Air Pollution reduction during China's 11th Five-Year Plan period - Local implementation and achievements in Shanxi province

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Abstract

Facing the increasing environmental degradation locally and globally, the Chinese government set mandatory goals of 10% reduction of SO_2 emission in its 11th Five-Year Plan period (FYP, 2006-2010). In this paper we use Shanxi province to illustrate how policies and measures are implemented in practice at a provincial level as a response to the National FYP issued by the central government. Local policies are described and their effects are analyzed. We find that the 11th FYP goal for SO_2 pollution reduction in Shanxi has been surpassed. SO_2 reduction from estimated baseline level was calculated for the FYP period in order to identify which sectors have had the largest reductions. Regarding SO_2, we find that Flue-gas desulfurization (FGD) in power plants has been the most important, while either the FGD operation rate or the efficiency, or both, are much lower in practice than officially required. SO_2 emission reduction from closing down outdated production capacity is small according to our estimates. This is due to the comparatively small use of coal in the units being closed down in Shanxi. Necessary steps to achieve the targets in the 12th FYP are briefly discussed.

Key words: China; Pollution reduction; Environmental Five Year Plan; targets;

1. Introduction

China's recent rapid economic growth has been accompanied by a dramatic increase in energy use (D. Zhang et al., 2011). The energy structure dominated by coal and the rapid growth of polluting industries have resulted in great impacts and pressures on the environment, which have caused considerable international and domestic concerns (Gan, 1998; Economy, 2007; Vennemo et al, 2009). The World Bank (2007) estimated that the economic burden of air and water pollution in China was between 362 and 781 billion RMB Yuan in 2003, or 2.7 - 5.6 percent of GDP. According to the 2005 Environmental Sustainability Index published by Yale University and Columbia University (Esty et al, 2005), China's score was 38.6 (the top score is 75.1), or 133rd among all 146 countries. In 2005, the State Environmental Protection Administration of China (SEPA) reported that severe pollution prompted 51,000 public disputes[1], while the Central Committee of the Communist Party of China has identified pollution as one of four social problems linked to social disharmony (Nankivell, 2005). Regarding its impact on global climate change, China's CO_2 emissions have increased dramatically from about 1.4 billion tonnes in 1978 to 8.3 billion tonnes in 2010 (25% of global emissions), and overtook USA (which emitted 6.1

[1] "'Unexpected' pollution comes as no shock", October 16, 2006. http://english.peopledaily.com.cn/200610/16/eng20061016_312042.html

billion tonnes in 2010) as the world's largest emitter of energy-related CO_2 in 2006 (BP, 2011).

Facing the mounting pressure, the Chinese government has initiated many efforts to control the environmental problems. Since the early 1980s, a series of national plans, policies and laws have been enacted. In 1994, a broad strategy was laid out to achieve sustainable development in China. Two years later, the first Five-Year Plan on environmental protection (EFYP) (1996-2000) was developed. More recently, a new "scientific development" concept was proposed to achieve a harmonious society and a balanced relationship between humans and nature (Fu et al., 2007). The State Environmental Protection Administration (SEPA) was promoted to Ministry of Environment Protection (MEP) in 2008, implying that higher priority should be given to environmental protection. This is also reflected in China's development goals. In the 11th FYP for Economic and Social Development (NDRC, 2006), mandatory goals for pollution reduction for the 2006-2010 period were stated. While the national economy was planned to maintain a relatively stable and fast growth, the environmental quality of key regions and cities should be improved, and the ecological deterioration be brought under control[2]. By 2010, the total amount of major air and water pollutants (SO_2 and COD[3]) released should be reduced by ten percent.

The targets indicate that the Chinese government was serious in its call for the new "scientific development" concept to assure a sustainable environment. However, the 11th FYP was widely considered to be too ambitious, considering that China's 10th FYP had also set goals for environmental protection (in the main plan), that were not achieved (MEP, 2007a). There was general agreement that it would be impossible to achieve the new goals without strong involvement of provincial and local governments. The problem was how local authorities would contribute, considering that, in China, environmental efforts have

[2] There are also mandatory goals for the 12th FYP. See discussion section.
[3] COD-Chemical Oxygen Demand which is an indicator of the amount of organic compounds in water.

lacked effectiveness, resulting in an implementation gap, and that the biggest obstacles to environmental policy implementation are at the local level (OECD, 2006).

In this paper we use Shanxi province (see Fig. 1) as a case to illustrate how policies and measures were implemented in practice at a local scale as a response to the National FYPs issued by the central government. The paper describes efforts to reduce the release of pollutants with emphasis on SO_2 in Shanxi during the 11^{th} FYP period (2006 – 2010). It describes the major policies and policy changes that seem to have been instrumental to the increased success of the 11^{th} FYP as compared to previous FYPs. For efforts and achievements in the Shanxi Province on energy conservation and energy intensity, see our previous paper (D. Zhang et al., 2011), and also J. Zhang et al (2011) and Kostka and Hobbs (2012).

a **b**

Fig. 1. Shanxi Province: (a) Location of Shanxi, (b) Map of Shanxi (11 key cities)

2. Air pollution in Shanxi

According to Shanxi EPB (2006; 2007), emissions of main pollutants far exceeded the environmental capacity by the end of the 10^{th} five year period, and the environmental situation was serious. Implementation of a series of control policies and measures led to improvement in the environmental situation in Shanxi during the 11th FYP period.

According to Shanxi EPB (2006), none of the 11 key cities (see Fig. 1b) satisfied the grade II standard for air quality[4] and only 2 met the grade III standard[5] (the least stringent standard) in 2005 (see Fig. 2a). Linfen, Datong and Yangquan were the 3 most polluted cities among the 113 key cities in China inspected by MEP, and 5 of the 11 Shanxi cities were listed among the 30 most polluted of the 113 cities. Linfen (1.4 million urban population) was the worst, followed by Datong (1.5 million urban population) and Yangquan (0.7 million urban population). However, the air quality of other cities inspected by Shanxi EPB (but not included in the 113 cities inspected by MEP), such as Xinzhou, was even worse than that of Linfen, according to Shanxi EPB (2006). 13 of the 41 counties/municipalities in Shanxi that do have air quality monitoring had a pollution index higher than Linfen.

a **b**

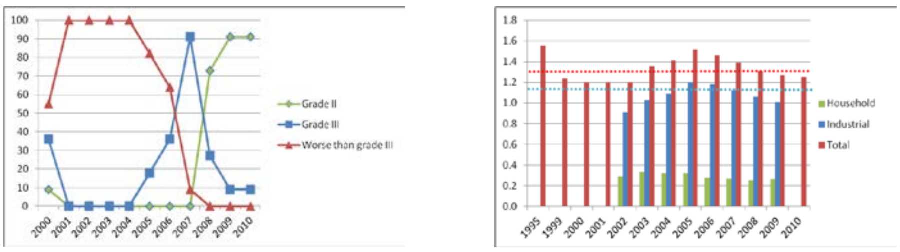

Fig. 2. Development in Shanxi of main pollution indicators: (a) Air quality trends (Percentage of 11 key cities meeting ambient air quality standard), (b) SO_2 emission (million tonnes) (…10th FYP target; …11th FYP target).

