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Long-term Energy Sustainability Development Analysis to Reducing Carbon Emissions and Air Pollutions of China Based on LEAP Simulation Model

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Abstract

The energy demand of China is gradually increasing with the rapid economic development, according to the new low-carbon energy development strategy, China will enhance the renewable energy proportion and reduce the fossil energy, the energy demand forecasting has the important significance for the future energy development planning of China. This study built an energy forecasting model based on the Long-Range Energy Alternatives Planning (LEAP) computer software in order to analyze the future energy development of China. The LEAP model was used to estimate the total energy demand, electricity demand and the energy demand structure by 2030 of four sectors of industries in BAU, BAL and BAH three different scenarios. As the forecasting results shown, the energy demand will reach 4,800-5100 Mtce in 2020 and 5,300-5,700 Mtce in 2030, and although the coal will dominate the energy, it will peak by 2030, the renewable energy will enhance its proportion in the energy structure, especially the wind and solar energy. The electricity will increasing stably increase near 10,000 Billion kWh by 2030. The prime objective was to give some reference of the long-term energy development planning policy, which help reducing the carbon emissions and air pollution to the environment.

Keywords: electricity development, renewable energy, energy forecasting, LEAP simulation

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INTRODUCTION

Energy sustainability development researchers are focus on reducing the carbon emissions to protect the environment during the increasing energy consumption pressure, while simultaneously either preserving or enhancing the economic development. This challenge will be implement by usage mass of the renewable energies. Due to the renewable energies' unstable and intermittent characteristics, they are always difficult to use to supply the energy directly, the way of effective to usage the renewable energy is to rely on the electricity conversion. Therefore, many countries government have been obliged to keep a significant renewable energy generations ratio in total electricity generations in their long-term development plans.

China had promised that the new plan of controlling the national carbon emissions level is reducing China's carbon intensity (carbon emissions per unit of GDP) by 60-65% in 2030 compared to that in 2005, which had been announced in China-US Joint Announcement on Climate Change in the end of the 2014. Due to the energy resource endowment of China, China is characterized as rich coal, meager oil and little gas. Although China's renewable energy's generations are all increasing rapidly, the prevailing electricity generations are mainly the coal-fired generations in China. In the end of 2016, the thermal generation still exceeds half of the total generations, which is about 64%, in which the coal-fired' generation's ratio is 89.4% in the thermal generation and 57.3% in total generation, and the ratio of renewable energy (mainly are wind power and solar power) is 13.7%. Therefore, China's government should pay high attention to the energy structure

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adjustment, especially controlling the coal consumption and enhancing the renewable energy's consumption (Shuai et al. 2016).

According to the China's government work report in 2016 and the Thirteenth Five Years' long-term Plan, the coal production capability will be gradually declined to 62% in the energy consumption at the end of 2020, and the renewable energy consumption will be increased to 15% in 2020. It is clearly that China will control the total amount of the coal production and consumption, and many scholars are generally thinking that the coal consumption will peak at a maximum point at a certain future time then enter a decline development trend, and the coal productions have been gradually appearing the slow growth during the past five years, therefore, the peak of the coal production and usage becomes a hot topic issue.

The peak coal forecasting problem can be considered as a long-term forecasting issue, and the methods of the long-term forecasting are divided into two types: (1) the time series forecasting method, and (2) the scenario analysis simulation forecasting method. The first type forecasting method always employs the history data to forecast the coal peak problem. The popular peak forecasting models are Hubbert model (Hubbert 1949) logistic growth model (Höök and Aleklett 2009) and Gaussian curves model (Mohr et al. 2011). For example, Wang et al employs the logistic model (or Hubbert model) to analyze the China's coal production problem and the results show that China's coal will peak at 2025 and the peak production is about 3.9*109MT (Jianliang et al. 2013), and they also points out that different ultimately recoverable resources may lead to different coal peak time and peak value, and they give the different coal peak future outlook in their researches (Jianliang et al. 2013). Lin et al apply the logistic curve and Gaussian curve to forecast the coal demand peak of China, according to the results, the peak year is during 2036-2040, and the peak value is in 4.8-5.8Gt (Boqiang et al. 2012). Ediger et al. uses the typical time series forecasting model ARIMA and SARIMA methods to study the peak forecasting problem for fossil energy usage and point out that the fossil fuel production will reach the peak before 2040 in Turkey (Ediger et al. 2006). Above researches give a certain merit in coal peak forecasting or fossil energy peak forecasting, however, the time series forecasting models are always criticized as lack of considering other influence factors, such as economic factor, environment factor and technology factor.

