CARBON MITIGATION AND BENEFIT EVALUATION IN CHINA: STUDY BASED ON DISCRETIZED PRODUCTION COST CURVE

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Introduction

With the Paris commitment put into action in Nov 4th 2016, China's INDC targets in 2030 are drawing much more attention. Specifically, the energy system optimization analysis based on energy modelling emerged with large amount in recent years. However, for most of China's bottom-up model, in the supply module, the assumption of resource costs are set referring to their prices, thus the supply curves are horizontal lines. There are several short comings with this kind of supply curve. First, based on these supply curves, the model can not analysis the changes of resources supply; second, the model can not distinguish the effect on resource substitution and technology improvement; Third, thus the model might overestimate the resource substitution effect, and can not offer the absolute energy optimization solutions, which are extremely important for the INDC relevant analysis.

This paper introduces resource supply curve. Our study takes into consideration of the supply of resources, including domestic production and import, looking into different resource production regions (like North China, East China, Northeast China, Central south, Southeast and the West, etc.), and the resource supply under different production capacities and costs. Resource supply curve is important because in bottom-up energy optimization models, the price ladder of resource supply will directly affect the choice of technologies, thus make the technology structure after energy optimization more reasonable. The study tries to embedding the detailed energy supply curve into the bottom-up model, aiming to optimize China's energy models.

There are already some studies on energy supply curve. An US EPA report, Documentation for Integrated Planning Model (IPM) Base Case v.4.10[1], contains a chapter of coal supply curve. They constructed coal supply curves for supply regions in the USA from 2012 to 2030, using detailed data of cost and production of coal mines of each year in each product region. The report also gives specific steps to make the supply curve. First, make a table of the producers, listing their costs and productions, then sort them by cost from lowest the highest, and plot them cumulatively by production. As data of different years are independently collected, the development mechanism of the supply curve is not stated. There are also some other ways to construct supply curves, like econometrics. A document from EIA[2] uses the two-stage least squares (2SLS) methodology to get the regression equation of price on output, productivity, wage, etc, and then the regression equition was transformed into a function between price and production.

Scholars from Stanford university studied the world steam coal trade flow, and constructed the marginal cost curves for each producer[3]. As for China, the COALMOD model contains four supply regions as producers. Each producer chooses their production and investment to maximize their profits. And the cost of each producers changes as production commulates, and cost curves are constructed for each producer from 2006 to 2040. The base year marginal cost curve uses real data, and the future years' curves are derived from the base year curve, through the change in intercept and slope. In this paper, we mainly use this method to make future curves for each province.

In the energy system model literature, a few papers about foreign countries energy system have considered the energy supply curve. Egging et al[4] included the supply curve of natural gas in Europe in their study of European natural gas market. In some energy system research field, supply curve is still not popular in foreign countries. The report from German Federal Ministry of Transport and Digital Infrastructure (BMVI)[5] about the perspectives for development in transport sector calculated natural gas price in EU based on crude oil price, which is far from accurate. Scholars from University College London, Li and Strachan[6], used BLUE (Behaviour Lifestyles and Uncertainty Energy model) to study actor inertia in energy transition, and fuel price is set to grow by a user input rate k_f. Charlier and Charlier[7] in their study used the energy price projection from iea.

However, China has few studies on supply curve. Xie et al[8] combined GAINS-China model with CGE Model to assess the economic impacts of air pollution in 2030 in two scenarios, in the CGE production module, energy is considered as input, but the energy supply curve is not mentioned. Huang et al[9] used the single cost of energy in the study of integrated electricity and natural gas. In a master thesis[10], there are two assumptions about supply curve, linear and non-linear, to study the ladder pricing, for which the construction of realistic supply curves will be of good help. Lin and Liu[11] constructed the energy saving supply curve, which is close to the energy supply curve.

Methods

There are some fundamental principles for the endogenous price problem of resource supply. First, the use of resources is strictly ranked according to cost levels. Second, if the price is higher than its cost, the resource will be depleted completely, which means once the mining activity starts, the mineral deposits will be mined until the deposits has been depleted. With the production progress going on, per unit production cost will increase. Because the high quality mineral resources with lower production cost are explored first, and with the production progress going on, other reserves with higher cost are explored gradually, with new investments. The short-run cost curve moves upwards when the cumulative production amount increases, and its slope also changes due to the new investment. And in the long run, as the residual of mineral reserves decreases, the exploitation difficulty is enlarged gradually, causing per unit production cost to increase rapidly.
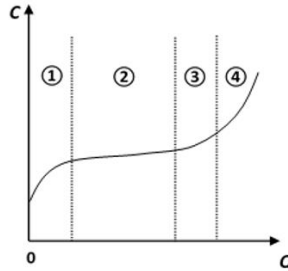

Figure 1 long-run cost curve of one supply region

The intercept and slope of the marginal cost curve in the base year is set based on the data collected, and they will change in future years. According to the COALMOD, the increase rate of intercept is influenced by factors such as the amount of recoverable coal resources, the annual production and some other geological factors, the setting in the COALMOD for China supply regions could be referred to and adjusted for the construction of supply curves in different provinces. The slope change rate is decided by the type of the supplier, and there are mainly four types, as shown in Figure 1. The slope could increase, decrease, or not change in different stages in the long run. For stage 1 and 4, slope increases, and new investment will accelerate the increase of the marginal cost. In stage 2, new investment will make the slope decrease. When the supplier is in the stage of type 3, the slope is constant, and the change is zero.. As the slope change rate is influenced by the cumulative investment, the investment forecasting is also of great significance. Some institutes have published forecast reports about China's energy investment, like the WEIO from IEA[12]. Some data from the reports could be used for our study. The equation 1 and 2 show the principle of the change of the intercept and slope of the marginal cost curves.

