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Integrated Assessment of Energy Related SO_2 Emissions Control in China's 12th Five-Year Plan

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Abstract

China has reduced the SO_2 emissions by 14.3% in the 11th Five-Year Plan (2006 - 2010). However, air pollution is still a severe problem in some industrial regions in China, due to excessive use of coal and other fossil fuels. China plans to reduce SO_2 emissions by 8% in the new 12th Five-Year Plan (2011 - 2015), along with other CO_2 reduction targets and pollutants reduction targets. This study makes a comprehensive assessment of energy related SO_2 emissions control in China's 12th Five-Year Plan, by using a large scale non-linear integrated assessment model. According to the results, the popularization of wet-type SO_2 scrubbers and improvement of the environmental emission standards play an important role in the achievement of SO_2 control target by 2015. In addition, the changes in energy consumption structure contribute to SO_2 and other energy related emission controls, as well as the sustainable development of energy. In China, future environmental policy should concentrate on the provinces which emit SO_2 seriously, like Shandong, Inner Mongolia and Henan, or relevant industrial sectors such as electric & heat power, ferrous metals and nonmetal mineral sectors.

Keywords: SO_2 control, Economic impact, 12th Five-Year Plan, China

1. Introduction

As the world's second-biggest economy, China consumes 21.9% of the total primary

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energy in the world in 2012 and China is now the world's largest energy consumer (BP, 2013). Coal-dominated energy consumption structure in China leads to a series of environmental problems such as acid rain, air pollutions and a large amount emissions of greenhouse gas (GHG). Against these problems, the Chinese government has carried out a suite of environmental projects and strategies to improve air quality. In the last decade, China has established national objectives to control SO_2 emissions. The reduction target of 10% below 2000 levels appeared in the National 10th Five-Year (2001-2005) Plan for Environmental Protection. However, the local government tended to place great emphasis on GDP growth and omit the necessary environmental protection during this 10th Five-Year Plan period. Moreover, the lack of effective evaluation metrics and distractions from several air pollutant controls resulted in a failure achievement of the SO_2 emission reduction target, that the SO_2 emissions in 2005 increased by approximately 27.8% comparing to the 2000 levels (NBS, 2006), and only 33.5% of total industrial SO_2 emissions are removed. In the subsequent 11th Five-Year Plan (2006-2010), the Chinese government also set a mandatory goal of reducing SO_2 emissions 10% below 2005 levels. Effective evaluation metrics and targeted consequences in case of failure achievements for local governments were explicitly defined during this period to assure the implementation of industrial desulfurization. As a result, China successfully accomplished the goal of SO_2 emission control, with approximately 14.3% below 2005 levels (NBS, 2011). Details about 10/11th Five-Year Plan of China can be found in Table 1, and SO_2 emissions (1992-2010) are shown in Figure 1. Schreifels et al. (2012) concluded that six factors contributed to achievement: ① instrument choice, ② political accountability, ③ emission verification, ④ political support, ⑤ streamlined targets, and ⑥ political and financial incentives, all of which are closely connected with China's current development context.

Different geographic features and economic developmment levels result in an uneven

Tab.1 SO_2 emission controls in 10/11th Five-Year Plan of China (NBS, 2006 & 2011)

	10th (2001-2005)	11th (2006-2010)
SO_2 reduction targets	10% below 2000 levels	10% below 2005 levels
SO_2 reduction results*	27.8% above 2000 levels	14.3% below 2005 levels
Industrial emissions meeting discharge standards*	79.4%	97.9%
Industrial desulfurization rate*	33.5%	66.0%

* The percentages refer to the target year's percentages, namely 2005 in the 10th Five-Year Plan and 2010 in the 11th Five-Year Plan.

