Industrial SO_2 pollution and agricultural losses in China: Evidence from heavy air polluters

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Abstract

This paper aims to assess the agricultural losses caused by the 2069 state-monitored heavily air polluting enterprises located in 899 Chinese counties. We examine the correlation between per capita number of state-monitored enterprises and other socio-economic indices to show the negative impacts of sulphur dioxide (SO_2) industrial air pollution on agricultural development in the regions. Despite these enterprises being the main drivers of economic development in China's counties, surrounding agricultural land continues to be degraded because of the associated SO_2 emissions. The cost of agricultural losses due to pollution is estimated at US$ 1.43 billion, representing 0.66% of the total agricultural value added of the 899 Chinese counties. The findings highlight the importance of cleaner production and have policy implications for dealing with industrial air pollution.

Keywords: Yield loss; sulphur dioxide; externalities; Chinese counties; air quality monitoring; impact pathway.

1. Introduction

Most environmental challenges have their root sources in activities that are happening locally (ICLEI, 1993; Thomson and Jackson, 2007; Wei et al., 2010) and pursuing economic growth is no doubt one of them. China is a good example of this. A high-GDP fever by county-level governments[1] has produced astonishing results. Between 2000 and 2006, the 13.8% annual average GDP growth of the middle China counties was much higher than the national level (Wei et al., 2010). This rapid economic development however has been a heavy burden on the environment.

The energy-extensive industries on which the Chinese counties have heavily relied for economic growth are largely based on fossil fuel consumption and this has caused increased emissions of sulphur oxides (SO_x), nitrogen oxides (NO_x), carbon dioxide (CO_2), soot and fine particulates (Wang et al., 2007). The conventional air pollutants associated

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[1] County or county level division is the official English translation of the Chinese word Xian. It describes the third (or in some provinces second level) of the administrative hierarchy, although there are also autonomous counties. It is estimated that mainland China has 1,464 counties (http://www.china-county.org/a/xianyujingjitansuo/2012/0529/7493.html). In English Xian sometimes is translated as township.

with industrial development, such as PM_{10} (particulate matter with a diameter of 10 micrometres or less), SO_2 (sulphur dioxide), NO_x (mono nitrogen oxides) and surface-level ozone cause considerable damage not only to human health but also affect the natural and social environment, including crops, forests, water resources, ecosystems, buildings, historical monuments etc. (Bell et al., 2011; Mirasgedis et al., 2008; Zhou, 2010). Industry released gases, such as SO_2, can cause acid rain that affects the quality of the soil and the growth of crops leading to agricultural losses.

With SO_2 being such a significant air pollutant in China (Tian et al., 2012), the country's consecutive five-year plans have set specific targets for its reduction (10% between 2006 and 2010 and a further 8% between 2011 and 2015). However, due to the inconsistent availability and even lack of cleaner production technologies and pollution treatment facilities, the rapid regional industrialisation of many counties continues to create pollution and furthers environmental vulnerability (Wei et al., 2010). The high risks of people being exposed to pollution and overall deterioration of the natural environment have raised grave concerns about the hidden costs of economic development in the regions.

China has the highest output of grain and other staple foods in the world (Wong & Huang, 2012) and the agricultural sector is still the main source of income in regional areas. Many counties however have already started to promote the development of secondary industries, such as manufacturing, construction and public utilities (Wei et al., 2010), in addition to the resources sector. While achieving continuing rapid growth for these industries has been feasible, their demands and subsequent environmental pressures have raised sustainability concerns. Industrial projects are likely to take up large amounts of land and if left unchecked are also likely to produce pollutants which threaten agriculture.

These damages imposed on society (and related costs) are considered to be external costs (or externalities). Agricultural loss due to industrial air pollution is one of them. Unless these costs are valued, it is difficult to assess the impact of industrialisation on farmers. The availability of estimates like this can encourage the government to put tougher regulations in place, including taxes and fines. The present study evaluates the damages caused by industrial SO_2 emissions on agricultural land and estimates that an alarming 0.66% of agricultural value-added is lost due to this type of pollution. Such a valuation of the damage cost of pollution on regional counties' agriculture is done for the first time and provides reliable validation for cleaner production policies and implementation of technologies that can avoid or mitigate the negative load of pollution.

