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CO_2 Emission Reduction Potential in China's Electricity Sector: Scenario Analysis Based on LMDI Decomposition

Baihe Gu[a], Xianchun Tan[a,]*, Yuan Zeng[a], Zekun Mu[a]

[a] *Institute of Policy and Management, Chinese Academy of Sciences, Beijing 100190, China*

Abstract

The CO_2 emission reduction from China's electricity sector will matter not only for China but impact the result of the global action on climate change. This paper firstly analyzed the main factors that affect the CO_2 emission in accordance with the LMDI decomposition model. Then three scenarios were assumed based on the main factors to explore the CO_2 reduction potential. Furthermore, LMDI method was used again to measure the contribution of each factor to CO_2 emission reduction potential in the future. The results showed that the CO_2 emission will continue to grow in the three scenarios from 2010 to 2020, with an annual growth rate of 10.7%, 6.5% and 4.5%, respectively. The active low carbon policies taken on the driving factors will contribute to 2701Mt - 3688Mt CO_2 emission reduction. The share of low-carbon power generation and thermal power generation efficiency are most important factors for emission reduction. However, in the long run, low-carbon power generation will contribute more. Terminal electricity consumption is always the most important factor driving CO_2 emission up. Finally, policies for low-carbon development of China's electricity sector are proposed based on the analysis results.

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Keywords: Chinese electricity sector; CO_2 emission; Decomposition

1. Introduction

Climate change has become a global issue of common concern to the international community, and a major factor for the sustainable social and economic development in the future. Since 2007, the CO_2 emission in China has surpassed that in the United States [1], standing in the first place of the world, with high pressure for low-carbon development. For this reason, China must achieve low-carbon development for sustainable development on the basis of guaranteeing energy security and social progress.

The electricity sector serves as a basic sector for the development of the economy, and it is also a major energy consumer and CO_2 emitter. In 2011, the energy consumption of China's electricity sector was 1.22 billion tce [2], accounting for 35.14% of China's total energy consumption. And the power generation structure mainly based on coal results in a large amount of CO_2 emission. In 2011, the CO_2 emission in China's electricity and heat production sector was 4.01 billion tons [1], accounting for 50.1% of the total nationwide CO_2 emission. Therefore, it is of significant importance to effectively control the CO_2 emission in the electricity sector in order to achieve the low-carbon development in China. In order to design efficient policies, knowledge about the influencing factors and their impacts on CO_2 emissions overtime is required.

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* Corresponding author. Tel.: +86 1059358821; fax: +86 1059358889-903.
E-mail address: txc@casipm.ac.cn.

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Up to now, many studies have been conducted to explore CO_2 reduction potential and emission reduction routes in the electricity sector, and these studies are generally classified into two categories. One is to explore CO_2 reduction potential resulting from separate effect of technology[3][4], power structure[5][6] or an individual emission reduction policy[7][8], and other factors. These studies can better quantify the reduction potential of a single factor, but they have difficulties to give an overall emission reduction potential of the electricity sector from an overall perspective. The other one is to build a series of integrated scenarios for possible future economic structures, technical levels, and energy efficiency by referring to national and industrial low-carbon policies, development plans, and advanced technologies, and discuss the CO_2 reduction potential in different development scenarios[9-11]. Many scholars have also studied the CO_2 reduction potential in China's electricity sector. Chen et al. (2011) summarized applicable low-carbon technologies in China, analyzed the emission reduction potential of key low-carbon technologies in accordance with a comprehensive power mix planning model, and proposed a low-carbon development roadmap for China's electricity sector[12]. Many scholars analyzed the key factors for developing China's electricity sector by using different decomposition techniques, and believed that the main factors for the CO_2 emission reduction in China's electricity sector include power consumed, electricity generation efficiency, share of electricity generation, share of thermal power generation, electricity intensity, transmission and distribution losses, generation dispatching mode and GDP, etc[13-15]. Cai et al. (2007) assumed three different development scenarios for China's electricity sector based on the LEAP model, obtained the future CO_2 reduction potential in China's electricity sector by comparing these three scenarios, and quantified the costs of the key measures for emission reduction[16].

Although these studies have made useful exploration on the scenarios of the future CO_2 emission reduction in China's electricity sector, few studies were conducted for further quantitative analysis on the factors of contributing to the CO_2 reduction potential, and therefore it is difficult to propose target-oriented policies. For this reason, this paper first considers electricity generation, transmission, supply, consumption, and other aspects to analyze the carbon emission structure system in the electricity sector, construct a CO_2 emission accounting model. Using LMDI decomposition method, we quantitatively analyze the main factors related to the CO_2 emission from 2000 to 2010. Then we employ three scenarios to simulate different develop paths based on factor decomposition results in 2015 and 2020, explore the CO_2 reduction potential. Based on the results of scenario analysis, LMDI decomposition method is used again to analyze the contribution of all factors to the CO_2 emission reduction in the future. Finally, policy recommendations are proposed to reduce the CO_2 emission in China's electricity sector.