On the other hand, simulation forecasting methods with different scenarios development assumption are employed to coal peak or fossil energy peak forecasting problems, one of the main advantage of the simulation methods is good at considering others influence exogenous factors at the different development situations, and the simulation methods are always applied by major famous energy analysis and prediction agency, such as IEA and BP.

Based on the above researches, most of the researches are concluded that the peak time of the Coal will appear before 2020 (Mohr and Evans 2009). Some of the researches point out the peak time will before 2030 (Shiwei and Yiming 2012). Although there are different results of the coal peak time and coal peak value in the above researches, the conclusions all point out that China will face the stage of the coal peak.

Due to the electricity industry is the one of the most coal consumption parts of the China, a few problems are coming to need solve in the background: what will the trends of the coal-fired power generation production and demand in the future? and how many and what time will the coal-fired power generation or consumption peak? These problems are becoming the hot issues, however, the related research is relatively few. To better forecast coal consumption and the coal-fired power demand and the power demand structure in the future of China, this paper develops, validates, and utilizes a simulation model based on Long-range Energy Alternative Planning (LEAP) System.

METHODOLOGY

LEAP Model

In order to achieve the main goal of the research, The LEAP simulation model is employed to analyse and forecast the coal demand and every type of the power demand of China as well as the carbon emissions of the energy demand before 2030. LEAP, developed by Stockholm Environment Institute and Boston University, is a bottom-up energy demand analysis model. LEAP has a EDB (Environment Database), which includes the environment impact coefficients, such as carbon emission coefficients of all kinds of primary energy. LEAP is an accounting framework, and it can help researches create energy demand and environment impaction analysis models only focus on the account activities.

LEAP model needs historical data at least a base year and several future years, it permits the LEAP model user to assume different development scenarios and estimate

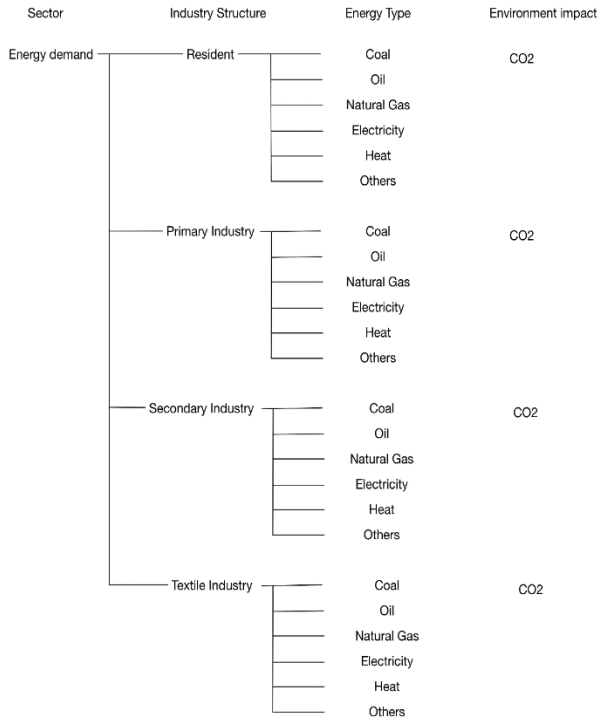

Fig. 1. The framework of the LEAP model

the future energy demand and environment impact. LEAP model faces the end user and analyses the energy demand from a hierarchical tree perspective. According to the results of the different scenarios, it can easily and clearly assist the policy makers to make a reasonable decision. The framework of the LEAP model as **Fig. 1**.

Scenarios Key Factors Assumptions

GDP

According to the 13th Five years development Plan, announced by the Chinese government, GDP will double by 2020 compared to 2010. Based on the GDP growth rate in the China Statistical Yearbook, if China wants to achieve the double goal at the end of 2020, the average GDP growth rate should no less than 106.5% during the 2016-2020. Therefore, we considered it as the scenario 1: Business as usual (BAU). Due to some researches have assumed the GDP growth rate in 106%-107%, we choose the 106% as the scenario 2: Business as low development (BAL); and the 107% as the scenario 3: Business as high development (BAH).