Source: SOE of Shanxi 2000-2010 (Shanxi EPB, 2001-2011)

SO_2 and PM_{10} were the major components affecting Shanxi air quality in 2005, with SO_2 causing most violations of air quality standards. Among the 11 key cities', 2 slightly

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[4] Grade II standard requires annual average values below 60µg/m^3 for SO_2; 100 µg/m^3 for PM_{10}; and 80 µg/m^3 for NO_2.
Note that the guidelines from World Health Organization for PM_{10} and SO_2 are much lower than the grade II values, respectively 50 µg/m^3 and 20 µg/m^3 for 24-hour mean. The guidelines are available at :
http://whqlibdoc.who.int/hq/2006/WHO_SDE_PHE_OEH_06.02_eng.pdf

[5] Grade III standard requires annual average values below 100µg/m^3 for SO_2; 150 µg/m^3 for PM_{10}; and 80 µg/m^3 for NO_2.

exceeded the grade II SO_2 standard; most of the others had concentrations 2-7 times this standard (see Fig. 3a).

a **b** **c**

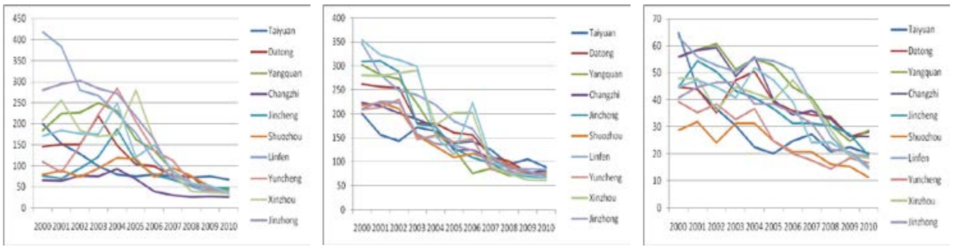

Fig. 3. SO_2, PM_{10} and NO_2 concentration in 11 key cities of Shanxi (μg/m^3): (a) SO_2 concentration, (b) PM_{10} concentration, (c) NO_2 concentration.

Source: SOE of Shanxi 2000-2010 (Shanxi EPB, 2001-2011)

PM_{10} pollution was also very serious in 2005 in Shanxi. PM_{10} concentrations in all 11 key cities exceeded the grade II standard with up to 100% (see Fig. 3b). All 11 cities in Shanxi met the grade II standard of NO_2 concentration in 2005 (see Fig. 3c).

Provincial SO_2 emissions were 1.5 million tonnes in 2005 (see Fig. 2b) ranking Shanxi third among the Chinese provinces. It had increased 26% compared with emissions in 2000, while the 2005 target was 1.10 million tonnes, which corresponds to an 8% reduction compared to 2000. Per unit GDP and per capita SO_2 emissions in Shanxi in 2005 were 2.6 and 2.2 times higher than the national averages, respectively.

Provincial TSP (total suspended particulates) emissions in 2005 from industrial production and households were 1.82 million tonnes (industrial soot 909,600 tonnes, household soot 212,300 tonnes and industrial dust 694,700 tonnes), the highest among provinces in China. It had increased 18% compared with emissions in 2000.

According to Shanxi EPB (2011), considerable improvements were achieved in air quality in Shanxi during the 11^{th}FYP. Among 11 key cities, 10 met with grade II in 2010, which is a 91 percentage points increase compared with 2005, and the last one, Taiyuan, reached grade III. Compared to 2005, the annual average concentration of SO_2 had decreased 73.2% and that of PM_{10} had decreased 47.2% by 2010 (Shanxi EPB, 2011) (see Fig. 3a and 3b). In 2010, SO_2 emission amounted to about 1.25 million tonnes, 17.6% lower than in 2005 (see Fig. 2b). The target for 2010 was 1.30 million tonnes (State Council, 2006), so according to the figures from Shanxi EPB (2011) the province had surpassed its 11th FYP goal for SO_2 reduction.

However, it has been questioned whether the official SO_2 emission data in China may be understated (Vennemo et al. 2009). For instance, Ohara et al. (2007) have developed an emission inventory for Asia and estimated that China's SO_2 emissions in 2003 were about 70 percent higher than officially reported. Moreover, research at Tsinghua University in Beijing also suggests that SO_2-emissions in 2005 may be 24% higher than official figures (Zhao, 2006 and 2011).

Shanxi's emission data might also be understated as the national values, but data from alternative sources are scarce. Zhao (2006) estimated that Shanxi's SO_2 emission in 2000 was about 1.3 million tonnes and also presented the province estimate from Ohara's emission inventory for the same year (Ohara et al. 2007) which was about 1.1 million tonnes. The official data for 2000, which was about 1.2 million tonnes, thus fell in between.

3. Policies and measures in Shanxi for reaching the pollution reduction targets of the 11th FYP period

In August 2006, the State Council approved a scheme disaggregating the 11th FYP's national pollution reduction targets into provincial reduction targets (State Council, 2006). Regarding SO_2 emission reduction, Shanxi was given a target of 14% from 2005. Based on this target and relevant national policies, a package of polices to reduce SO_2 emissions has been put in place in Shanxi (see Figure Appendix A).

3.1. Disaggregated targets and planning

3.1.1. Shanxi Provincial Government Notice[6] on major pollutants control in the 11th FYP Period

In order to realize the pollution reduction goals set for the 11th FYP period, Shanxi Provincial Government approved the provincial pollution reduction targets disaggregation scheme to the 11 key cities (see Fig. 1b), which was based on each city's economic structure, in July 2006, in *Shanxi Provincial Government Notice on major pollutants control in the 11th FYP Period* (*the Notice*). The disaggregated reduction targets for SO_2 range from 8% to 18%. For details, see Appendix B.

The Notice also required the 11 city governments to further disaggregate their targets to counties, and integrate the evaluation results on the performance of local officials in reaching the targets into the official appraisal system as an important basis for promotion.

