas \tag{3}$$

X_f is the fossil energy consumption, η is the rate of change in remaining reserves. Part of the mined fossil energy used directly as non-electric energy *NEL*, and partly as fuel for power generation *EL*, namely:

$$X_{f,t} = NEL_{f,t} + EL_{f,t} \tag{4}$$

To this end, non-electric energy supply costs are as follows:

$$C_{NEL,t} = \sum_{i \in NEL} P_{i,t} \cdot NEL_{i,t} \tag{5}$$

Electric energy production generally requires three input elements: capacity *KD*, operation and maintenance costs *OM* and fuel *EL*. Because these three essential elements are for the production of electricity, they cannot be an alternative to each other, wherein an amount is equal to the actual power supply capacity of the smallest element. Therefore, the following is the production function using the Leontief form:

$$E_{ELj}(t) = \min\left\{\mu_j KD_j(t); \tau_j OM_j(t); \xi_j EL_j(t)\right\} \quad j = coal, gas, oil, nuclear, hydropower, solar, bio, wind \tag{6}$$

of which, μ_j is the device utilization efficiency, τ_j reflects the operation and maintenance costs of different electricity generation technologies, ξ_j is the efficiency of the fuel into electric energy, i.e.,