Population

According to the reports of the China National Population Development Strategy Research Group (CNPDSRG), the actual average population growth rate is about 0. 5% during the 2010-2015, the 12th Five-Year development period, and the growth rate is lower than the anticipate plan value, which is 0.7%. It can be deduced that the population increasing will be faced down in 13th Five period. The report also pointed out that the population growth rate will remain at the 0.5% level before 2030. Therefore, the population's growth rate was assumed as 0.5% for all the scenarios.

Industry structure

China will adjust its industry structure in the 13th five year's development plan periods, as the tentative plan, the primary industry's ratio will remain unchanged basically, and the tertiary industry's ratio will enhance further, the secondary industry's ratio will reduce. As the research report announced by China's National Academy of economic strategy, the industry's structure of all the scenarios is assumed as the primary industry will remain the 9% level, and the tertiary industry's ratio will reach the 55% level, the rest 36% is the secondary industry's ratio.

Carbon emissions

Chinese government had promised that the plan of controlling the national carbon emissions per unit of GDP (carbon intensity) level will be reduced by 40-45% in 2020 compared to that in 2005. According to the promise, the central number 42.5% is assumed in BAU scenario, the lower limit 40% and the upper limit 45% is considered in BAL and BAH scenarios respectively.

Energy structure

According to the Energy Development Strategy Behaviour Plan (2014-2020), published by China's government in 2015, the non-fossil energy's ratio is no less than 15% in the primary energy, and the ratio of natural gas will exceed the 10%, the ratio of the coal will control no more than 62%. We assume this situation as the BAL scenario, and in BAU scenario, the coal will reduce 1% more, which reach 16%, and the 1% will be substituted by non-fossil energy. The BAH scenarios will reduce coal 1% more again, which is 17%, and it is also replaced by non-fossil energy.

Electricity generation structure

China's National Grid Enterprise has announced the 13th Five Years' Development Plan in the end of the 2015, in which pointed out that the excepted generation will reach 2.07 trillion kW in the end of 2020, and the renewable energy generation will enhance by 39.3% in 2020 compare to 31.6% in 2014. Under the situation, the non-fossil energy demand will exceed 15.5% in the primary energy demand. The plan's situation is considered as the BAU scenario, and the ±10% deviation is considered in the BAH and the BAL scenarios.

Table 1. The results of the total energy demand from 2016 to 2030 (Unit:Mtce)

Year	BAL	BAU	BAH
2016	4,338.34	4,383.19	4,411.37
2017	4,476.87	4,548.14	4,597.99
2018	4,602.48	4,698.50	4,768.54
2019	4,715.59	4,834.78	4,923.59
2020	4,816.61	4,957.44	5,063.70
2021	4,898.56	5,048.59	5,179.31
2022	4,974.11	5,129.70	5,282.12
2023	5,043.37	5,201.02	5,372.56
2024	5,106.43	5,262.82	5,451.06
2025	5,163.40	5,315.35	5,518.04
2026	5,214.38	5,358.83	5,573.89
2027	5,259.48	5,393.52	5,619.01
2028	5,298.80	5,419.63	5,653.77
2029	5,332.45	5,437.39	5,678.54
2030	5,360.53	5,447.01	5,693.69