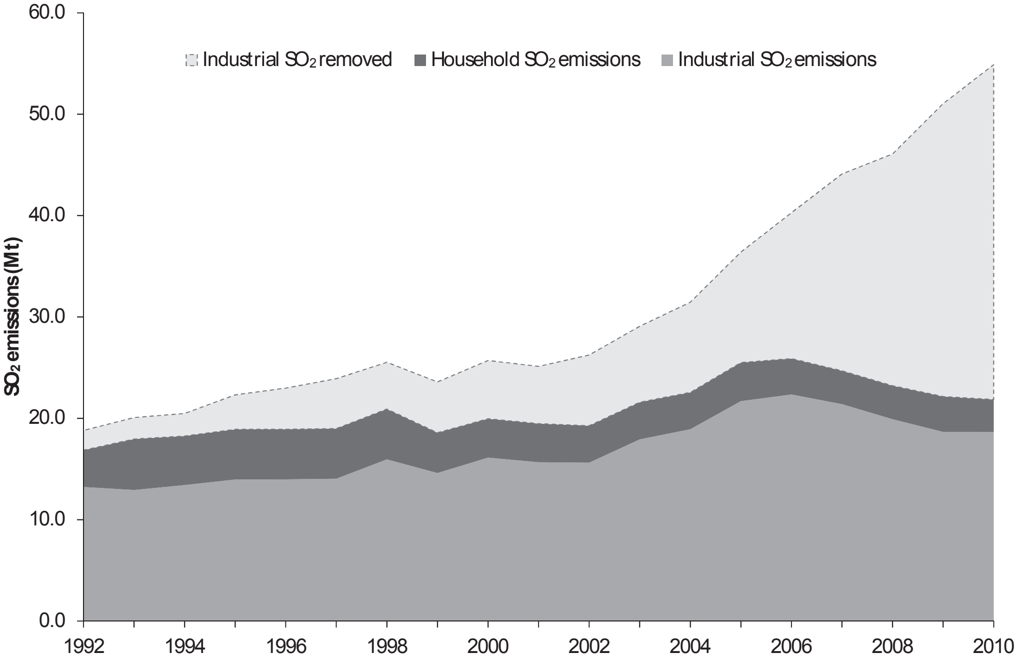


Fig.1 SO_2 emissions of China (1992-2010)

Source: NBS (1990-2012), NBS & MEP (1998-2012)

SO_2 emissions among different provinces in China. As shown in Figure 2, Shandong province contributes the most SO_2 emissions in 2010, due to the heavy industries and the large-scale coal consumptions, although its desulfurization rate reaches 69.5%, higher than the whole country's mean desulfurization rate of 66.0%. Three heavy industrial provinces of northern China – Liaoning, Hebei and Henan, and two economic development southern China provinces – Jiangsu and Guangdong, have relative high SO_2 emissions. Three main coal production provinces - Inner Mongolia, Shanxi and Shaanxi, which acount for 50% of China's total coal production, also have high levels of SO_2 emissions because of the large-scale coal consumptions. In addition, Sichuan and Guangxi, emit proximately 9.6% of all the SO_2 emissions of China, still have relative lower desulfurization rate of 48.1% and 53.7%, respectively. Heavy industries concentrated areas mentioned above should have more effective controls on SO_2 emissions due to the centralized application of desulfurization units. However, all the heavy industrial provinces mentioned previously except Shandong province, have less-than national mean desulfurization rates. It indicates that China has a large potential in industrial desulfurization. The geographic features and economic developmment levels are considerable problems when the SO_2 control policies are made. Kana-

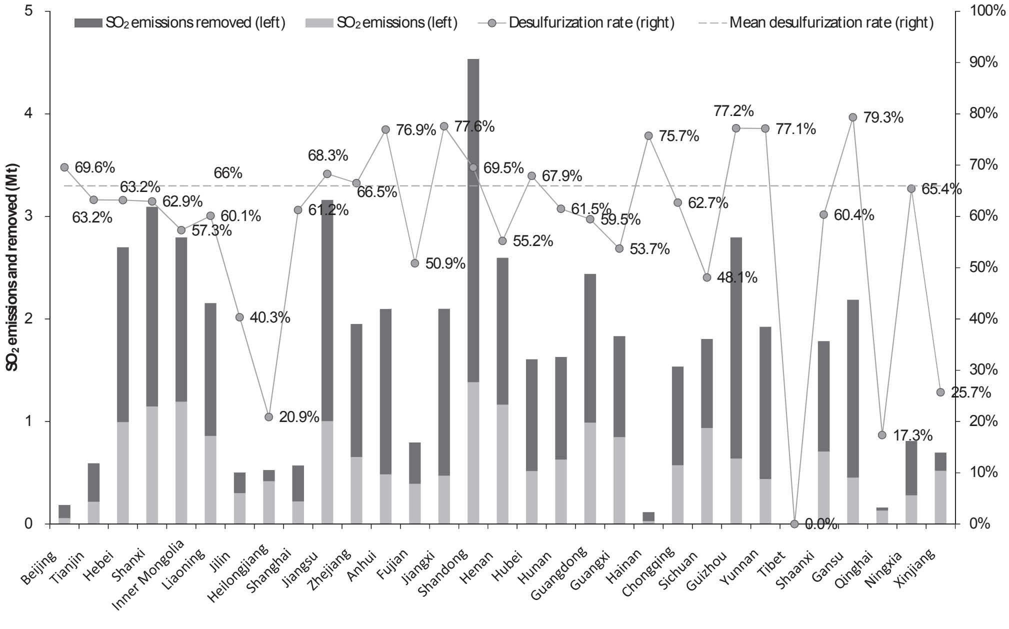


Fig.2 SO_2 emissions and desulfurization rates by provinces of China in 2010

Source: NBS (2011)

da et al. (2013) discussed this issue according to an analysis of reduction potential and cost-effectiveness of 5 mega-cities in China, and proposed that the policy design should consider the local conditions.