3.1.2. The Shanxi Provincial Government Decision on Implementation of "Blue Sky and Clean Water" Program

In order to realize the goals of environmental protection set for the provincial 11th FYP period and reverse the environmental degradation trend, Shanxi Provincial Government issued, in June 2006, *The Shanxi Provincial Government Decision on Implementation of "Blue Sky and Clean Water" Program* (the Program).

[6] The legal status of administrative documents in China: regulation > government order, decision, implementation scheme, measure or method > notice or opinion (Characteristics of Common Types of Official Documents. http://office.nwsuaf.edu.cn/edoas2/website7/level3.jsp?id=1186058812578066. In Chinese).

The Program covers 11 cities and 32 counties out of the 119 counties in Shanxi. The cities and counties included in the Program cover the main urban areas in Shanxi situated along the main highway (from the northernmost, Datong, to the southernmost, Yuncheng) and along the main river, Fen River. Administrative areas, with 58% of Shanxi's population and responsible for 79% of SO_2 emission and 94% of the COD discharge in Shanxi, are covered. For details, see Appendix C.

3.2. Implementation of pollution reduction measures in Shanxi

Several measures to improve energy efficiency and restructure the economy away from the heavy dependence on secondary industry have contributed to less pressure on the environment as described in D. Zhang et al (2011). In this section we will emphasize measures directly targeting pollution reduction (not energy efficiency).

The actions taken in Shanxi to reach the pollution reduction targets can roughly be summarized into four categories: pollution control engineering, economic restructuring, enhancing environmental management, and supplementary policies. They will be illustrated separately in the following (except category economic restructuring), while, in fact, they are closely integrated when implemented.

3.2.1. Pollution control engineering: FGD facilities for SO_2 reduction

In 2005, SO_2 emission from coal-fired power plants in Shanxi accounted for 49% of the total, and the emission from other industrial sectors was 30% of the total. Thus, desulphurization in the coal-fired power plants was the key to reach the provincial SO_2 reduction target.

In 2005, Shanxi People's Government issued "The Notice regarding Tasks Assignment for the Desulphurization of Existing Coal-Fired Power Plants within a Prescribed Time Limit in The Whole Province" (*The Desulphurization Notice*). According to *The Desulphurization*

Notice, the establishment of FGD and installation of online monitoring systems should be completed by the end of 2005 for the 83 smallest coal-fired power plants (totally 246 generation units with total 4222 MW installed capacity); as a second step the same applied to 19 medium power plants (42 generation units with 6865 MW installed capacity) by the end of October 2006; and finally for the 7 largest power plants (17 generation units with amount of 4550 MW installed capacity) by the end of 2007. The power plants that met the requirement would enjoy subsidies from the electricity price premium described in Appendix B, while those that failed would be shut down.

In 2006, the General Office of Shanxi People's Government issued "The Implementation Opinions on Accelerating the Desulphurization in Coal-Fired Power Plants" (*The Opinions*) to further strengthen the construction of FGD facilities. *The Opinions* required not only that the existing power plants should complete FGD construction before due time, but new-built power plants should install FGD during plant construction. *The Opinions* asked to strengthen the supervision in order to ensure proper operation of FGD facilities. Unauthorized stop of FGD facilities would be punished by cutting the subsidy from the price premium. *The Opinions* ordered the governments at different levels to accelerate the construction of FGD facilities by using various incentive policies, clearly defining responsibilities of local government departments, making strict performance assessment of officials and strengthening the accountability system.

During the 11^{th} FYP period, 72 sets of generation units that failed to complete the FGD construction before due time were shut down in Shanxi. Most of these were small units and the average size was about 20 MW (1527 MW in total). All the other power plants had completed the construction of FGD by the end of 2008. Furthermore, coke making industry had also realized coke oven gas desulphurization by the end of 2010 (Liu, 2011).

3.2.2. Enhancing environmental management

3.2.2.1. Environmental management of key industries

More than 80 local environmental legislation and regulations promulgated during the 11th FYP period, such as *Shanxi Provincial Government Order on the Control Measures to Pollution Sources from Key Industries* and *Shanxi Supervision Regulations on Pollution from Key Industries,* form a basis for improved environmental management.

Shanxi Provincial Government approved *The Control Measures to Pollution Sources from Key Industries* (*the Measure*) at its 77th executive meeting in August 2006.

Key industries in *the Measure* are the industries of coal, power, metallurgy, chemical, coke, building materials and paper. *The Measure* specified the responsibility of local governments, and required phasing out production facilities with high energy consumption, heavy pollution and outdated technology, listed in the “Phasing out Category” of *The Guiding Catalog of Industrial Structure Adjustment*. According to *the Measure*, all key industries should have installed cleaning devices and meet the emission (or discharge) standard by the end of 2008, and should also strictly implement emission (or discharge) permit systems and environmental impact assessment system. *The Measure* also required all key industries to make sure that the cleaning devices work satisfactorily and install online monitoring devices. Penalties for any violation were also specified.

The 33rd Meeting of the Tenth People's Congress Standing Committee of Shanxi Province approved *Shanxi Supervision Regulation on Pollution from Key Industries* (*the Regulation*) in Sep. 2007. *The regulation* specifies that the governors at different levels have the main responsibility for the environmental quality in their jurisdiction, gives higher level EPBs legal right to punish local governments for neglect and dereliction of duty on environmental law enforcement, and gives the public legal right to know, to participate and to supervise the government’s supervision of pollution from key industries.

3.2.2.2. Enhanced environmental management through institutional development.

In 2009, Shanxi EPB was updated to be a cabinet department of the Provincial Government rather than a department directly under it. The updating reflects the increasing power of Shanxi EPB in provincial policy-making. All 119 counties established independent environmental management administration structures (most of them were part of other governmental departments before).

3.2.2.3. Strengthened environmental management through capacity building.

During the 11th FYP period, Shanxi invested about 1.4 billion RMB in capacity building in environmental management, and took the lead in China in establishing online air quality monitoring stations. The network covers all 119 counties in Shanxi. Online pollution source monitoring and control systems were also established in 756 enterprises with 5000 monitoring and control spots covering waste gas emission and pollution control facilities performance, etc.