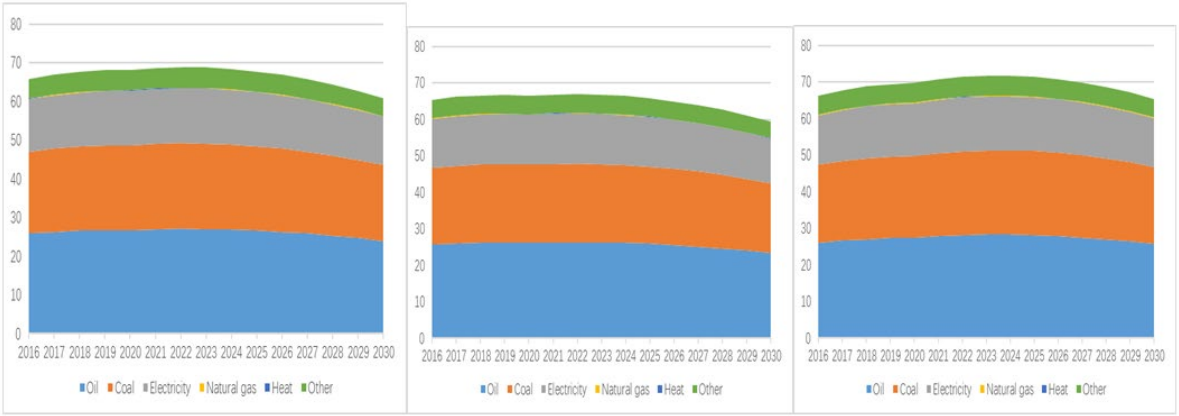

Fig. 2. Primary Industry's energy demand structure

RESULTS AND DISCUSSION

LEAP model has been running for obtaining the future development results of the difference scenarios of China by 2030. The results include the total energy demand, energy structure, electricity structure and electricity load demand, the carbon emission are also estimated by the LEAP model. The result of all the three scenarios show that the renewable energy will gradually increase until 2030, and the electricity demand is also maintaining an increasing trend until 2030, on the contrary, the coal will appear its peak value before 2030 and then the coal's proportion in the energy structure will turn down.

In the LEAP model, year 2001 was considered as the base year and the LEAP model covered from 2001 to 2030, in which, Year 2001-2013 is the history data and the 2014-2030 are the forecasting result based on history data and the assumptions, the forecasting results include energy demand, energy structure for each industry sections, the electricity generation structure and the carbon emissions in the future.

Table 1 shows the results of the total energy demand from 2016 to 2030, and the results show that the total energy demand is still keeping increasing trend before the 2030, and the total energy forecasting result is about 4,816 4,957 5,063 million tce in BAL, BAU and BAH respectively in 2020, and it will reach 5,361 5,447 and 5,694 million tce in BAL, BAU and BAH respectively in 2030.

The energy structure of the three industries are shown in **Fig. 2-Fig. 6**. In order to conveniently compare the energy demand and the related environment with different assumptions, the BAU scenario is set as a reference, because the assumption is based on the baseline of the China long-term economic or energy development plan.

Fig. 2 shows the energy structure in the primary industry, it is clearly seen that the energy structure is stable in the three scenarios, and oil and coal are the main energy of the primary industry, the total energy demand will peak near 2023, then the total energy demand will turn down in the future.

The manufacturing industry is the most energy demand in all the industries, and the main energy of the manufacturing industry is coal, so manufacturing causes

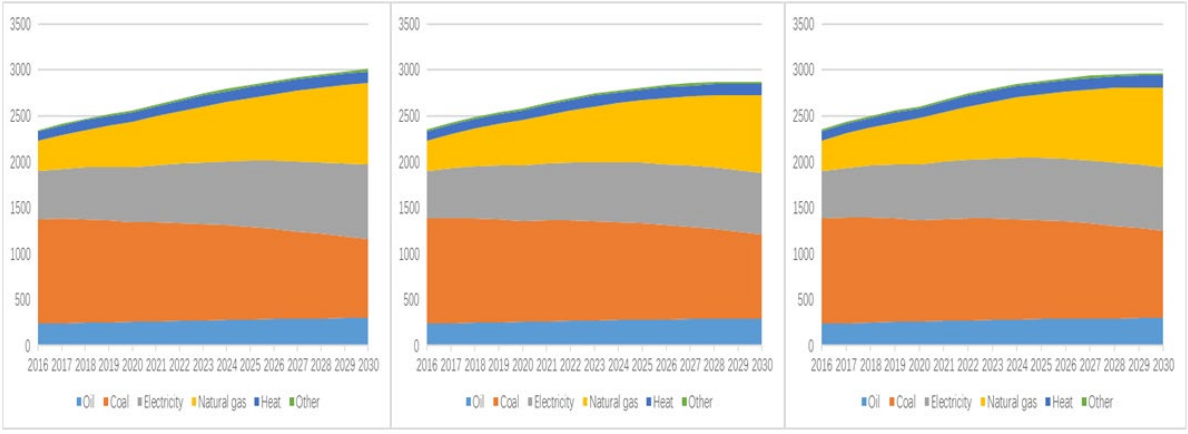

Fig. 3. Manufacturing Industry's energy demand structure from 2016 to 2030 in BAL,BAU,and BAH