As to different sectors, SO_2 emissions are mainly contributed by several energy-intensive sectors or decentralized energy utilization sectors which are difficult to equip desulfurization units. In Figure 3, 44.5% of toal SO_2 emissions are emitted by the sectors that produce and distribute electric and heat power. In China, thermal power plants produce approximate 80% of toal electricity, and almost all of the thermal power plants use coal as energy sources (NBS, 2012), resulting in a large amount of SO_2 emissions. Therefore, the mean desulfurization rate of China is determined primarily by electric and heat power production sectors, as shown in Figure 4. The desulfurization rate of 68.3% of electric and heat power production sectors is close to the national mean desulfurization rate of 66.0%. Besides, other energy-intensive sectors like ferrous metals, nonferrous metals and chemical materials sectors are also main sources of SO_2 emissions. For the nonmetal mineral sector, most of the SO_2 emissions are from the cement production processes. The concentrated sectoral SO_2 emissions below national mean desulfurization level also indicate a large industrial desulfuriza-

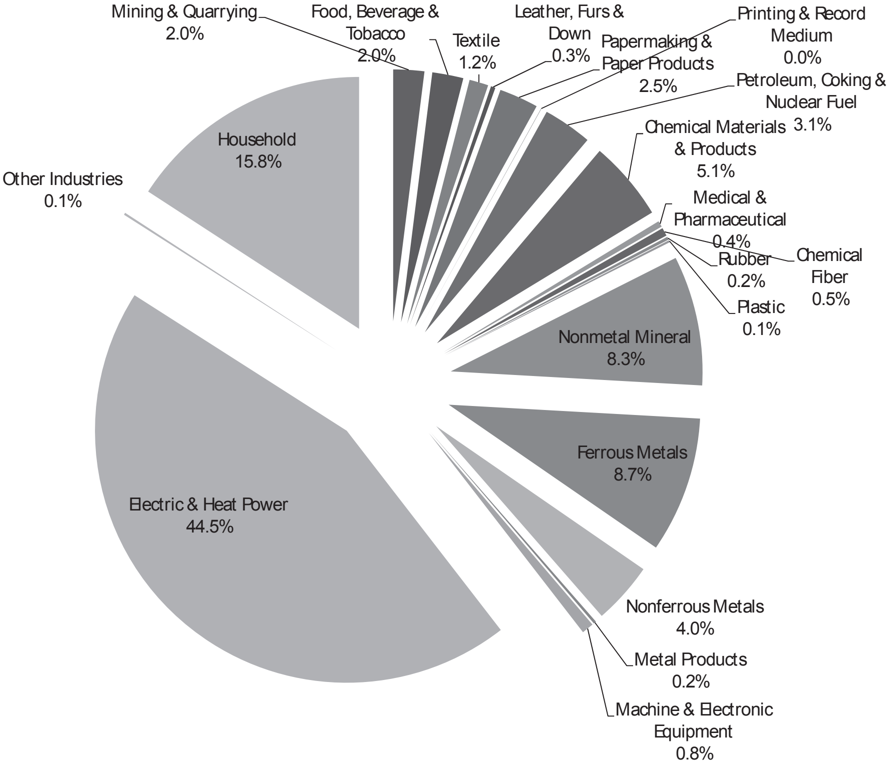


Fig.3 SO_2 emissions by sectors of China in 2010

Source: NBS (2011)

tion potential and relative lower costs for centralized application of desulfurization units like flue gas desulfurization (FGD). It is also worth noting that the SO_2 emissions from household account for 15.8% of total SO_2 emissions of China. These SO_2 emissions are mainly from direct use of coal and it is unreasonable to remove SO_2 emissions from these small scale decentralized energy utilization processes. However, the situation will be alleviated if people turn to anthracite or use liquefied petroleum gas/natural gas as substitutions.

The desulfurization rates of advanced scrubbers like wet scrubbers are greater than 90% (US EPA, 2003). According to Xu (2011)'s survey, most China's SO_2 scrubbers use wet-type technologies, and the rate of industrial emissions meeting discharge standards for SO_2 emissions in 2010 is up to 97.9% as well (NBS & MEP, 2011). Nevertheless, the mean national desulfurization rate in 2010 is lower as 66.0% (Figure 4). It is partly because only some of the installed FGDs are operated continuously and properly due to high operation costs (Xu, 2011; Schreifels et al., 2012). In addition, the emission standard of SO_2 control is relative lower in the previous 11th Five-Year Plan. For example, the allowable emission concentration for thermal power plants must meet the standard of 1200 mg/m^3 in 2010 while 2100 mg/m^3 is permitted in 2005 (MEP, 2003). But it is still insufficient due to the current moderate mean national desulfurization rate. Therefore, the Chinese government raises the standard to 200 mg/m^3 for the existing coal-fired boilers or 100 mg/m^3 for the new-built coal-fired boilers in the 12th Five-Year Plan (MEP, 2011). It will undoubtedly contribute to achieving the latest SO_2 emission reduction target.