3.2.2.4. Improved environmental management through strengthened law enforcement.

In cooperation with 14 different government departments, Shanxi EPB issued more than 20 regulations and took actions against 4420 violations of environmental regulations. To reach annual targets, Shanxi punished enterprises which did not phase out their outdated capacities within due time by the "Five Stops", i.e. cutting off power supply, water supply, coal supply, transportation services and loans. In order to punish environmental violation in a region, "Regional Restricted Approval" was introduced. Environmental impact assessment approval might be stopped for all construction projects within the region. During the 11th FYP period, 15 counties experienced punishment through "Regional Restricted Approval". "The Elimination System of the Worst" was introduced to phase out the most polluting enterprises and processes based on yearly evaluation. 1236 enterprises with serious pollution and 1606 sets of outdated facilities were phased out during the 11^{th} FYP period in Shanxi (Liu, 2011).

3.2.3. Incentive policies

A series of incentive policies have been adopted in Shanxi in addition to the national economic incentive policies (see Appendix D), including the new appraisal and reward programs and financial incentives.

3.2.3.1. *The appraisal and reward programs in Shanxi*

Appraisal and reward programs have proved important for emphasizing the leadership responsibilities of local government officials at all levels as well as of enterprises.

Appraisal Program for Regional Economic and Social Development during the 11^{th} FYP period in Shanxi

As described in detail in D. Zhang et al, 2011, Shanxi Provincial People's Government approved *The Appraisal Program for Regional Economic and Social Development during the 11^{th} FYP period in Shanxi* (the *Appraisal Program*) in August, 2006. This was a response to the call for a new appraisal system, based on the *Scientific Concept of Development*, for major leaders of local governments regarding their regional economic and social development to replace the old one which was based on economic indicators only. 39 indicators in total are included in the *Appraisal Program*, 31% of them are relevant to sustainable development, and SO_2 emission reduction target as a mandatory indicator is among them. This means that if local governments fail to meet their annual target for this indicator, the top leaders of local governments will fail their annual appraisal.

Interim Measures of environmental protection performance appraisal for leading cadres in Shanxi Province

Shanxi Provincial Government issued *Interim Measures of environmental protection performance appraisal for leading cadres in Shanxi Province* (*the Interim Measures I*) in Feb. 2007. *The Interim Measures I* includes performances in six areas: enforcement of leadership responsibility for environmental protection, enforcement of environmental protection laws and regulations, environmental quality improvement in their jurisdiction, achievements on main pollutant emission reduction targets in their jurisdiction, completion of key environmental protection projects, and the public satisfaction regarding the environmental protection in their area. *The Interim Measures I* further specified the performance appraisal criteria for leading cadres of relevant departments of local governments at all levels and of state owned enterprises.

Interim Measures of Evaluation, Reward and Punishment for Environmental Pollution Control in Shanxi Province

In Dec. 2008, Shanxi Provincial Government issued additional incentive policy measures to governments at different levels for promoting the implementation of “Blue Sky and Clean Water” Program and realization of pollution reduction targets, *Interim Measures of Evaluation, Reward and Punishment for Environmental Pollution Control in Shanxi Province* (*the Interim Measures II*). *The Interim Measures II* are based on the city’s or county’s rank of environmental quality, the rank regarding environmental improvement and the rank of achievement in reaching pollution reduction targets. Among the cities that have reached their annual pollution reduction target, the city with the best air quality will get a 3 million RMB reward; the city with the biggest air quality improvement will get 1 million RMB reward; and each of them will also get extra 10 million RMB for a capacity building fund. The 10 counties with best air quality and the 10 counties with biggest air quality improvement will get a 0.5 million RMB reward and an extra 2 million RMB for a capacity building fund. The city and the 10 counties with worst air quality, and the city and the 10 counties with the largest deterioration of air quality, will be punished by circulating a notice of criticism and their main leaders will lose their right to compete for any rewards. Main leaders from the cities or counties who are being punished for two consecutive years will receive admonishing remarks and those for three consecutive years will receive administrative sanctions according to relevant regulations. Deception in the assessment and evaluation can lead to criminal charges.

During the 11th FYP period, 80 government officials were punished according to the appraisal and evaluation rules, while 72 institutes and individuals lost their right to compete for any rewards. Meanwhile, more than 80 million RMB were rewarded to cities and counties for their excellent pollution reduction performance.

3.2.3.2. *Financial incentives*

In addition to a series of national financial policies encouraging pollution reduction (see Appendix D and D. Zhang et al. 2011), Shanxi issued the following financial incentives:

Shanxi Management Method of Special Fund for Major Pollutants Reduction, issued in September 2007, required that government finance departments at all levels should establish special funds for supporting pollution reduction, in forms of subsidized loan interest rates, direct subsidies, grants and rewards. The funds shall support pollution reduction engineering projects; environmental management capacity building, such as improving the “Three Systems” construction (i.e. monitoring system, supervision system and statistics system); shutting down or moving enterprises for pollution reduction; and other projects contributing to pollution reduction determined by the provincial financial department and Shanxi EPB. In addition these funds are used to reward cities, enterprises, units and individuals that have achieved outstanding results in pollution reduction.

During the 11^{th} FYP period, 4.7 billion RMB were allocated from governments at all levels as the *Special Fund for Major Pollutants Reduction*.

Shanxi Special Compensation Fund for Eliminating Backward Production Capacity, issued in May 2008, required a special compensation fund, raised by the provincial finance department from the Coal Sustainable Development Fund, the Power Construction Fund and the provincial budget, for compensating investments in new industry replacing backward production facilities which are dismantled before due time set by the government. (An extra 10% of the compensation rewards to facilities dismantled one year earlier than the due time, 20% to those dismantled two years earlier, and no compensation to those dismantled later than the due time.) These funds also finance the restoration of landscapes where backward production facilities are dismantled.

By the end of Sep. 2010, Shanxi had allocated 1.31 billion RMB to compensate for the phasing out described above, and 1.49 billion RMB had been rewarded from the central government.

In December 2009, Shanxi People's Government issued *Guidelines on Starting Paying for the Use and Trading of Pollution Release Rights in the Whole Province* as an incentive to stimulate further pollution reduction in the last year of the 11^{th} FYP period and beyond by initiating emission trading mechanisms through trial projects.

In March 2010, Shanxi EPB and China People's Bank Taiyuan Branch jointly launched *Shanxi Evaluation Method on Green Credit Policy Implementation* to promote pollution reduction through the integration of credit policy and pollution reduction policy.

