Scenario analysis of China's future energy demand based on TIMES model system

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Abstract

The China TIMES model system, integrated with China energy service demand projection model (ESDPM) and TIMES model (the integrated MARKAL-EFOM system), is built to study China's future sustainable energy and environment development strategy, based on energy demand projection with scenario analysis. On the basis of reasonable assumptions on the future economic growth and social development, the model system is employed to project China's energy demand from 2010 to 2050. The result shows that China's energy demand is expected to maintain a sustained and rapid growth before 2020, and then slow down gradually, reaching 6.6 and 6.2 billion tce in 2050 in reference scenario and policy scenario respectively.

Keywords: energy demand; TIMES model system; energy service representative; final energy demand; primary energy consumption.

1. Introduction

As we knew, China has announced a series of policies and actions for sustainable energy and environment development. In 2007, the Chinese government published its target of 20\% reduction in energy intensity by 2010 compared to the 2005 level. In November of 2009, the State Council announced China's goal of 45-45\% reduction in carbon intensity and non-fossil fuels target of 15\% for primary energy consumption in 2020. However, the data showed that China's energy consumption in 2008 was about 2.9 billion tce, with GDP per capita low as 3.4 thousand dollars \cite{1}. Based on various of researches, China's energy demand in 2050 is expected to reach 6 billion tce, assuming China will achieve the level of middle-class developed countries by the time, even if using the highest energy efficiency of OECD countries \cite{2}. It implies that China's energy demand would doubled by then on the current basis, imposing...
great challenges to China’s future sustainable energy and environment development.

So it’s very meaningful to do some energy system analysis with China energy system model to analyze future energy and environment development strategy, describing what kind of a way on which China can not only achieve economic development goal, but also meet the constraints of energy supply and environment protection. To achieve this target, energy demand projection will be undertaken firstly in order to provide updated drivers for energy system model, and it’s also the base for energy modeling.

Now, China is undergoing rapid industrialization and urbanization. Industry, transport and resident sectors account for over 90% of final energy consumption in recent years, and their energy service representatives (ESR, the physical quantities to represent the activity level of energy service) [3] have increased dramatically, such as energy intensive production, private cars and floor areas, which will all show saturation trend according to OECD countries’ experience. The past rapid growth and future saturation trend of these ESR cause a great uncertainty of China’s energy demand projection.

The China TIMES model system, integrated TIMES model (the integrated MARKAL-EFOM system) with China energy service demand projection model (ESDPM), is built to study this issue. On the basis of reasonable assumptions on the future economic growth and social development, the model system is employed to project China’s energy demand from 2010 to 2050 for reference scenario and policy scenario respectively, giving the future strategy on primary energy supply development and final energy demand control, which will provide the reference for future sustainable energy and environment development.

2. Methodology and data assumptions

2.1. Model system building design

According to relevant studies, there was a clear positive correlation between ESR and their drivers, such as passenger transport was correlated with GDP per capita while freight transport was correlated with the total GDP, and there were similar correlations in other sectors [4-6]. Econometric methods and models can describe this relationship appropriately, and have been widely used because they are simple and practical, especially the regression analysis method [7-8].

However, if above methods are simply used to forecast the energy intensive production, the floor area per capita and car ownership directly, the projection would be much higher than expected, because these ESR increased sharply in the past recent years, as shown in Figure 1 taking the energy intensive production as an example. Therefore, it’s necessary to build an all-sided functioning model to project energy demand systematically, especially to project above ESR with saturation.