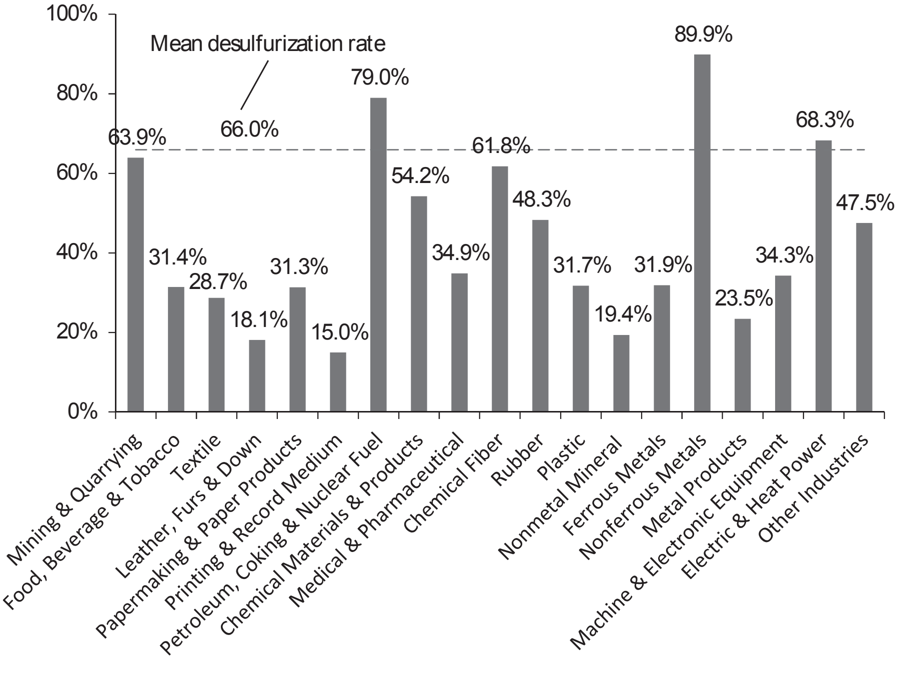


Fig.4 Industrial desulfurization rates by sectors of China in 2010

Source: NBS (2011)

In the new 12th Five-Year Plan, the Chinese government establishes the evironmental pollutants control targets that SO_2 and NO_x will be reduced by 8% and 10% below 2010 levels, respectively, along with intentional relative lower GDP growth of 7% (SCC, 2011). Subsequently, The Comprehensive Work Plan for Energy Conservation and Emission Reduction During the 12th Five-Year Plan Period (SCC, 2011) is announced by the State Council of China, to ensure the attainment of the compulsory energy conservation and emission reduction targets laid down in the outline of the 12th Five-Year Plan and to assign the tasks to provincial levels according to regional economic development and energy consumptions. The work plan defines the energy conservation targets, COD control, ammonia emission control, SO_2 emission control and NO_x emission control plans for all the provinces of China, specifically. With respect to the SO_2 emission control, the provinces that emit SO_2 seriously like Shandong, Jiangsu and Guangdong are assigned high emission reduaction targets, as 14.9%, 14.8% and 14.8%, respectively, comparing to 2010 levels. Furthermore, as the most important industrial and commercial municipalities (province level equivalently) in China, Shanghai and Beijing are also allocated relative stringent SO_2 emission control targets, reducing 13.7% and 13.4% below 2010 levels, respectively. In particular, some provinces are even allowed to increase the SO_2 emissions due to previous lower emissions, such as Hainan, Qinghai and Gansu, that are able to raise the SO_2 emissions by 34.9%, 16.7% and 2% above 2010 levels, respectively. Some quota is reserved for SO_2 emission trading pilot projects among different regions. The allocation of SO_2 emission allowances depending on the local nature increases the feasibility of the SO_2 emission control plan. As stated in Schreifels et al. (2012), the SO_2 reduction efforts in the previous 10/11th Five-Year Plan also provide "valuable lessons" for the establishment of this new environmental policy.

Based on recent studies about the SO_2 emission controls in China, this paper assesses the energy related SO_2 emissions control in China's 12th Five-Year Plan by using a large scale non-linear integrated assessment model. It begins with a brief introduction of the methodologies and model used in this study. Then section 3 provides the SO_2 emission projections of four different economic growth scenarios in 2015 with five different desulfurization levels, when section 4 gives the conclusions and possible policy direction from this study.