2. Methodology and Data Sources

2.1. Accounting method

To reflect the impacts of all factors on the CO_2 emission in the electricity sector, this paper firstly provides a preliminary structural decomposition of the electrical system for carbon emission. The CO_2 emission in the electricity sector mainly results from power generation. However, the generation capacity mainly depends on the power consumption with the character of immediate consumption after generation for electricity. Due to the line loss during the transmission from power generators to consumers, the total generation capacity is subject to both the electrical power consumption and line loss rate. Electrical power generation structurally involves low-carbon resources and thermal power generation. However, this paper calculates only CO_2 emission from thermal power generation because little CO_2 arises from low-carbon energy resources. The CO_2 emission from thermal power generation relates to the internal structure and efficiency. Therefore, the accounting formula for CO_2 emission in the electricity sector is as follows:

$$CE = \sum_{i \in \psi} CE_i = \sum_{i \in \psi} \frac{P}{1-\mu} \times (1-\alpha) \times TP_i \times EF_i \times e_i \tag{1}$$

Where:

CE: Total CO_2 emission in the electricity sector (Unit: ton);

CE_i: CO_2 emission form thermal power generation of fuel type i (Unit: ton);

ψ: The set of all types of thermal power generations (including coal-fired, oil, and natural gas power generations)

P: Total consumption of electrical power (Unit: kWh)

μ: Line loss rate (Unit: percent)

α: Share of low-carbon power generation (herein referring to the power generation without CO_2 emission, such as hydropower, nuclear power, wind power, solar power, and biomass power) (Unit: %)

TP_i: Proportion of electricity generated from fuel type i in the total thermal power generation (Unit: %)

EF_i: Fuel consumption per unit electricity generated from thermal power generation of fuel type i (Unit: GJ/kWh)

e_i: CO_2 emission factor of fuel type i in thermal power generation (Assuming that the value remains unchanged in the time span of analysis) (Unit: ton/GJ)

2.2. LMDI decomposition method

Among the methods for studying the factors related to CO_2 emission, the index decomposition method (IDA) is the most frequently adopted one. Shrestha and Timilsina (1996) firstly studied on CO_2 emission issue in China through this method [17]. Ang (2004) compared various decomposition methods and argued that the LMDI analysis was the preferred method due to its theoretical foundation, adaptability, ease of use, transparency in the interpretation of results [18]. Moreover, the LMDI method effectively solved the residual problems in the decomposition and settled the zero and negative values in the data. It was applied in several energy and environmental studies [19-21]. The LMDI method is also adopted in this paper to analyze the factors related to CO_2 emission in the electricity sector in compliance with the accounting model established previously. At the earlier time, some scholars [14][15] adopted the LMDI method to analyze the factors related to CO_2 emission in China's electricity sector, but they did not make decomposition in terms of the CO_2 emission accounting in the sector.

We briefly describe the LMDI approach but refer to Ang et al. (2003) [22] for a more detailed description. For easy decomposition, assume $1/1-\mu=U$ and $1-\alpha=A$ in formula (1), and then convert formula (1) as follows:

$$CE=\sum_{i\in\psi}CE_i=\sum_{i\in\psi}P\times U\times A\times TP_i\times EF_i\times e_i \tag{2}$$

Therefore, the change of CO_2 emission in the electricity sector can be decomposed as the effects from the following five factors:

1) Effect from activities: total electricity consumption (abbreviation: P);
2) Effect from low-carbon energy sources: the share of power generation from low-carbon energy sources (hydropower, nuclear power, wind power, solar power, and biomass power, etc.) in the total power generation (abbreviation: A);
3) Effect from the internal structure of thermal power generation: the share of power generation from all types of thermal power generation (abbreviation: TP);
4) Effect from the efficiency of thermal power generation: fuel consumption per unit of power generated from each type of thermal power generation (abbreviation: EF);
5) Effect from the line loss rate in power transmission (abbreviation: U);

The logarithmic mean function L (x, y) is introduced and defined as follows:

$$L(x,y)=\begin{cases}(x-y)/(\ln x-\ln y), x\neq y\\ x, x=y\\ 0, x=y=0\end{cases} \tag{3}$$

Formula (2) can be decomposed as follows through the LMDI decomposition method:

$$\Delta CE=CE_T-CE_0=\Delta P+\Delta U+\Delta A+\Delta TP+\Delta EF \tag{4}$$

Where, $\Delta CE=CE_T-CE_0$ presents the change in CO_2 emission in the electricity sector from the initial year 0 to year T, and other items present the contributions of all factors to the change in CO_2 emission in the electricity sector, as listed in formula (5).