3.2.4. Data quality assurance and control

In order to assure and control data quality and avoid local officials fabricating data, Shanxi Provincial People's government, in July 2008, issued *The Shanxi Implementation Scheme on the Statistics of Total Pollution Control of Major Pollutants* and *The Shanxi Implementation Scheme on the Monitoring of Total Pollution Control of Major Pollutants.* Reported pollution reduction data from local government will be triple checked and verified by panels of experts from local, provincial and central government level by considering consistency with other indicators, e.g. general economic development, population and indicators of environmental status, before they are published by MEP and NBS. Any false reporting will be punished according to *Interim Measures of Evaluation, Reward and Punishment for Environmental Pollution Control in Shanxi Province.*

4. Effect estimates of pollution reduction measures in Shanxi

By implementing pollution control policies and measures more than 1,400 seriously polluting enterprises were closed in 2006. Newly established power plants were required to install desulphurization facilities, and an installed capacity of 13 GW power generators completed construction of desulphurization facilities. In 2007, more than 4,000 enterprises were closed, construction of desulphurization facilities was accelerated and the national policy of preferential electricity price[7] was applied to power-generating plants to encourage construction of desulphurization facilities. By 2008, all the coal-fired power plants, with

[7] A plant with desulphurization facilities with 100% operation can add 0.015 RMB per kWh for electricity sold to the grid compared to a plant without the facilities.

capacity of 30.56 GW, were equipped with desulphurization facilities. Meanwhile, 476 enterprises that failed to reach environmental standards were ordered to stop on 1st January, 2009. Among the other 9,208 key industrial pollution sources that have built pollutant disposal facilities, 1,015 sources fully reached environmental standards by 2008. By the end of 2010, the district heating coverage and gas supply for household use had increased by 44.9% and 14% respectively compared to 2005 (Shanxi EPB, 2011).

Publicly available, systematic reporting of effects of the provincial pollution control programs is lacking. This limits the possibility to link the progress in overall SO_2 emission reduction to the different policies and measures described above. In an effort to estimate the effects of the provincial programs, we have estimated a baseline SO_2 emission for the period 2006-2010, assuming no change in SO_2 cleaning after 2005. The baseline is calculated from reported coal consumption (SBS, 2011), a constant SO_2 emission per unit of coal consumption of the non-electricity generation sectors (SBS, 2011; Shanxi EPB, 2006) throughout the 11th FYP period, and the formula in Eq (1) (MEP, 2007b) for the electricity generation sector. The formula is based on the assumptions that the sulfur content of coal used is S and 80% is combustible. The ratio 80% is based on data for the 11th FYP (MEP, 2007b). For the 12th FYP, it is assumed to be 85% (MEP, 2011). Using the latter value would, of course, increase all emission amounts calculated by Eq. (1) by 6.3%. The factor of 2 converts amount of S to amount of SO_2.

$$SO_2 \text{ emission} = (\text{Amount of coal combusted}) \times S \times 0.80 \times 2 \qquad \text{Eq (1)}$$

Estimates were made for S equal to 1%, which is considered the most likely value, and lower and upper limits of 0.6% and 1.5% (SPG, 2009)[8]. In the following, sensitivity estimates using these S content limits are provided in parenthesis along with estimated SO_2 reductions. Compared to the estimated baseline SO_2 emission, 10.58 (8.15-13.66) million tonnes in total for the period 2006-2010, Shanxi reduced the SO_2 emissions by about 3.90 (1.45-6.96) million tonnes from 2006 to 2010 (see Table 1).

Table 1

SO_2 reduction estimates compared to baseline SO_2 emission. Values in the two last rows were obtained with S contents in coal of 1%. Simple sensitivity estimates are provided in the parenthesis, using an S content of 0.6% and 1.5%, respectively, ignoring other uncertainties.

Unit: million tonnes

	2005	2006	2007	2008	2009	2010	Sum (2006-2010)
SO_2 emission control target	1.52	1.43	1.37	1.30	1.30	1.30	
Reported SO_2 emission[a]	1.52	1.48	1.39	1.31	1.27	1.25	6.70
Estimated baseline SO_2 emission	1.52	1.94 (1.52-2.47)	2.11 (1.65-2.69)	2.12 (1.63-2.73)	2.09 (1.60-2.72)	2.32 (1.75-3.05)	10.58 (8.15-13.66)
Estimated SO_2 emission reduction	0	0.46 (0.04-0.99)	0.73 (0.26-1.30)	0.81 (0.32-1.42)	0.83 (0.33-1.45)	1.07 (0.50-1.80)	3.90 (1.45-6.96)

[a] Source: Shanxi EPB, 2006-2011.

In the following we attempt to disentangle the emission reductions from some main SO_2 reducing policy measures in order to understand which ones have been the most effective. As data on emission reductions are not available for individual sources or policy measures

[8] Average 1% S content is confirmed by personal contact in Shanxi EPB.

we estimated emissions reduction from different sources and measures and compared to the baseline of Table 1. We estimated SO_2 emission reduction from electricity generation by flue gas desulfurization (FGD), and by closing down outdated production capacities, mainly in key industries described in section 3.2.2.1.

For FGD, we used two different methods. Method 1 (M1): We subtracted reported SO_2 emissions for the relevant power plants from the estimated amounts obtained by Eq (1) as done above to obtain the results in Table 1. Method 2 (M2) is used to check consistency in reported numbers: We combined the SO_2 emission estimates obtained by Eq (1) with FGD installation rate (see Table 2) assuming that 70% of new-built FGD started operating at the same time as the operation start-up of the new-built power generation units (MEP, 2007c). According to the official requirements, the operation rate of well-functioning FGDs should be 95% (SPGGO, 2009) and the efficiency of FGD 90% (SPG, 2007) which were used in our estimation in M2. To estimate the SO_2 emission reduction obtained by closing down outdated electricity generation capacities (PCD stands for Power sector Closing Down, hereinafter), Eq (1) was used directly based on estimated amount of coal used in the facilities before closing as given in D. Zhang et al (2011). To estimate the SO_2 emission reduction from closing down outdated emission sources in non-electricity generation sectors (NPCD stands for Non-Power sector Closing Down, hereinafter), the SO_2 emission intensity of coal consumption in these sectors and the estimates of coal saved given in D. Zhang et al (2011) were used. Due to lack of data, we assume that the SO_2 intensity is the same in outdated facilities as the baseline intensity, which may be an underestimate.

Merknad [DD1]:
Daisheng: 70% is the percentage of the new-built FGD each year started working compared to the total new-built FGD each year.
95% is the percentage of FGD working hours compared to the whole year round; if 100%, it means the FGD has worked nonstop for the whole year. By the way, there is a term "penetration rate", but I do not know how to use it here.

Table 2

Per cent of power generation capacity in Shanxi with FGD installation

	2005	2006	2007	2008	2009	2010
FGD installation rate[a]	10	20	54	100	100	100

Note: [a]: calculated based on the data for annual total power generation capacity and the capacity with FGD installed from SBS (2006-2011) and Shanxi EPB (2006-2011).