2. Methodologies

This study uses a large scale non-linear integrated assessment model, which mainly consists of three sub-models: the macroeconomic sub-model, energy balance sub-model and environmental evaluation sub-model. In the macroeconomic sub-model, the production output is defined as the sum of consumption, investment and energy cost. The investment is determined by the initial investment and the annual growth rate. The relationship of the production, capital stock, labor, electricity and non-electricity is denoted by a two-level constant elasticity of substitution (CES) production function. The main linkage between macroeconomic sub-model and energy balance sub-model is energy demand, which is subdivided into electric and non-electric energy demands. In addition to energy demand, energy cost in the macroeconomic sub-model also comes from energy balance sub-model. The key constraint in the energy balance sub-model is the demand and supply balance. Also, the depleting fossil fuels, such as coal, oil and natural gas, and the annual available renewable energy are considered as strictly constraints. The environmental evaluation sub-model is to calculate the emissions of CO_2, SO_2 and NO_x under specific scenarios.

Energy emission factors vary from region to region in accordance with different sectors, as well as the characteristics of specific fuels. The relative emissions are defined as energy thermal consumption multiplied by emission factors, considering corresponding removal efficiency. Hence the SO_2 emission is estimated according to equation (1). The coefficient 2 means that the atomic weight of SO_2 is twice as S.

$$SO2_r = \sum_s \sum_e 2Q_{rse} S_{re} \alpha_{re} (1-\delta_{re}) \tag{1}$$

- $SO2_r$: SO_2 emissions in specific region.
- Q_{rse}: Energy thermal consumptions in specific region, sector and energy source.
- S_{re}: Sulfur content in specific region and energy source.
- α_{re}: SO_2 emission factor in specific region and energy source.
- δ_{re}: Desulfurization rate in specific region and energy source.

The objective of this model is to maximize the discounted consumption, and figure out the level of each decision variable under optimized state. The “5” in equation (2) refers to 5 years per period in the model.

$$UTIL = \sum_{r=1}^{R} \sum_{t=1}^{T} \left(5 \times \prod\nolimits_{j=0}^{t-1} (1-udr_{j,r})^5 \times \log(C_{t,r}) \right) \tag{2}$$

- $UTIL$: Discounted consumption.
- C: Annual consumption.
- udr: Utility discount rate.

This study creates four GDP growth scenarios with five different SO_2 emission reduction levels for China during the 12th Five-Year Plan. Among the GDP growth scenarios, the 7% growth scenario is defined according to the 12th Five-Year Plan of China, which sets a new annual GDP growth at 7% over the next five years. Three additional GDP growth scenarios, 5%, 9% and 11% are added to demonstrate the possible development trajectories for China in near future. As to the SO_2 emission control, the desulfurization rates are given exogenously due to the uncertainty of the popularizing rates of desulfurization equipment. Therefore, this study assumes five possible desulfurization rates in 2015, 50%, 60% 70%, 80% and 90%, covering the desulfurization rate in 2010 of 66.0%. All the scenarios are simulated in view of China's current economic development and energy consumption, considering relevant environmental protection and greenhouse gas emission reduction, to assess the SO_2 emission control of China.

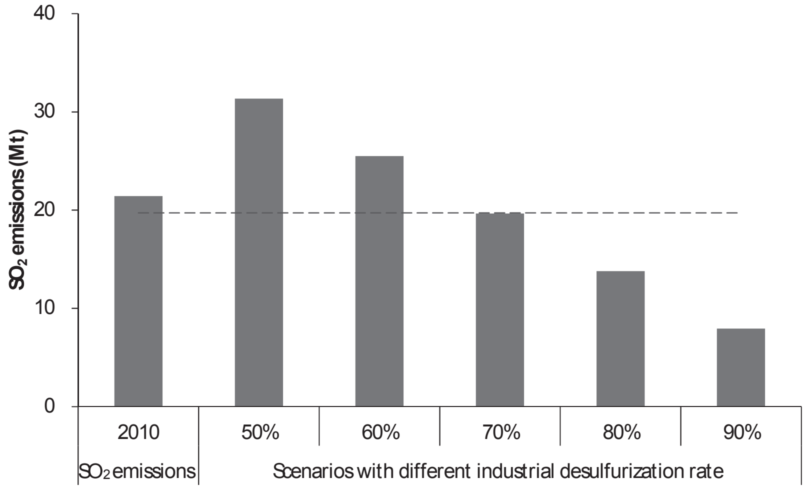
3. Results and Discussion

Based on the GDP growth scenarios defined in section 2, the SO_2 emissions and related development indicators of China in 2015 are shown in Table 2. In the planned 7% growth scenario, China consumes 2818 Mtoe primary energy and generates 5893 TWh electricity in 2015, increasing by 20.4% and 32.2%, respectively, from 2010 levels. With regard to the energy use efficiency, the 7% growth scenario reduces 14.0% of energy consumption per unit of GDP, slightly lower than the target of 16% set in the 12th Five-Year Plan. The gross SO_2 emission of the 7% growth scenario reaches 65.0 Mt, increasing by 21.0% above 2010 levels. For the 11% growth scenario, the gross SO_2 emission increases rapidly due to the increased electricity generation and reaches 80.7 Mt. As to all the GDP growth scenarios, the household SO_2 emissions show little change due to the single emission source, namely the direct use of coal. SO_2 emitted by household use of petroleum gas/natural gas is ignored in this study.