$$\Delta P=\sum_{i\in\psi}L(CE_{i,T},CE_{i,0})\ln\frac{P_T}{P_0},\quad \Delta U=\sum_{i\in\psi}L(CE_{i,T},CE_{i,0})\ln\frac{U_T}{U_0},\quad \Delta A=\sum_{i\in\psi}L(CE_{i,T},CE_{i,0})\ln\frac{A_T}{A_0},$$

$$\Delta TP = \sum_{i \in \psi} L(CE_{i,T}, CE_{i,0}) \ln \frac{TP_{i,T}}{TP_{i,0}}, \quad \Delta EF = \sum_{i \in \psi} L(CE_{i,T}, CE_{i,0}) \ln \frac{EF_{i,T}}{EF_{i,0}} \tag{5}$$

2.3. Methods of analyzing the CO_2 emission reduction potential

This paper adopts the scenario analysis method to explore the CO_2 emission reduction potential in China's electricity sector, and assume different scenarios for future development based on the factors in the LMDI decomposition method. The parameters of these scenarios were made based on our feasibility researches in accordance with the currently available literatures and government planning reports for the future development of the electricity sector in China. As a result, the rationality and internal consistency of the assumption are ensured in all scenarios. Parameter values in each scenario are taken in Formula 1 to obtain the CO_2 emission in the future. The potential of CO_2 emission reduction can be obtained by comparing the CO_2 emission in different scenarios. The target years are set at 2015 and 2020 for the scenario analysis.

2.4. Data sources

IEA (2001–2011) provides detailed data about the power generation based on all types of energy sources [23]. The coal consumption for coal-fired power generation and line loss rate are collected from China Electric Power Yearbook [24]. We fail to find the data about the efficiency of oil and natural gas power generation from public statistics. The data about the efficiency of oil and natural gas power generation is substituted by the data about the CO_2 emission per unit of oil and natural gas power generation which is collected form IEA. Because the 2000–2010 period analyzed in this paper is relatively a short term, we assume that the carbon emission factors of coal, oil, and natural gas are constant, and extract them from the Guideline for Preparing the Provincial Greenhouse Gas Inventory.

3. Results and Discussions

3.1. Historical CO_2 emission

Figure 1 shows the change of CO_2 emission from China's electricity sector in the years from 2000 to 2010. The total CO_2 emission increased from 1179.9 Mt in 2000 to 3034.8 Mt in 2010, except for a slight decrease in 2008 compared with that in 2007, with an annual growth rate of 9.9% by average, and totally increased by 1.57 times during the decade.

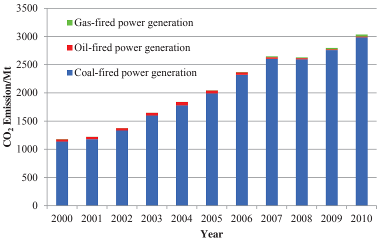

Fig.1. CO_2 emission in China's electricity sector from 2000 to 2010

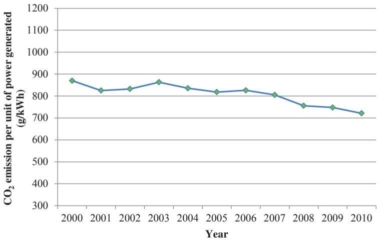

Fig. 2. Change of CO_2 emission per unit of power generated in China's electricity sector from 2000 to 2010

Because of the coal dominated fuel structure, the CO_2 emission in China's electricity sector from 2000 to 2010 mainly resulted from the coal-fired power generation, which accounted for 98.4% of the total CO_2 emission in 2010. The proportion of CO_2 emission from oil-fired power generation decreased year by year, and even the absolute emission decreased after 2004. The oil-fired power generation will be eliminated in the future due to the lack of oil resources in China. The CO_2 emission from gas-fired generation accounted for a low proportion in the total emission, but has been increasing all the time, reaching 1.2% of the total by 2010 and surpassing that from oil-fired power generation. Gas-fired power generation will be further developed in the future, owing to the high conversion rate, low environment cost and investment, and short construction period. However, its developing speed is still uncertain because of the low production and the highly rising price of natural gas in China.

According to the CO_2 emission per unit of power generation shown in Figure 2, the overall CO_2 emission per unit of power generation in China's electricity sector decreased from 2000 to 2010, from 870.0 g/kWh to 721.2 g/kWh, with a total decrease of 17.1% for the decade. However, a large offset value existed in comparison with many developed countries. In 2010, the CO_2 emission per unit of power generation is 522 g/kWh in the United States and 416 g/kWh in Japan, which is much lower than that in China. This indicates a long way to go for low-carbon power generation in China in the future.