Since the majority of farm land in China is found in the regions, the study analyses the agricultural economic impacts of industrial SO_2 emission caused by the 2069 state-monitored heavily air polluting enterprises located in the counties, and examines the geographical distribution of the created external costs. This large sample of enterprises is identified by China's Ministry of Environmental Protection (MEP), the main agency charged with the responsibility to protect and monitor the state of the country's air, water and soil. The sample includes industrial enterprises with a relatively large volume of major and toxic pollutant discharge, centralised sewage treatment plants (with capacity of >10,000 tonnes/day) and hazardous waste disposal plants. They cover more than 65% of the total industrial pollution and the list is compiled on an annual basis by MEP together with the provincial environmental protection administration (Institute for Public and

Environmental Affairs, 2011). These key polluters are required to report to MEP on a seasonal basis.

Based on the country's 2008 environmental statistical data and over 80 thousand enterprises investigated for their emissions of SO_2 and NO_x, China's environmental authorities identified 3472 enterprises as in need of strict monitoring for airborne pollution. Nearly 60% or 2069 of these enterprises are located in 899 counties, with the others situated in urban provincial or prefectural areas. The year 2008 is the latest for which detailed data are available and hence this is also the year for which we estimate the agricultural losses caused by these enterprises.

The article has the following structure. Section 2 positions this study within the area of quantifying external costs of industrial pollution in China. The analytical approach for the external cost evaluation model and data examination used, described in Section 3 form the methodology of the valuation. The assessment of the agricultural losses is presented in Section 4 which also includes an analysis of the correlations between the key airborne polluters and the socio-economic development in the counties. Section 5 reflects on policy implications and finally, conclusions are provided in Section 6.

2. External costs of industrial pollution

Environmental external costs in China are fast becoming an active area of research. Existing studies include damage costs from fossil fuel electricity generation (Zhang et al. (2007), physical damages from air and water pollution (World Bank, 2007), environmental damage of pollution in major Chinese cities (Wei et al., 2009), including Wuhan (Wu et al., 2005), Taiyuan (Mestl et al., 2005) and Daqing (Sun and Yang, 2007). This research continues the focus on China by analysing agricultural losses due to industrial pollution.

Air pollution affects agriculture through various channels. According to Cao (1989), the ambient concentrations of SO_2 and fluoride typical for some Chinese cities and industrial areas in the 1980s, can reduce the growth and yield of local crops and vegetables by 5-25%. Ground (or surface)-level ozone and its precursors (such as carbon monoxide, methane, non-methane volatile organic compounds and nitrogen oxide) are other important industry-related pollutants causing considerable agricultural losses (Wang et al., 2007). The synergistic effects of ozone and SO_2 make industrial air pollution even more threatening to agriculture (Chen et al., 1996).

As a major air pollutant resulting from industrial processes, SO_2 has been under close scrutiny in China since 1970s. Despite the importance of surface-level ozone as well as other pollutants and ozone precursors, the data about them are still patchy. By comparison, there are reliable data available about SO_2 emissions which reached 17.05 million tonnes with industrial SO_2 emissions accounting for 84% (National Bureau of Statistics, 2011). China’s rapid industrialisation has so far been closely linked to this pollutant (Wei et al., 2012); however nobody has yet quantified the external costs of industrial SO_2 emissions in relation to agricultural losses. As regional economic development further expands, having a good understanding of its impact on agriculture will strengthen the case for implementation of industrial cleaner production.

3. Methods

The methods used to estimate the agricultural losses due to air pollution include the human capital approach (Ridker, 1967), opportunity cost and market value method (Xia et al., 1995; Xu and Zhao, 2004; Wu and Wang, 2007) and impact pathway approach (Carbonell et al., 2007). The methodology of the ExternE project, initiated in 1992 and funded by the European Commission, is an example of the latter and uses a detailed bottom-up impact pathway approach (IPA). It has proven a widely accepted method for environmental external cost assessment (Mirasgedis et al., 2008; Thanh and Lefevre, 2000; Wei et al., 2009) as it applies a consistent accounting framework for the assessment of externalities associated with various airborne pollution emissions (European Commission, 2005; Carbonell et al., 2007; Rabl and Holland, 2008; Mirasgedis et al., 2008). This is the method adopted also for this study.