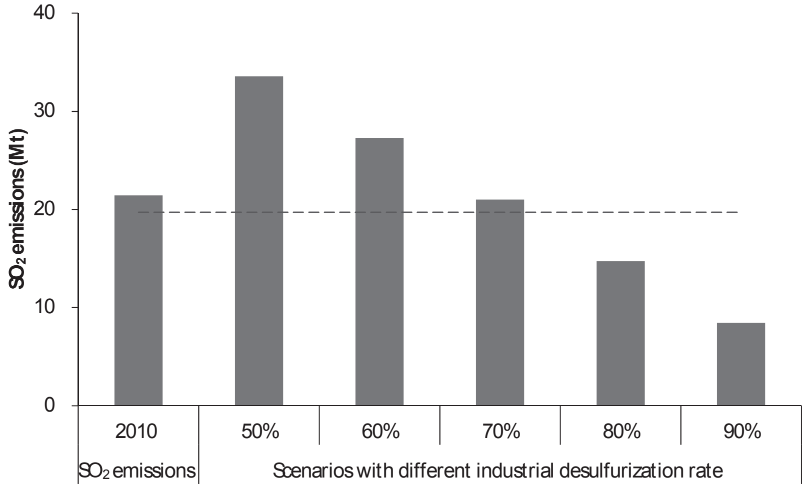
Tab.2 SO_2 emission scenarios of China in 2015

GDP growth Scenarios	Primary energy consumption	Electricity generation	Gross SO_2 emissions	Household SO_2 emissions
(%)	(Mtoe)	(TWh)	(Mt)	(Mt)
5%	2673	5306	60.6	2.1
7%	2818	5893	65.0	2.2
9%	3001	6434	69.0	2.2
11%	3405	8193	80.7	2.3

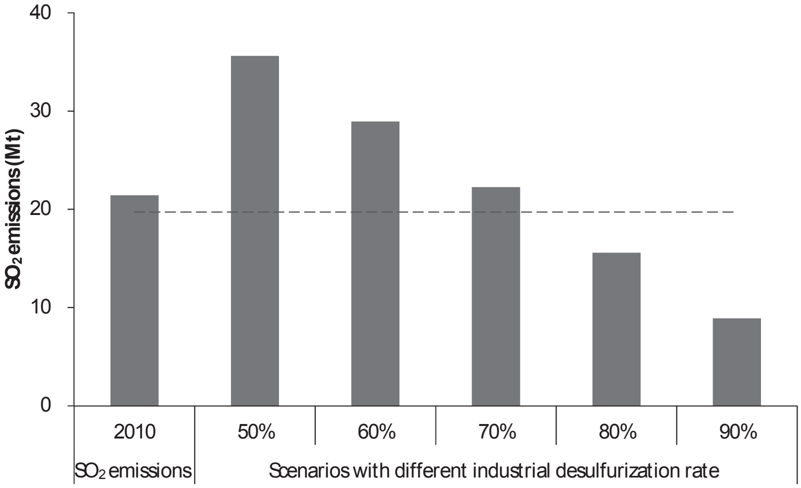
With regard to different GDP growth scenarios, this study considers five possible desulfurization rates and the results are shown in Figure 5. The dash line in each figure represents the SO_2 emission target in 2015 and the scenarios which go below the dash line indicate that it is able to achieve the SO_2 emission reduction targets with the relevant desulfurization rates. For example, China can fulfill the SO_2 emission targets in all the GDP growth scenarios with 80% and 90% desulfurization rates in 2015. The 5% growth scenario with 70% desulfurization rate can also reach the SO_2 emission reduction target, although it is close to the planned target level. If calculated as exactly to meet the target, the desulfurization rate needs to be at least 69.9%. Analogously, the meeting-target desulfurization rates of 7%, 9% and 11% growth scenarios are 72.1%, 73.8% and 77.8%, respectively. It implies that if China wants to achieve the planned SO_2 control target, the desulfurization rates should be raised above 70% due to the uncertainty of GDP growth. According to NBS (2011), only six provinces (Gansu 79.3%, Jiangxi 77.6%, Guizhou 77.2%, Yunnan 77.1%, Anhui 76.9% and Hainan 75.7%)