3.2. Decomposition analysis

The results of factor decomposition for CO_2 emission in China's electricity sector from 2000 to 2010 based on the LMDI method are shown in Table 1 and Figure 3. The results reveal that the most important factor driving CO_2 emission reduction in the recent ten years is the increase in the efficiency of thermal power generation (ΔEF), followed by the increase in the share of low-carbon power generation (ΔA) and the decrease in the line loss rate (ΔU). Terminal electricity consumption (ΔP) is the most important factor that increases the CO_2 emission, and the change in the internal structure for thermal power (ΔTP) slightly causes the increase in CO_2 emission.

(1)Effect of terminal electricity consumption

The terminal electricity consumption increased by 214% from 2000 to 2010. Due to the increase of power consumption, the CO_2 emission in China's electricity sector increased by 2234.3 Mt, and contributed 120.5% to the total growth. Therefore, power consumption is the most important factor driving CO_2 emission increase. The constant increase in power consumption is closely related to the constantly rapid growth of the economy of China in recent years, and the average annual growth rate of China's GDP is up to 10.5% from 2000 to 2010. More and more power-consuming equipment for manufacturing use electricity rather than other energy sources because of the continuous advance of China's industrialization. Moreover, with the rising urbanization level and the improvement of life quality, a growing number of electrical appliances and electronic products, such as computers, electric vehicles, and air conditioners, are widely used. This makes the proportion of electricity increase in the overall structure of energy consumption in China. In the terminal energy consumption, the proportion of electricity increased from 14.8% in 2000 to 21.3% in 2010, and may continue to increase in the future.

(2) Effect of the share of low-carbon power generation

The share of low-carbon power generation (ΔA) causes different effects on the change of CO_2 emission in different years, as shown in Table 1. However, the cumulative effects from 2000 to 2010 are negative. During the 10 years, the share of low-carbon power generation (ΔA) has cumulatively reduced CO_2 emission of 71.3Mt, up to 3.8% of the total changes, and ranked the second largest contributor for emission reduction. Especially after 2007, the renewable power generation in China developed rapidly, owing to the implementation of the Renewable Energy Law, the release of the Mid- and Long-term Development Plan of Renewable Energy Development and a series of policies such as financial subsidies and Feed-in Law designed to promote renewable power generation. The generation capacity increased by 6.8 times for wind power and 1.5 times for biomass power from 2007 to 2010. It is worth mentioning that the new added generating capacity for renewable energy in 2007 reached 120.3TWh, up to 61.9% of the total new generating capacity of China. This leads directly to the decrease of CO_2 in the total emission from China's electricity sector from 2007 to 2008, as shown in Table 1. Due to the decreasing availability of the fossil energy, increasing environment-protection pressure, and other issues in the future, China will pay more attention to the development of renewable power.

(3) Effect of the internal structure for thermal power

During the study period, the total increase of CO_2 emission caused by the change of the internal structure for thermal power (ΔTP) is 3.5 Mt, which accounts only for 0.2% in the total changes because of the stable internal structure for thermal power in the past 10 years. The share of coal-fired power generation with a dominant position in thermal power increased by only 2% in 10 years, from 95.3% in 2000 to 97.5% in 2010. The effects of oil-fired and gas-fired power generation on the total emission are negligible due to a small proportion. Therefore, in total, the change of the internal structure for thermal power results in small effects on CO_2 emission.

(4) Effect of thermal power generation efficiency

From 2000 to 2010, the most important factor to reduce CO_2 emission is the increase of the thermal power generation efficiency (ΔEF), which has cumulatively reduced the CO_2 emission of 284.7 Mt, up to 15.3% of the total changes. Since 2006, the contribution of the thermal power generation efficiency to CO_2 emission reduction has become particularly prominent, thanks to a series of policies issued intensively by Chinese government after beginning of the “11th Five-Year Plan”. China shut down small thermal power units of 76.83 GW in total from 2006 to 2010. By 2010, in China’s 693.5 GW thermal power generating capacity, 36.8% was above 600 MW and 72.7% was above 300 MW; only 11.1% was below 100 MW.

(5) Effect of the line loss rate

Line loss rate (ΔU) is always a negative factor for CO_2 emission except the years 2002 and 2003. The line loss rate cumulatively reduced CO_2 emission of 26.9Mt, up to 1.5% of the total CO_2 changes from 2000 to 2010. During the “11th Five-Year Plan”, China invested hugely in construction of ultra-high voltage grids, trans-region power grids, regional and provincial backbone power grids, urban and rural power grids. The power grid scale expanded, power grid structure was optimized, and the safety, reliability and economy of power grids were improved. From 2005 to 2010, the length of 220 kV and above transmission loop in China increased by 75.7%, from 253700 km to 444600 km, of which the length of 500 kV voltage loop increased from 62900 km to 135200 km. With the implementation of smart power grid strategies based on ultra-high voltage grid in China in the future, the line loss rate will continue to decrease.