We estimate that FGD (by using M1) and PCD and NPCD gave a total reduction of 3.39 (0.87-6.66) million tonnes during the 11th FYP compared to that of the baseline emission of 10.58 (8.15-13.66) million tonnes, see Table 3. The reduction from the power sector, which was 3.37 (0.85-6.64) million tonnes, contributed the lion's share of the estimated total SO_2 emission reduction. The reduction by FGD dominated the total reduction (82%), followed by the *other* control options (13%). This may be efforts to reduce SO_2 emissions from existing production capacities in other industrial sectors than the power sector, and from the domestic sectors, e.g. closing down small-to-medium boilers through expanding the coverage of district heating supply and replacing domestic coal use for heating and cooking by expanding the coverage of coal gas supply. However, it must be kept in mind that the values for "other control options" are obtained as differences between large numbers with considerable uncertainties, and are thus only rough estimates. The SO_2 emission reduction from closing down outdated production capacities is rather low consistent with the fact that the estimated coal used in these closed down production capacities only accounted for 4% of the total reported coal consumption during 2006-2010. Nationwide, Cao et al (2009) also found FGD to be significantly more effective than closing down outdated facilities.

However, the closing down of outdated production capacities and domestic sources might contribute much more to the substantial SO_2 concentration decrease showed in Fig. 3a than its share of the emission reduction, since the emission height of these sources is low in most cases and hence the local impact larger.

Estimated SO_2 reduction from FGD by using M2 for the year 2008, 2009 and 2010 are higher than that of the estimated total SO_2 reduction (showed in Table 1) for these three years. This is discussed further in the next section.

Table 3

SO_2 emissions reduction by various control options. Values (except the second last row) were obtained with S contents in coal of 1%, and, in parenthesis, the range 0.6%-1.5%.

Unit: 1000 tonnes

	2006	**2007**	**2008**	**2009**	**2010**	**Sum**
Estimated SO_2 reduction from FGD (M1)	429 (3.5-960)	549 (86-1127)	657 (167-1270)	695 (197-1319)	866 (289-1704)	3196 (743-6380)
Estimated SO_2 reduction from FGD (M2)	170 (102-256)	479 (288-719)	999 (599-1499)	1178 (707-1767)	1364 (818-2045)	4190 (2514-6286)
Estimated SO_2 reduction from closed down outdated power generation capacities (PCD)	6.11 (3.67-9.17)	39 (23-59)	28 (17-41)	51 (30-75)	51 (30-77)	175 (104-261)
Estimated SO_2 reduction from closed down outdated non-power generation sectors' capacities (NPCD)	0.73	8.17	6.60	3.52	3.10	22
Other[a]	28 (20-32)	131 (106-143)	117 (102-129)	77 (52-99)	155 (16-178)	508 (296-581)

[a] Derived from the estimated SO_2 emission reduction in Table 1 minus FGD (M1), PCD and NPCD in Table 3.

Although we do not have as detailed data for PM emissions as for SO_2, Fig. 3b shows a substantial decrease in PM_{10}-concentrations in Shanxi cities. Xie et al (2009) describe a study of airborne particles (PM_{10}) in Taiyuan in July 2003. They found a very complex mixture of particles which could be grouped as 20 different types. The three types containing the highest number of particles in the collected samples seemed to be mainly caused by coal burning. At that time the use of raw coal or briquettes for cooking and heating in households was still fairly common in some areas of Taiyuan. The emissions from these sources are close to the ground and the effect on the particle concentrations substantial. The decrease in PM concentration since 2003 may in part be due to gradual phase-out of these household fuels, and partly a side effect of WET-FGD systems, as these systems also entail reduced PM emissions (Zhao et al, 2011).

5. Discussion

Due to the lack of detailed data for SO_2 emission from other industrial sectors than power plants, we have assumed a baseline where *the pollutant release intensity of those sectors together* is kept constant at the 2005 level in Shanxi throughout the 11th FYP period. This assumption may underestimate the baseline pollutant release and thus the reduction, considering that the ratio of added value of heavy industry and light industry increased from 15:1 to 18:1 during the 11th FYP (SBS, 2011).

Results using M1 for FGD reduction estimation depend on assumptions of S content and percentage of combustible S in coal. These data are not available for each individual power plant. Using M2 for FGD reduction estimation, the results are sensitive to the assumed fraction of new-built FGD each year operating from the onset (70%), the operation rate of FGD (95%) and the efficiency of FGD (90%). In Shanxi 100% FGD coverage of the power generation units were reached already in 2008 and 70% of new-built FGD each year were thus assumed to be operating (95% of the time) in 2006 - 2008. Considering that the fraction of 70% is the national average in 2006 (Chinaenvironment, 2009), the uncertainty in this assumption is considerable. The fact that estimates using M2 are much higher than the estimated total reduction for 2008, 2009 and 2010 in Table 1 indicates that either the FGD operation rate or the efficiency, or both, are much lower in practice than officially assumed. This finding is consistent with Zhao et al (2011), who concluded that the SO_2 removal efficiency of FGD in practice in China is 75%. Note that both M1 and M2 as well as the estimated SO_2 reductions in Table 1 rely on official coal consumption data. We are aware that these may be too high or too low (see e.g. Guan et al., 2012), and do not address the reliability of these data as such in the current paper. If the FGD operation rate and/or efficiency are overestimated in the official figures, the reported SO_2 emissions (Table 1) would be underestimates. This would imply that the SO_2 reductions in Table 1 are overestimated, making the discrepancy between M2 results and total emission reductions even larger.

We may also have underestimated the SO_2 emission reduction from closing down outdated emission sources in non-electricity generation sectors by assuming that the SO_2 intensity is the same in outdated facilities as the baseline intensity. However, there can be little doubt that this reduction so far has been only a small fraction of the total SO_2 emission reduction.

In spite of data gaps and large uncertainties in our calculations, it seems clear that the pollution reduction achievements in Shanxi have been substantial in the 11th FYP period, even though SO_2 emission was still higher than the targets in the 10th FYP according to Fig. 2b. A series of policies have been implemented. The data available indicate that these policies have resulted in substantial improvements in environmental quality.