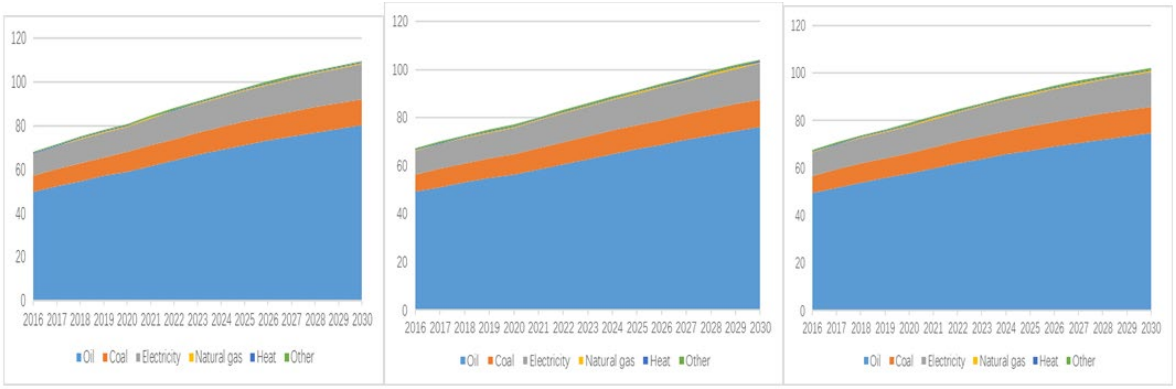

Fig. 4. Construction Industry's terminal energy demand structure from 2016 to 2030 in BAL,BAU, BAH

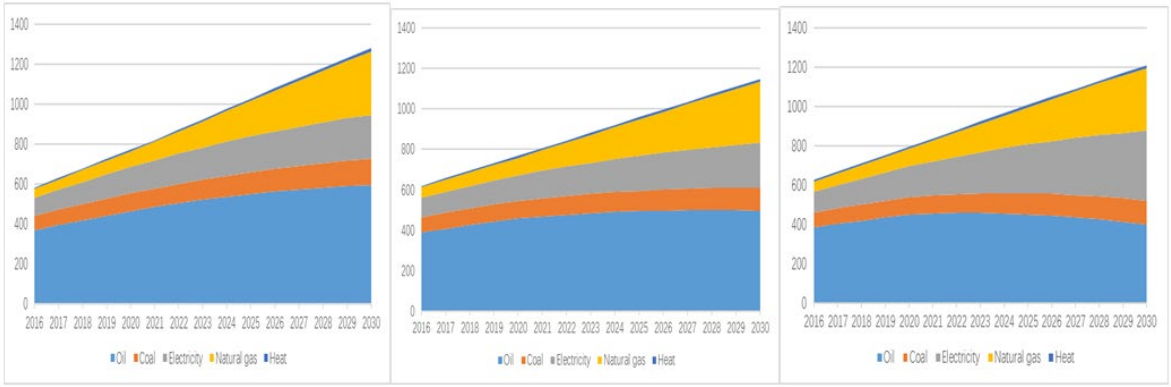

Fig. 5. Textile Industry's terminal energy demand structure from 2016 to 2030 in BAL, BAU, and BAH

lots of carbon emissions and the environment problems. **Fig. 3** shows the energy demand forecasting and the energy structures of manufacturing industry of three scenarios in 2016-2030. It can be clearly seen that the coal's proportion is decreasing year by year, and the proportion of the electricity's proportion is increasing year by year.

Fig. 4 shows that the terminal energy demand of construction industry will maintain an increasing trend during 2016-2030. Oil is the most energy demand in the total energy demand and it is also increasing year by year. Electricity has a small increasing trend by 2030, and the coal will maintain a stable trend in the future.

It was analyzed through **Fig. 5** that the energy demand of textile industry was calculated to be about 1243, 1179 and 1315 Mtce in BAU, BAL and BAH respectively. And the natural gas and the electricity will be used widely in the total energy demand of textile industry during 2016-2030.

The growth of the residental energy demand is impressive and it will become the rapidest growth section of all the four industry's sections in the future,