Table 1 Decomposition of CO_2 emission change of electricity sector in China Unit: Mt

	ΔP	ΔA	ΔTP	ΔEF	ΔU	ΔCE
2000-2001	97.9	-33.6	1.0	-19.5	-3.4	42.5
2001-2002	141.2	16.2	1.5	-3.5	-0.4	155.0
2002-2003	239.6	33.8	0.1	-3.8	3.1	272.8
2003-2004	253.5	-25.6	-2.0	-31.1	-3.0	191.7
2004-2005	238.3	5.1	1.9	-32.9	-7.1	205.4
2005-2006	309.0	21.5	3.1	-6.1	-4.0	323.3
2006-2007	342.9	10.7	-2.6	-72.5	-1.9	276.8
2007-2008	146.8	-80.8	1.5	-78.9	-5.1	-16.4
2008-2009	191.5	0.5	-6.6	-16.8	-2.0	166.6
2009-2010	361.5	-43.6	-5.1	-69.6	-5.9	237.3
2000-2010	2234.3	-71.3	3.5	-284.7	-26.9	1854.9

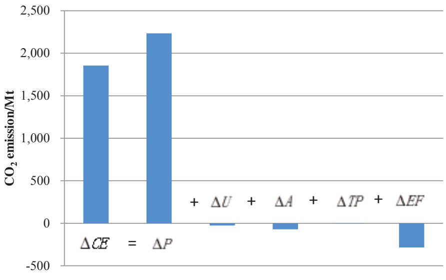

Fig. 3. CO_2 emission decomposition results: contributions of different factors, 2000–2010

3.3. Emission reduction potential analysis

(1)Scenarios assumption

This paper provides three different scenarios for China's electricity sector. These scenarios involve Business As Usual (BAU) scenario, current policy scenario (Scenario 2), and low-carbon policy scenario (Scenario 3). Each scenario is based on different policy assumptions, and represents a future development route. The main parameters in these scenarios include the aforesaid terminal electricity consumption, share of low-carbon power generation, internal structure for thermal power, thermal power generation efficiency, and line loss rate. It should be noted that the assumptions of China's future GDP and electricity percentage in the terminal energy consumption are consistent in the three scenarios. The Outline of the 12th Five-year Plan of China has taken into full consideration the need for transforming and upgrading the economic structure in China over the next 10 years and has lowered the expected growth rate of GDP. The annual growth rate of China's GDP is set at 7% from 2011 to 2015. Due to the report of the Eighteenth National Congress of the CPC, China's GDP in 2020 will be double the figure of 2010. Therefore, we assume that the annual growth rate of China's GDP will remain 7% from 2016 to 2020. With consideration of the further development of the social and economy, as well as China's coal-dominated energy structure, the percentage of electricity in the total terminal energy consumption will increase in the future, reaching 25% in 2015 and 30% in 2020 for assumption.

In the BAU scenario, we assume that China does not adopt additional policies for energy conservation and climate changes from 2010. The average annual growth rate of the terminal electricity consumption will reach 10.5% from 2011 to 2015, and 11.0% from 2016 to 2020 due to the increase of electricity percentage in terminal energy consumption. The power structure, thermal power generation efficiency and line loss rate remains the same as that in 2010. Although the BAU scenario is almost certainly impossible to take place, it is set as a benchmark to compare with other two scenarios to get the CO_2 emission reduction potential in the future.

The current policy scenario (Scenario 2) is mainly based on the existing development plans and policies issued in the electricity sector, including the "12th Five-Year Plan" of energy development and the "12th Five-Year Plan" of renewable energy development. Considering the increasingly severe pressure for resources and environments at home and abroad, China will limit the total power consumption through a series of measures such as demand side management. The average annual growth rate of the terminal electricity consumption in China will be limited to 8% from 2011 to 2020. The share of low-carbon power generation gradually increases. By 2015, the installed capacity will reach 260 GW for conventional hydropower plants and 30 GW for pumped storage power plants. Nuclear power will be developed with reassurance that safety is prioritized, and only the construction at coastal sites is approved. Wind, solar and biomass energy are developed and utilized at a faster speed. By 2015, the installed capacity will reach 100 GW for wind power generation, 21 GW for solar power generation, and 13 GW for biomass power generation. The cogenerated heating, electricity, and refrigeration system (CHER) based on natural gas is actively promoted, and the government support is provided for power generation by using the gas from the coal-bed methane. During the "12th Five-Year Plan", a total of 20 GW backward coal-fired units will be eliminated, and 300 GW high efficient coal-fired units will be added, with 70 GW for combined heat and power(CHP). By 2020, the percentage of installed capacity for ultra-supercritical units will be more than 25% in coal-fired units[25]. IGCC, however, will be commercially used only in a small scale, due to its high cost. A strong and smart power grid will be built fully by 2020.