![Fig. 1 Historical trend of energy intensive production](image)

In the car ownership projection study, Gomperta model was used to project future car ownership with saturation [9-10]. Its theory can be used to build a saturation limit projection module (SLPM) to project future energy intensive production, and also for private cars and
floor areas. When it is used to project the energy intensive sectors, assuming the number of sectors is $m$, and each sector has $n$ levels of saturation, then SLPM module is described as following:

$$I_{i,j} = S_{i,j} \cdot \exp[\alpha \exp(\beta GDP)]$$

(1)

$$\forall S_{i,j} \in [I_{i,\min}, I_{i,\max}] \quad 1 \leq i \leq m, 1 \leq j \leq n.$$ 

(2)

Where $I_{i,j}$ is per capita demand; $GDP$ is the GDP per capita; $S_{i,j}$ is the saturation level of per capita demand; $I_{i,\min}$ and $I_{i,\max}$ are the minimum and maximum of per capita demand of resource $i$; and the parameters $\alpha$ and $\beta$ are determined by the equation curve [11]. We can use SLPM module to forecast ESR with saturation trend, and can also use regression analysis or other econometric methods and models to project other energy demand such as transport. To make model more systematic, we incorporate above methods into the traditional demand projection module (TDPM) [11]. Now, we can build ESDPM model by setting a judging step to link these two modules, and then connect ESDPM model to TIMES model.

2.2. Model system framework

In the model system framework, the final energy demand sectors was disaggregated into agriculture, industry, transportation, commerce and resident sectors, named by their first three letters and can be further disaggregated into several sub-sectors. Based on the above design, the first step to build China TIMES model system is to judge whether or not the target sector will develop with a saturation trend, and then we can run ESDPM model to get the final reasonable projection results, which can be finally incorporated into TIMES model, integrated with resources, technologies, constraints and other parameters energy system optimization module needed. TIMES model will select the optimal technology portfolio subject to the relevant constraints and minimize the total cost [12]. On this basis, the model system can evaluate current policies or analyze future policies and strategies by setting different demand and parameters. Fig. 2 illustrates the framework of TIMES model system.

2.3. Main drivers and scenarios assumption

From analysis of the historical data, it can be observed that the key factors of energy demand are GDP, population, urbanization, etc. Based on relevant development plans and projections, the future economic
growth and social development are assumed as shown in Table 1. The population is expected to reach the peak value at 1.47 billion in 2035, and the average annual GDP growth rate is estimated in every decades.

<table>
<thead>
<tr>
<th></th>
<th>2007</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
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</thead>
<tbody>
<tr>
<td>Population (million)</td>
<td>1321</td>
<td>1358</td>
<td>1440</td>
<td>1468</td>
<td>1467</td>
<td>1442</td>
</tr>
<tr>
<td>GDP growth rate (%)</td>
<td>10</td>
<td>8</td>
<td>6</td>
<td>4.5</td>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td>Urbanization (%)</td>
<td>45</td>
<td>47</td>
<td>55</td>
<td>62</td>
<td>69</td>
<td>75</td>
</tr>
</tbody>
</table>

Taking into account that future development of ESR is faced with many uncertainties, this paper analyze future energy demand using scenario analysis which has been widely used in demand projection.

First of all, the model system set a Reference Scenario (RS, will be shown in dotted curves in figures) to describe the continuance of energy saving and sustainable development strategy. Because the base year of model system is set to be 2007, the RS scenario will only consider the implement and continuance of energy policies and plans before 2007, such as the energy intensity decrease by 20% in "11th Five Year Plan", national renewable energy development plan, and the state nuclear power development plan, etc. On the demand side, the energy service representatives are expected to follow the current rapid growth.

On the other hand, China has announced a series of new policies and actions since 2007, such as new energy industry revitalization and development plan, reduce the intensity of carbon dioxide per unit of GDP in 2020 by 40 to 45 percent compared with the level of 2005, and the non-fossil fuels target in 2020. So, the model system set a Policy Scenario (PS, will be shown in solid curves in figures) to simulate and evaluate the updated policies and analyze the enhancement of sustainable development strategies in the future. The PS scenario will not only consider more renewable energy supply, but also control the quick increase of ESR, such as reduce the peak production of energy intensive, control the rapid growth of floor areas, and reduce the growth rate and intensity of private cars.