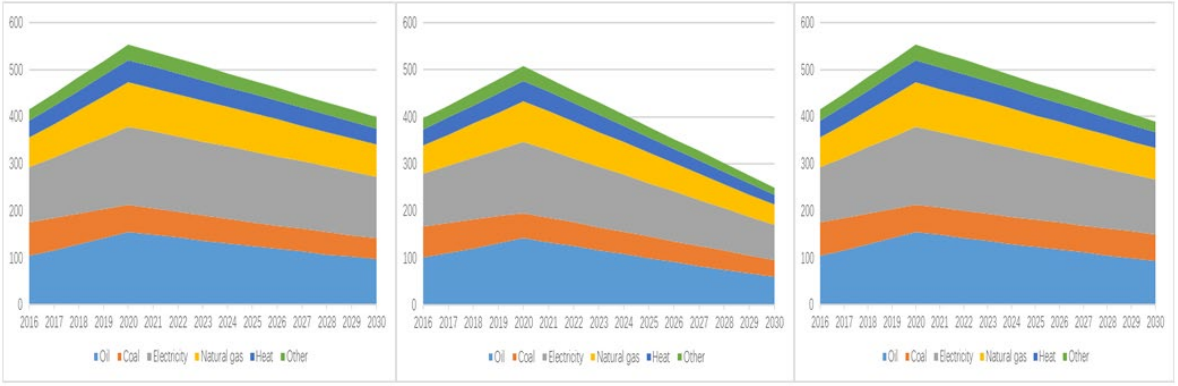

Fig. 6. Resident terminal energy demand structure from 2016 to 2030 in BAL, BAU, and BAH

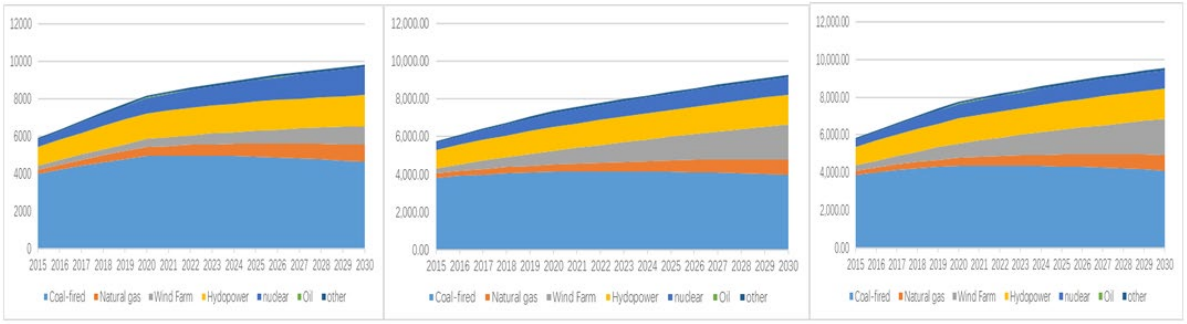

Fig. 7. Resident terminal energy demand structure from 2016 to 2030 in BAL, BAU, and BAH

the forecasting results are shown in **Fig. 6**. The energy structure of the residental energy demand is decreasing coal and increasing electricity, and the natural gas and oil will maintain the increasing trend near 2025 then trun down the decreasing trend.

Due to the focus of the environment's pressure, Chinese government and Chinese National Energy Administration have promoted the developing the new clean energy and decreasing the coal energy strategy. Currently, it is considered efficiency that use the new clean energy, such as wind and solar energy, to generate the electricity and satisfy the terminal energy demand requirement. As a result, the electricity is increasing year by year until 2030.

Fig. 7 shows the results of the electricity demand of the three scenarios in 2016-2030. According to the energy development strategy, the coal-fired generation electricity demand will increase at first, and then turn down, therefore, the peak will appear before 2030 in all three scenarios. However, the electricity generated from coal-fired is still occupying the most proportions in the total electricity demand. The total electricity demand is between 7,200 and 8,100 in 2020, and it will arrive between 9,287 and 9,830 in the three scenarios. The generated electricity form wind farm is increasing rapidly and it will occupy more proportion in the total electricity demand.

CONCLUSION

The study created a LEAP simulation system to forecast the future energy demand and energy structure of China during 2016-2030. The results have given the detailed data for several industries, including primary, manufacture, construction, textile and resident's industry. It can provide a valuable tool for energy supply and energy development planning of China.

According to the results, the total energy demand of China will reach 4,800-5100 Mtce in 2020 and 5,300-5,700 Mtce in 2030, the coal's proportion will be under the 60% by 2030. The electricity demand will in 7,200-8,100 Billion kWh in 2020, and 9,200-9,900 Billion kWh in 2030. In all the industries, the electricity will substitute the fossil energy, especially the coal in the energy structure. As a result, it will reduce the carbon emission and other pollutions such as NOx, SOx and PM10 in the environment.

According to the results of the three scenarios, the more economic development is, the more energy demand will be used. From the energy structure perspective, Coal is still maintaining a dominate proportion in the total energy demand for a long time in the future, but its peak will appear before 2030, and the proportion will turn down. The renewable energy will enhance its proportion in the energy demand, in

which the wind energy has the rapidest increasing rate in the renewable energy.

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