Compared with Scenario 2, the low-carbon policy scenario (Scenario 3) is more optimistic by adopting more radical policies to promote low-carbon development in the electricity sector. The total energy consumption target will be determined in a more stringent manner, and the average annual growth rate of terminal electricity consumption will decrease to 7% from 2011 to 2020. The share of low-carbon and natural gas power generation further increases compared with that in scenario 2. Considering that some small thermal power units will continue to play important roles in the regional power grid of China as they are, irreplaceable in solving regional employment issues[26], only more 10 GW small thermal power units are eliminated in Scenario 3 on the top of that in Scenario 2. The percentage of installed capacity for ultra-supercritical units will be more than 30% in coal-fired units in 2020, and IGCC will be commercially used on a larger scale assuming that it breaks through in the bottleneck of cost. As the refined management and control of the power grids will be improved, the line loss rate will reach 5.7% in 2020, which equals that in Germany in 2007.

See Table 2 for the parameters of the three scenarios.

Table 2 Parameters for the development scenarios in China's electricity sector from 2015 to 2020

		Scenario 1			Scenario 2			Scenario 3		
	Unit	2010	2015	2020	2010	2015	2020	2010	2015	2020
GDP	Billion Yuan	39800	55800	78300	39800	55800	78300	39800	55800	78300
Terminal electricity consumption	TWh	3936.6	6480.4	10906.9	3936.6	5784.2	8498.8	3936.6	5521.3	7743.9
Share of low-carbon energy power generation	%	20.8	20.8	20.8	20.8	23.9	25.0	20.8	25.0	30.0
Thermal power generation efficiency										
Coal-fired power generation	gce/kWh	312.0	312.0	312.0	312.0	301.0	292.0	312.0	293.0	286.0
Oil-fired power generation	gCO_2/kWh	1043.7	1043.7	1043.7	1043.7	837.0	837.0	1043.7	837.0	837.0
Gas-fired power generation	gCO_2/kWh	506.9	506.9	506.9	506.9	489.0	474.4	506.9	476.0	464.6
Internal structure for thermal power										
Coal-fired power generation	%	97.5	97.5	97.5	97.5	96.8	95.4	97.5	96.6	94.6
Oil-fired power generation	%	0.4	0.4	0.4	0.4	0.2	0.1	0.4	0.1	0.0
Gas-fired power generation	%	2.1	2.1	2.1	2.1	3.0	4.5	2.1	3.3	5.4
Line loss rate	%	6.5	6.5	6.5	6.5	6.3	6.0	6.5	6.0	5.7

(2) CO_2 emission reduction potential

The parameters are taken to Formula 1 to obtain the CO_2 emission in each scenario before 2020, as shown in Figure 4. Generally, the CO_2 emission will increase all the time before 2020 even in the low-carbon policy scenario. However, the CO_2 emission growth in each scenario is different because of different intensity of policy measures taken.

In the BAU scenario, the CO_2 emission will reach 8408 Mt in 2020, 2.8 times that in 2010, and exceed the total CO_2 emission from fossil fuel combustion in China in 2010 due to rejection of the positive policies against climate changes. In the current policy scenario, China's electricity sector will develop in accordance with the energy plan issued by the Chinese government. The CO_2 emission in 2020 will decrease by 2701 Mt compared with that in the BAU scenario, and the average annual growth rate will be only 6.5% for CO_2 emission from 2010 to 2020. Therefore, it is believed that the emission reduction of 2701 Mt is possible because the parameters in current policy scenario are subject to the issued prospective plans. In the low-carbon policy scenario, the measures for power demand side management will be implemented in a more stringent manner, the power structure will be further improved, and the average installed capacity for thermal power generation will be on a larger scale. By 2020, the CO_2 emission will be only 4720 Mt, decreasing by 3688 Mt compared with that in the BAU scenario. We believe that this is the upper limit of CO_2 emission reduction potential in China's electricity sector.