3. Results and Discussion

3.1. Key energy service representatives

Fig. 3 and 4 illustrate the projection results for key ESR (PS scenario are shown in solid curve). The model result shows that the most important ESR such as the energy intensive production, private cars and residential floor areas are expected to increase fast firstly, then slow down gradually from 2020, reaching their peak values between 2030~2040 and then maintain on a stable level or decline gradually. The urban residential and commercial floor areas are expected to rise up continuously, but also slow down gradually.

3.2 Final energy demand

Fig. 5 illustrates that future final energy demand is expected to increase rapidly in both scenarios before 2020. In RS scenario, the final energy demand in 2050 is expected to reach 5.2 billion tce, 2.6 times of the
value in 2007, and the annual growth rate during 2010~2020 and 2020~2050 would be 4.74% and 1.03% respectively. The share of industry is expected to decline from 71.3% in 2007 to 49.7% in 2050, while commerce and transport would increase from 5.5% and 10.3% to 10.3% and 25.7% respectively.

It can be seen that industry will still increase a lot before 2020 and continue play a significant role in final energy demand, although its share would appear to decline. After 2030, the increasing energy demand would mainly come from transport, commerce and resident sectors, so they are considered as key sectors for controlling final energy demand during that period. Therefore, China should make large efforts in elaborating future final energy demand controlling strategy in these key sectors. If we can continue to take and enhance energy saving strategy, reduce the peak production of energy intensive, control the rapid growth of floor areas, and reduce the growth rate and intensity of private cars, the final energy demand in 2050 in PS scenario is expected to be 4.9 billion tce, saving 300 million tce compared with RS scenario.

3.3 Primary energy consumption

The model result shows that the primary energy consumption is expected to show the similar trend to the final energy demand does, as shown in Fig. 6. In RS scenario, the primary energy consumption in 2050 is expected to reach 6.7 billion tce, 2.5 times of the value in 2007, and the annual growth rate during 2010~2020 and 2020~2050 would be 4.17% and 1.06% respectively. In the primary energy fuel mix, the share of coal is expected to decline from 73.4% in 2007 to 47.6% in 2050, while the share of oil, natural gas and primary electricity are expected to increase to 26.8%, 9.4% and 16.2% in 2050.

It can be found that coal is still dominated in China’s primary energy fuel mix, although its share would continue decline over time. After 2030, the consumptions of coal and oil are expected to maintain on a stable level, and the increasing energy demand is expected to be satisfied mainly by natural gas and primary electricity, especially the power generation by renewable energy. So natural gas and renewable energy are expected to be the key energy carriers for future energy supply, and they are also environment friendly. Therefore, China should continue to encourage the development of natural gas and renewable energy greatly. If we can insist on developing the low carbon energy, and also control the rapid increase of final energy demand, the primary energy consumption for 2050 in PS scenario can be reduced to 6.2 billion tce, and the share of coal is expected to decline to 41.9% in 2050.
down gradually. If we can control the rapid growth of key ESR, and continue to encourage the low carbon energy development, the energy demand and its dependence on coal can be controlled, but it’s still difficult to reverse the doubled growth of energy demand and the primary role of coal-based fossil fuels.

4. Conclusion

The key ESR which showed saturation trend in OECD countries have increased rapidly in China recently, bringing about many uncertainties for future energy demand projection. The China TIMES model system is built to project China’s future energy demand with scenario analysis. The result shows that these ESR are expected to increase rapidly before 2020, leading to the similar trend of final energy demand and primary energy consumption in both scenarios. Although the energy demand can be reduced through controlling the rapid growth of these ESR in policy scenario, it would be still difficult to reverse the fact that China’s energy demand is expected to be doubled on the current basis by 2050.

Based on the above analysis, to achieve future sustainable energy and environment development, the period before 2020 is very crucial, since it will not only determine the future develop direction of energy demand and supply, but also the stage of increasing energy demand. Therefore, China should transform its economic development patterns timely, to promote the upgrading of industrial structure; accelerate the technology innovation, to enhance the low carbon energy development; and transform the consumption patterns, to control the rapid growth of final energy demand. In order to do that, we need to analyze future energy demand systemically, and make a full preparation onto the sustainable development pathway.

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