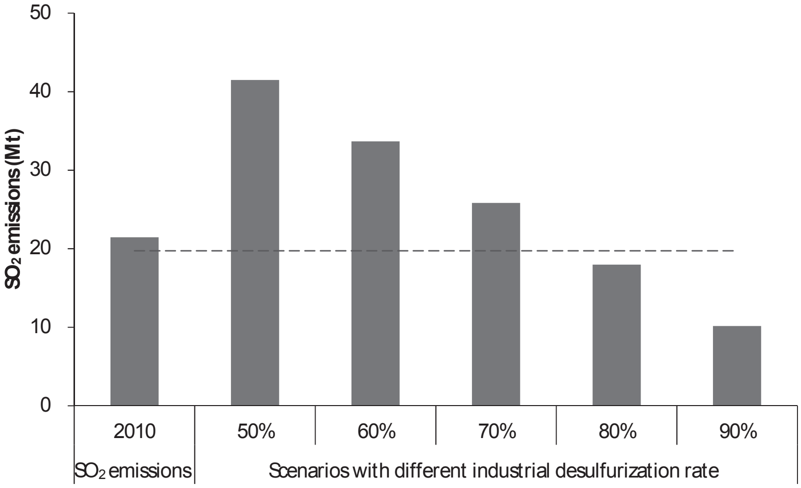
a. SO_2 emissions of 5% GDP growth scenario



b. SO_2 emissions of 7% GDP growth scenario



c. SO_2 emissions of 9% GDP growth scenario



d. SO_2 emissions of 11% GDP growth scenario

Fig.5 SO_2 emission reduction scenarios

have the desulfurization rates over 70% in 2010. However, none of them are heavy industries concentrated provinces with serious SO_2 emissions. Therefore, more efforts should be focused on the heavy industries concentrated provinces like Shandong, Inner Mongolia and Henan, in order to reduce SO_2 emissions effectively.

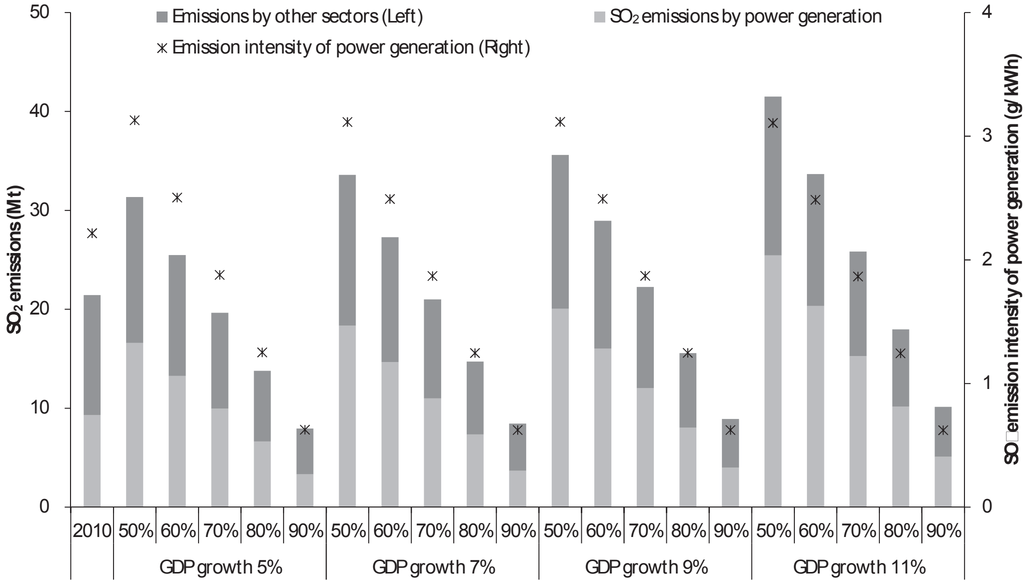


Fig.6 SO_2 emissions by power generation and other sectors, and SO_2 emissions intensity of power generation

The power generation industry sector contributes most of the SO_2 emissions among different industrial sectors in China (NBS, 1990-2012). In order to clarify the role of the power industry in SO_2 emissions reductions, this study distinguishes the SO_2 emissions between power industry sector and other sectors, as shown in Figure 6.