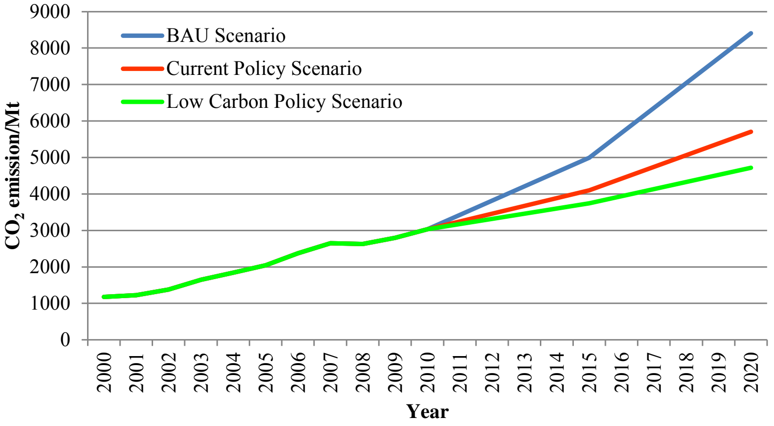

Figure 4 CO_2 emission forecast for different scenarios, 2000–2020

Predictions for CO_2 emission of China's electricity sector in the present study and earlier studies are shown in Figure 5 for comparison purposes. As Table 3 shows, Cai et al.(2007) estimated the CO_2 emission in 2020 to be 3102, 2959 and 2676 Mt in the baseline scenario, the current policy scenario, and the new policy scenario, respectively, based on LEAP(long-range energy alternative planning system) model[16]. Chen et al.(2011) projected the CO_2 emission by using a multi-scenario analysis based on a comprehensive power mix planning model, and the results showed that 3640 and 3200 Mt CO2 would be emitted in reference scenario and optimistic scenario respectively in 2020[12]. By using an accounting method form IPCC, Zhang (2012) incorporated key research conclusions from life cycle assessment(LCA) of emission reduction technologies, and the CO_2 emission in baseline scenario and emission reduction scenario were 8650 and 6727 Mt respectively[27]. Dai et al.(2013) estimated the CO_2 emission in 2020 to be 4548 Mt by using an integrated optimization model with the targets of lowest cost and least emission[10]. Compared with this study, the CO_2 emissions in most of the earlier studies are lower than that in our research. There are two reasons: Firstly, most of the earlier studies estimated the electricity consumption according to earlier historical data or earlier development plan which hasn't foreseen the rapid growth of electricity consumption in China; Secondly, some earlier studies have taken CCS(Carbon Capture and Storage) as an important CO_2 emission reduction measure, which haven't been considered in our study. The CO_2 emission in the future of Zhang(2012)'s research is slightly higher than our research, because only three major emission reduction technologies were considered in the emission reduction scenario in that study, and the emission factors were calculated based on life-cycle analysis.

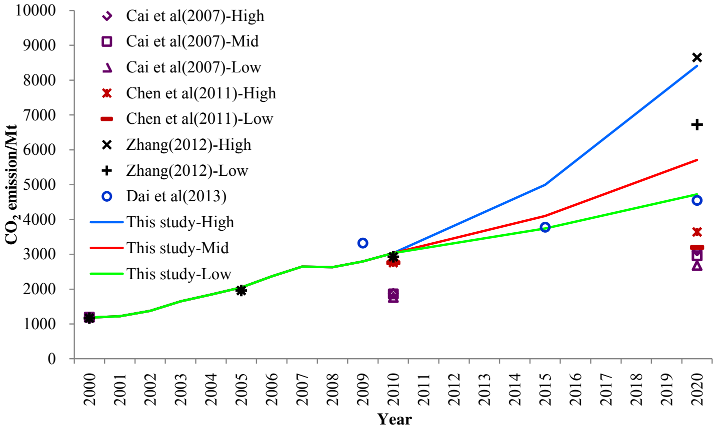

Figure 5 Predictions for CO_2 emission of China's electricity sector in the present study and earlier studies

Table 3 Some details in the selected former studies on CO_2 emission prediction of China's electricity sector

Author(s)	Methodologies description	Key assumptions	Data resource	Target year and results(Mt)
Cai et al. (2007)	Using LEAP model based on different technical compositions in generating electricity	The electricity production growth and economic development are the same in all three scenarios, and electricity production growth is set to be consistent with economic development	From earlier development plan and earlier other related studies	2020: 3102/2959/2676
Chen et al. (2011)	Using a multi -scenario analysis based on a comprehensive power mix planning model	The CO_2 emission allowance of China's power sector is determined according to some principles ,and is treated as compulsive constraints and integrated into the model	From recent development plan and earlier other related studies	2020: 3640/3200
Zhang(2012)	Using accounting method form IPCC based on life-cycle analysis	All additional power demand is met by conventional coal-fired power generation in baseline scenario	From industry association and recent development plan	2020: 8650/6727

Dai et al. (2013)	Using integrated optimization model with the targets of lowest cost and least emission	The energy saving capacity in both demand side and power grid are seen as virtual energy, and together with conventional energy in supply side are implemented for integrated optimization model	From recent development plan and earlier other related studies	2020: 4548
This study	Using a bottom-up accounting model incorporate the key factors of contributing to the CO_2 emission reduction	The economic development are the same in all three scenarios, but electricity production growth are different among scenarios.	From recent development plan and earlier other related studies	2020: 8408/5708/4720

3.4. Factor contribution analysis of emission reduction in the future

In order to learn about the factors' contribution to emission reduction in different scenarios, we decompose the scenario analysis results by using the aforesaid LMDI model, as shown in Table 4.