In Shanxi, the government's decision to focus on those sectors which yield the greatest immediate impact seems to be the main reason for the achievements. Shanxi government focused on the industrial sector through legislation on pollution control in key industries, implementing FGD projects, and phasing out obsolete production capacity. Our estimates indicate that SO_2 emission reduction (compared to the baseline) by FGD construction contributed about 82% to the total emission reduction achievements. This is consistent with the observation of the Ozone Monitoring Instrument (OMI) aboard NASA's Aura satellite (Li et al, 2010). During 2007-2008, OMI observed dramatic reduction of SO_2 emission over Datong and Shuozhou--two major power producing cities in Shanxi and without new power plants built between 2005 and 2007. To reach this, Shanxi invested 80 billion RMB in pollution control during the 11th FYP, a 60% increase compared to the investment in the 10th FYP. It was 2.93% of RDP, considerably higher than the national requirement which is 1% of RDP.

An important difference in 11th FYP vs. earlier FYPs was that the pollution reduction targets were defined as "compulsory", i.e. they are mandatory targets that the governments at both the central and local levels are responsible for achieving. Also, the fact that achievement of the target is tied to a person's political career by a personal penalty and reward system for governmental officials seems to have been effective at least in the short term. Thus pollution from many high-intensity polluters seem to have been reduced during the 11th FYP period due to the urgency of meeting compulsory targets and the various incentives linked to obtaining them. On the other hand, one may speculate whether the urgency may have let to a sub-optimal solution for the longer term. In this paper we have not been able to explicitly quantify in general how individual policies and measures have contributed to pollution reduction in Shanxi. However, we have used the available sectorial data in combination with information about the implemented policies and measures to suggest what may have been of most importance.

The World Bank Mid-term Evaluation of China's 11th FYP (World Bank, 2008) attributed the progress achieved so far to several key factors which also apply to Shanxi. These include a high level of political commitment, generally improved administrative capacity to rapidly roll out new initiatives, strong public support for the objectives, the adjusted accountability system that links implementation to performance assessment of local officials, and increased central funding. The policy measures introduced were described as comprehensive and relevant to the objectives.

Based on the experiences in the 11th FYP period, the national 12th FYP sets even stricter and more comprehensive binding targets by including CO_2 emission per unit GDP (17% reduction) and NO_x (10% reduction), in addition to SO_2 (8% reduction)[9]. Targets for Shanxi in the 12th FYP are: 11.3% reduction of SO_2 and 13.9% reduction of NO_x (State Council, 2011). Furthermore, Shanxi has added particle (PM) emission targets (10% reduction of industrial soot and dust emission) to its provincial 12th FYP binding targets in addition to the national ones (Liu, 2011). Reduction in emission of SO_2 during 11th FYP period is encouraging, but to reach the 12th FYP targets, many issues need to be addressed further:

(1) Most anthropogenic NO_x emissions in China (and Shanxi) are from coal burning, and the explosive growth in power generation since 2000 became the driving force behind the NO_x emission increase in China (Zhang et al, 2007). However, the contribution from vehicles is increasing with the rapid growth in number of vehicles (Zhang et al, 2007; Liu et al, 2010), and its contribution to ambient air quality is even higher than the emission fraction since the emission height is low (Zhang et al, 2007). So, more focus is needed on reduction of NO_x from power plants and vehicles.

(2) Rapid expansion of the deployment of FGD technology for SO_2 has contributed to reaching pollution reduction targets in the 11th FYP. However, our estimates in M2, indicating non-compliance with FGD operation management regulations, imply that it is challenging to keep these facilities in proper operation. Thus, special measures should be put in place and stronger supervision should be conducted to guarantee the proper functioning of these facilities.

[9] 12th FYP of People's Republic of China. http://news.xinhuanet.com/politics/2011-03/16/c_121193916.htm (in Chinese).

(3) With FGD installed and properly operating in all power plants, the possibilities for further SO_2 emission reduction from power plants will be limited, so policies and measures should focus on other sectors, such as coke making and metallurgical industry.

(4) During 12th FYP, more attentions should be paid to agricultural sources not covered in the current environmental statistics. For example, NH_3 emission to air from agriculture is also a major N-source to atmosphere, while focus is now on NO_x.

(5) Most of the pollution reduction solutions currently used, such as FGD technology for SO2 abatement, are end-of-pipe control solutions which generally increase energy consumption. According to Xu et al (2010), electricity energy consumed so as to make FGD system operate usually takes up 1.1-1.5% of the whole power plant's electricity energy consumption. Consequently, they increase emissions of CO2 to some extent. Hence, introduction and development of environmental friendly technologies should be further strengthened. Considering the seriousness of climate change, in the long run, great emphasis should be laid on shift to the low-carbon economy.

(6) Penalty and award mechanisms based on the new appraisal system seem to be an important incentive in energy conservation in Shanxi as in other provinces. But, millions in awards are also a temptation to manipulate the data. Thus, good monitoring and accounting systems are essential.

6. Conclusions

The 11th FYP goal for SO_2 emission reduction in Shanxi has been reached. Very detailed requirements and regulations have been issued by the provincial and local governments. The most effective measures so far seem to be in the industrial sector, particularly FGD for SO_2 reduction in power plants. However, Shanxi has still a long way to go to achieve its 12th FYP targets. Further improvement of pollution reduction will require continuing efforts to optimize the economic structure (in particular a shift to low-carbon economy and reduction in the dependence on heavy industry), promote the utilization of environmental friendly technologies, and improve the personnel appraisal system to provide stronger incentives for achieving pollution reduction. Furthermore, agriculture sources need to be taken into consideration during 12th FYP.

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References

British Petroleum (BP), 2011. BP Statistical Review of World Energy Full Report 2011. BP, London.

Economy, E.C., 2007. The great leap backwards. Foreign Affairs. http://www.foreignaffairs.org/20070901faessay86503/elizabeth-c-economy/the-great-leap-backward.html (accessed January 17, 2009).

Chinaenvironment, 2009. Pollution Control. http://www.chinaenvironment.com/action/Topic/shangxi/ViewNews.aspx?i=1898 (accessed June 16, 2011). In Chinese.

Esty, Daniel C., Marc Levy, Tanja Srebotnjak, and Alexander de Sherbinin (2005). 2005 Environmental Sustainability Index: Benchmarking National Environmental Stewardship. New Haven: Yale Center for Environmental Law & Policy. http://www.yale.edu/esi/ (accessed January 17, 2009).

Fu, B.J., Zhuang, X.L., Jiang, G.B., Shi, J.B. and Lu, Y.H., 2007. Feature: Environmental Problems and Challenges in China. Environmental Science & Technology 41 (22), 7597-7602.

Gan, L., 1998. Energy development and environmental constraints in China. Energy Policy 26 (2), 119–128.