intercept= previous period's intercept+previous period's slope*production in that year*intercept change factor   (1)

slope= base year slope+cumulative investment of previous periods * slope change factor   (2)

After making the marginal cost curves of each supply region, the overall supply curve of China could be constructed. As the marginal cost of each region is taken as a upward curve with different slopes, it is difficult to make a continuous line. So the average costs of each supply region in the model year is used in the supply curve, and a steped curve is constructed, as shown in Figure 2. The discretized cost curve is based on the fundamental that resource reserves are a series of degree resources with different unit production costs. Based the theories above, we draw the energy supply curves for China's exhaustible resources such as coal, crude oil, natural gas, etc. For renewable resources, although there is no total amount limit like exhaustible resources, because there are big differences between the production costs in different production regions, we can also draw the resource supply curves based on different technologies.
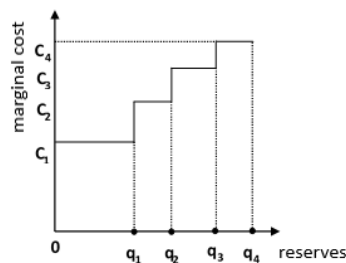

Figure2 discretized cumulative production cost curve

Results

In this study, the production capacity and average total costs are used to construct the supply curve. The supply curves of coal in 2010 and 2030 are shown in Figure 3 and 4. China's domestic coal resources are mainly distributed in the northern and western regions. For coal resources imported, our model mainly involves that from Australia and vietnam-Indonesia regions. We estimated the transportation costs for main coal production regions based on the data research about railway transportation distance and per unit standard coal transportation costs. Then the average total cost including transportation cost is calculated for each coal production region.

The natural gas supply curves in 2010 and 2030 are shown in Figure 5 and 6. The natural gas resources in China are mainly distributed in the eastern central region, the western region and southeastern coastal areas, and there are about nine main oil-gas bearing basins in China. Nonconventional natural gas resources are also considered in this paper, like coal bed methane(CBM) and shale gas. The CBM resources are distributed mainly in coal districts in the east, the central and the west, and large gas basins. The shale gas resources are main in northern and northwestern regions. Except for that, Sichuan and Qinghai-Xizang regions also show great exploration potentials. The supply curves of crude oil and renewable energy are also constructed in this paper.
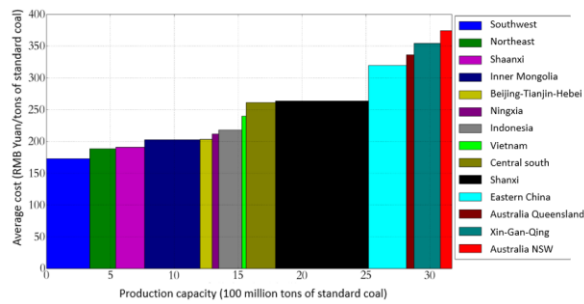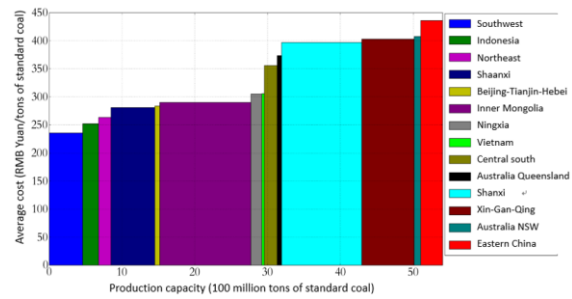

Figure 3 China's coal supply curve in 2010

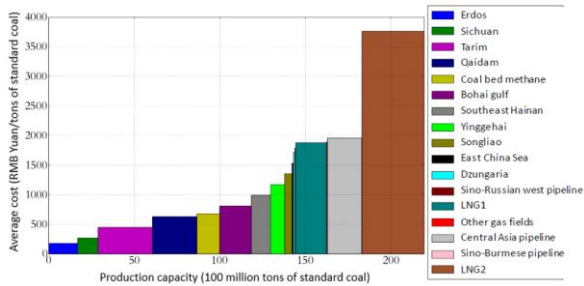Figure 4 China's coal supply curve in 2030

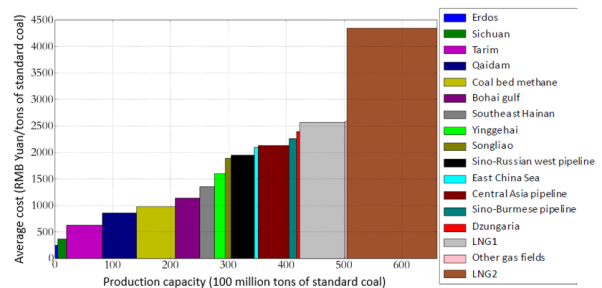Figure 5 China's natural gas supply curve in 2010

Figure 6 China's natural gas supply curve in 2030

Conclusions

This paper draw China's energy supply curves for exhaustible resources like coal, crude oil and natural gas, as well as curves for renewable resources. The production cost curves are drawn as discretized cost curves using S-shaped curve as trendline. The discretized cost curves are based on the fundamental that resource reserves are a series of degree resources with different per unit production costs. The ladder supply curve presents the alternative relationship between different resources, and makes the technology selection more reliable. The results of this study will be further embedded into China's bottom up model, called China-MAPLE, which is developed by our group, and helps to analysis the energy optimization issues in China for its INDC up to 2030.

In the initial, without considering the ladder price, the production mudule in the energy system model will be biased from the reality, causing the result to be unaccurate. The assumption of single price of energy will lead the equilibrium in energy market far from its real value, thus make the forecast unreliable. The improvement in the supply module will make the model more robust. Further improvement will also include the monetorization of health impact evaluation module, and all these improvement will perfect China-MAPLE model.

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