Table 4 Decomposition of CO_2 emission change in the electricity sector of China for different scenarios during 2010-2020

	ΔP	ΔA	ΔTP	ΔEF	ΔU	ΔCE
	Mt CO_2					
BAU scenario	5373.5	0.0	0.0	0.0	0.0	5373.5
Current policy scenario	3251.8	-230.0	-44.2	-280.9	-23.9	2672.8
Low-carbon policy scenario	2575.5	-469.9	-55.1	-331.7	-33.7	1685.1
	%					
BAU scenario	100.0	0.0	0.0	0.0	0.0	100.0
Current policy scenario	121.7	-8.6	-1.7	-10.5	-0.9	100.0
Low-carbon policy scenario	152.8	-27.9	-3.3	-19.7	-2.0	100.0

(1)Effect of terminal electricity consumption

According to the results, the largest factor that contributes to the CO_2 emission change in all scenarios is still the terminal electricity consumption in 2011–2020. This means that one of the most important approaches for the future CO_2 emission reduction in the electricity sector is to emphasize power demand side management and actively promote energy-saving products and technologies.

(2)Effect of the share of low-carbon power generation

Low-carbon power generation will play an increasing part in CO_2 emission reduction in 2011–2020, because China is increasingly focusing on the development of renewable energy. In the current policy scenario, low-carbon power generation cumulatively reduce CO_2 emission by 8.6% of the total changes, which is much higher than that of 3.8% in 2000–2010. As more radical policies and measures are taken to promote the development of low-carbon energy in the low-carbon policy scenario, the contribution of the low-carbon power generation to the CO_2 emission reduction reaches 27.9%, exceeding the thermal power generation efficiency and becoming the most important factor for emission reduction.

(3)Effect of the internal structure for thermal power

The structure for thermal power generation is improved, changing from a factor increasing CO_2 emission to a factor reducing CO_2 emission owing to the rapid development of gas-fired power generation in the current policy scenario and low-carbon policy scenario. If China can make a great breakthrough in the technologies for shale gas development in the future, the scale of gas-fired power generation will expand greatly. As a result, the structure for thermal power generation will be a more important factor for CO_2 emission reduction.

(4)Effect of thermal power generation efficiency

The increasing thermal power generation efficiency will also play an important role for CO_2 emission reduction in 2011–2020. However, the technology progress rate may decrease gradually with the continuously increase of power generation efficiency in the future, and the contribution to the CO_2 emission reduction may decrease accordingly.

(5)Effect of the line loss rate

Line loss rate is not greatly contributive to the CO_2 emission reduction in terms of relative quantity. However, it is still a stable factor for emission reduction and its contribution should not be ignored for the absolute quantity, as the electricity sector causes almost half of CO_2 emission from fossil fuel combustion in China.

4. Conclusions and Policy Suggestions

This paper aims to explore the CO_2 emission reduction potential in China's electricity sector. An accounting model is developed to estimate the historical CO_2 emission. Then LMDI decomposition model is used to analyze the factors related to CO_2 emission during 2000–2010. Based on the analysis, three scenarios are designed to obtain the CO_2 emission reduction potential before 2020. Finally, LMDI decomposition method is used again to analyze the contribution of all factors related to the CO_2 emission reduction in the future.

The decomposition results reveal that, the factor mostly contributive to CO_2 emission growth is always the terminal electricity consumption before 2020. Low-carbon power generation will be a more important factor to CO_2 emission reduction during 2011–2020. In the low-carbon policy scenario, the contribution rate of the share of low-carbon power generation to the CO_2 emission reduction reaches to 29.7%, exceeding the thermal power generation efficiency and becoming the most important factor. The thermal power generation efficiency will also play an important role for CO_2 emission reduction. However, the technology progress rate may decrease gradually with a continuously increasing power generation efficiency in the future, and thus its contribution to the total CO_2 emission reduction may decrease accordingly. The structure for thermal power generation is greatly improved and changes from an emission increasing factor to an emission reduction factor owing to the rapid development of gas-fired power generation in the future. Line loss rate is not greatly contributive to the CO_2 emission reduction in the electricity sector compared with other factors. However, it is still a stable factor for emission reduction and cannot be ignored.

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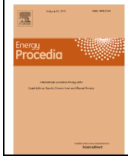

Biography

Xianchun Tan is a professor of the Institute of Policy and Management, Chinese Academy of Sciences, China. Her research field is mainly on Low Carbon Development and Green Manufacturing as well as Environment Risk Management.