Firstly, as to different GDP growth, the higher the growth rate is, not only the SO_2 emission quantity, but also the amount share in total SO_2 emissions are larger than that of lower gowth rate, due to the rapid increase in electricity generation, which mainly relies on coal thermal power plants. Nevertheless, with respect to different desulfurization rates within the same GDP growth, the percentage of SO_2 emissions from coal thermal power plants decreases as the desulfurization rate increases. For instance, in the 7% growth scenario with 70% desulfurization rate, the SO_2 emissions from coal thermal power plants account for 52.4% in total SO_2 emissions while the amount share decreases to 43.5% if the desulfurization rate reaches 90% due to the assumption that SO_2 emissions from household are unable to remove. Also, in the 7% growth scenario, the desulfurization rate needs to be raised to 72.1% according to the previous analysis, however, only petroleum, coking & nuclear fuel and nonferrous metals sectors, which account for just 7.1% of total SO_2 emissions, are above this desulfurization level, with 79.0% and 89.9% respectively in 2010. The industrial sectors, like electric & heat power, ferrous metals and nonmetal mineral sectors that emit SO_2 seriously are all under the meeting-target desulfurization level of the planned 7% growth scenario in 2010. The future SO_2 emission control policy needs to focus on these industrial sectors to ensure the achievement of the control target.

Secondly, during the last two decades, the energy consumption structure of China has not change much and coal is still the main energy source, although the renewable energy such as hydro-power, nuclear, wind and solar energy have increase slowly from 5.1% in 1990 to 8.6% in 2010 (NBS, 1990-2012). Thus the reduction of energy related SO_2 emissions relies mainly on the dry-type or wet-type SO_2 scrubbers, which are particularly effective when there is large potential within the maximum reduction effects of these scrubbers. Even though there is still leeway before "using up" all of the technical desulfurization potential, like wet scrubbers which can reduce more than 90% of total SO_2 emissions (US EPA, 2003), it would be a good direction for China to increase the use of renewable energy, not only for environmental consideration, but also for sustainable development. Accompany with different environmental emission control targets, China also plans to increase the renewable energy to 11.4% of total energy use by 2015, and 15.0% by 2020. The changes in the energy consumption structure contribute to SO_2 and other energy related emission control. Furthermore, as to the power generation, the SO_2 emission intensity of power generation has decreased to 2.1 g/kWh in 2010, comparing to the above 7.0 g/kWh level in early 1990s. The SO_2 emission intensity of power generation of future scenarios, although has little to do with the GDP growth, must not exceed 1.9 g/kWh, if the planned control target is achieved (see Figure 6). In particular, the 11% gowth scenario requires a emission intensity for the power generation sector as lower as 1.4 g/kWh to make the realization of the SO_2 emission control target become feasible. All in all, the popularization of the desulfurization units and the changes in energy consumption structure will both help China to achieve the environmental control targets effectively.

4. Conclusions

This paper makes a comprehensive assessment of energy related SO_2 emissions control in China's 12th Five-Year Plan based on a large scale non-linear integrated assessment model. Four GDP growth scenarios, 5%, 7%, 9% and 11% with five different possible desulfurization rates, 50%, 60%, 70%, 80% and 90% are simulated in this study, covering most of the economic development and environmental protection possibilities during the period of 12th Five-Year Plan. Firsly, the results indicate that there is a relative large potential for China to reduce SO_2 emissions technologically, as the mean desulfurization rate of the whole country is still below 70% in recent years, far from the maximum reduction effects of the advanced desulfurization units like wet-type SO_2 scrubbers, of which the removal efficiency are greater than 90%. In fact, most desulfurization units in China's industrial sectors adopt the wet-type SO_2 scrubbers. But the mean desulfurization rate is still low due to the insufficient opereation of the these equipments and relative lower environmental emission standards. The popularization of wet-type SO_2 scrubbers and improvement of the environmental emission standards play an important role in the achievement of SO_2 control target by 2015. Also, relative monitoring and validating systems are needed to ensure that the SO_2 scrubbers are operated adequately. Secondly, the improvement in energy consumption structure contributes to SO_2 and other energy related emission controls effectively, as well as the sustainable development of energy. The relative backward energy consumption structure is an obvious handicap for the economic and environmental development of China. Most environmental problems including SO_2 emissions China faces currently, will be solved to a certain extent with the changes in energy consumption structure. Thirdly, the thresholds of desulfurization for different growth scenarios, namely 5%, 7%, 9% and 11% scenarios, to achieve the SO_2 emission control target are presented in this study, as 69.9%, 72.1%, 73.8% and 77.8, respectively. However, recently only a few provinces and industrial sectors surpass the 70% desulfurization level, which is considered to be important for the achievement of the SO_2 emission control target. Future environmental policy should concentrate on the provinces which emit SO_2 seriously, like Shandong, Inner Mongolia and Henan, or relevant industrial sectors such as electric & heat power, ferrous metals and nonmetal mineral sectors. With respect to the SO_2 emission control target in China's 12th Five-Year Plan, albeit not a stringent one and being able to capture lessons from previous 10/11th Five-Year Plan, China still needs to make effort to fulfill the environmental protection goals.

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