Guan D.b., Liu Z., Geng., Lindner S. and Hubacek K., 2012. The gigatonne gap in China's carbon dioxide inventories. Nature Climate Chang, doi: 10.1038/NCLIMATE1560.

Kostka, G. and Hobbs, W., 2012. Local Energy Efficiency Policy Implementation in China: Bridging the Gap between National Priorities and Local Interests. China Quarterly (forthcoming).

Li, C., Zhang, Q., Krotkov, N.A., Streets, D.G., He, K.B., Tsay, S.C. and Gleason, J.F., 2010. Recent Large Reduction in Sulfur Dioxide Emissions from Chinese Power Plants Observed by The Ozone Monitoring Instrument. Geophysical Research Letters 37, L08807, doi: 10.1029/2010GL042594.

Liu, X.D., 2011. Speech of Liu Xiangdong, the general director of Shanxi Environmental Protection Bureau (Shanxi EPB), at the Annual Provincial Environment Protection Work Conference. Shanxi EPB, Taiyuan. http://www.sxhb.gov.cn/news.do?action=info&id=23935 (accessed June 16, 2011). In Chinese.

Liu, X.J., Duan, L., Mo, J.M., Du, E.Z., Shen, J.L., Lu, X.K., Zhang, Y., Zhou, X.B., He, C.N. and Zhang, F.S., 2010. Nitrogen deposition and its ecological impact in China: An overview. Environmental Pollution, doi:10.1016/j.envpol.2010.08.002.

MEP, 2011. The Checking Rules on the Statistic of The Total Amount Reduction of Main Pollutants during 11th FYP period. MEP, Beijing.

MEP, 2007a. China National Environmental Protection Plan in the Eleventh Five-Years (2006-2010). MEP, Beijing. http://www.mep.gov.cn/plan/hjgh/sywgh/ (accessed May 29, 2009). In Chinese.

MEP, 2007b. The Checking Rules on the Statistic of The Total Amount Reduction of Main Pollutants during 11th FYP period. MEP, Beijing.

MEP, 2007c. The guide on the planning of key pollutants reduction. MEP, Beijing. http://websearch.mep.gov.cn/info/gw/huanfa/200802/t20080222_118509.htm (accessed January 5, 2010). In Chinese

Nankivell, N., 2005. "China's Pollution and Its Threat to Domestic and Regional Stability," The Jamestown Foundation: The China Brief, 5 (22), http://www.jamestown.org.

National Development and Reform Commission (NDRC), 2006. Overview of the 11th Five Year Plan for National Economic and Social Development. NDRC, Beijing.

OECD, 2006. OECD Environmental Performance Review of China. <http://www.oecd.org/dataoecd/58/23/37657409.pdf> (accessed January 17, 2009).

Ohara, T, H. Akimoto, J. Kurokawa1, N. Horii, K. Yamaji, X. Yan, and T. Hayasaka, 2007. An Asian emission inventory of anthropogenic emission sources for the period 1980–2020. Atmospheric Chemistry and Physics 7, 4419–4444.

Shanxi Bureau of Statistics (SBS), 2006-2011. Shanxi Statistical Yearbook 2006-2011. China Statistics Press, Beijing.

Shanxi EPB, 2001-2011. Bulletin on the State of Environment in Shanxi 2000 (SOE of Shanxi, 2000-2010). Shanxi EPB, Taiyuan.

SPG, 2009. SPG's Notice on Printing and Distributing the Plan of Ecological Environment Restoration in Coal Mining Area in Shanxi. SPG, Taiyuan.

SPG, 2007. SPG's Notice on Printing and Distributing the Comprehensive Work Scheme on Energy Saving and Pollution Reduction in Shanxi. SPG, Taiyuan.

SPG's General Office (SPGGO), 2009. SPGGO's Notice on Printing and Distributing the Plan on The Amounts of Key Pollutants Reduction in 2009 in Shanxi.

State Council, 2011. State Council's Notice on Printing and Distributing the Comprehensive Work Scheme on Energy Saving and Pollution Reduction during the 12th FYP. State Council, Beijing. In Chinese.

State Council, 2006. State Council's Ratification on The National Control Plan of The Total Amount of Major Pollutants Discharging in 11th FYP Period (2006-2010). State Council, Beijing. In Chinese.

Vennemo, H., Aunan, K., Linhjem, H., and Seip, H.M., 2009. Environmental pollution in China: Status and trends. Review of Environmental Economics and Policy 3 (2), 209-230.

World Bank, 2008. Mid-term Evaluation of China's 11th FYP. The World Bank, Washington DC.

World Bank. 2007. Cost of Pollution in China. The World Bank, Washington, DC. http://siteresources.worldbank.org/INTEAPREGTOPENVIRONMENT/Resources/China_Cost_of_Pollution.pdf (conference version) (accessed January 17, 2009).

Xie, R.K., Seip, H.M., Liu, L. and Zhang, D.S., 2009. Characterization of individual airborne particles in Taiyuan City, China. Air Quality, Atmosphere & Health 2, 123-131.

Xu, G., Yang, Y.P., Wang, N., Yuan, X., Li, J., and Song, X.N., 2010. Analysis on Energy Consumption and Optimal Operation of FGD System in Power Plant. Power and Energy Engineering Conference (APPEEC), 2010 Asia-Pacific, 10.1109/APPEEC.2010.5448640.

Zhang, D.S., Aunan, K., Seip, H.M., and Vennemo, H., 2011. The energy intensity target in China's 11th Five-Year Plan period - Local implementation and achievements in Shanxi province. Energy Policy 39, 4115-4124 .

Zhang, J, Fu, M., Geng, Y and Tao, J., 2011. Energy saving and emission reduction: A project of coal-resource integration in Shanxi Province, China. Energy Policy 39, 3029-3032.

Zhang,Q., Streets, D.G., He, K.B., Wang, Y.X., Richter, A., Burrows, J.P., Uno, I. Jang, C.J., Chen, Dan., Yao, Z.L., and Lei, Y., 2007. NOx emission trends for China, 1995–2004: The view from the ground and the view from space. Journal of Geophysical Research, 112, D22306, doi:10.1029/2007JD008684.

Zhao, Y., Nielsen, C.P., Lei, Y., McElroy, M.B. and Hao, J., 2011. Quantifying the uncertainties of a bottom-up emission inventory of anthropogenic atmospheric pollutants in China. Atmospheric Chemistry and Physics 11, 2295-2308.

Zhao, Y., 2006. Emission inventory of primary pollutants in China. Presentation at Workshop at Opening of Sinciere, Beijing, China, November 22-23 2006. Department of Environmental Science and Engineering: Tsinghua University.