3.1 Quantification analysis of agricultural losses due to industrial air pollution

For the quantitative evaluation of the impact of SO_2 on agriculture, we assess the agricultural losses resulting from this airborne pollutant associated with the state-monitored enterprises in China’s counties based on ExternE (European Commission, 2005). This analysis follows the pathway with IPA providing a logical and transparent way of quantifying the external costs. Emissions and other types of negative externalities, such as risk of accidents, are quantified and subjected to impact assessment and valuation.

The principal steps of the IPA are as follows:

(1) **Emission**: this involves specification of the relevant technologies and pollutants; for example, kg of oxides of particulates per GWh emitted by a power plant at a specific

site. In this case to estimate the agricultural losses, the key pollutant is SO_2. As air quality monitoring stations are located only in the large and middle-sized cities, data from direct measurement of air pollutants on county locations are not available. Hence, we use estimates based on enterprise caused pollution as explained in point (2) below.

(2) **Dispersion**: this involves calculation of increased pollutant concentrations in all affected regions, for example, incremental concentration of particulates, using models of atmospheric dispersion and chemistry for particulates formation.

For this study, it was impossible to collect the data of ambient concentrations for the 2069 enterprises monitored for airborne pollution. The typical installation method developed by Mirasgedis et al. (2008) was used instead to estimate the impacts of airborne pollution. Since most of the enterprises monitored for airborne pollution are in the sectors of mining, mineral products, smelting and pressing of metals, production and supply of electric power and heat power, processing of petroleum and coking, they all have high volumes of SO_2 emission according to the MEP regulations (Institute for Public and Environmental Affairs, 2011). The enterprises monitored for airborne pollution belong to different industry sectors and there are differences in their specific SO_2 emissions. However, there is no data available at county level about SO_2 emissions by individual industrial installations. The county averages for SO_2 discharge per enterprise are available in the 2008 Environmental Statistics Database[2]. Therefore, we assume that the number of enterprises monitored for airborne pollution in each county multiplied by the average estimate for SO_2 discharge could be used as a proxy in the ExternE model for the volume

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[2] Ministry of Environmental Protection (MEP), http://www.zhb.gov.cn/gkml/hbb/bgt/201001/t20100119_184559.htm.

of generated pollution. By using this proxy to estimate the dispersion process we underestimate the level of pollution since the analysed industrial enterprises have been identified as heavy air polluters. As it becomes clear later in the analysis, despite this underestimation, the size of agricultural loss due to airborne pollution is alarmingly high.

According to regulations issued by MEP, the atmospheric impact of pollution sources should be assessed at three levels taking into consideration environmentally sensitive areas such as urban areas, nature reserves and scenic spots, namely 16–20 km for level 1, 10–14 km for level 2 and 4–6 km for level 3 (SEPA, 2006). As the key monitored polluters discharge comparatively large amounts of pollutants we consider them having a level 1 impact, with each affecting an area of 324 km^2 (or a square with an 18 km – middle of the level 1 interval – side). Overall this is quite a conservative estimate given the fact that the size of the impact according to EU standards can stretch up to 100 km.

Furthermore, ambient air quality in China is classified (according to the Prevention and Control of Atmospheric Pollution Law) in three zone classes: class I zones include nature reserves, scenic spots and areas subject to special protection; class II zones include mixed residential areas, prospective residential areas, cultural centres, industrial zones and rural areas; and class III zones include special industrial zones. The ambient air quality standards are clearly defined for the three zone classes and are also closely monitored. According to the 2009 Statistical Yearbook of China (National Bureau of Statistics, 2009), the concentrations of SO_2 in 85.2% of the Chinese cities in 2008 corresponded to class II. Hence we assume that the 2069 enterprises monitored for airborne pollution also fall within class II zones, and we take accordingly the SO_2 concentration limit value as 0.06

mg/m^3 as an estimate for the air pollution they generate. This is an estimate

(3) **Impact**: this step requires calculation of the dose from the increased concentration of pollutants, followed by calculation of impacts (damage in physical units) from this dose, using a dose-response function; for example, the yield losses of wheat due to high concentration of SO_2.

Agricultural losses due to air pollution are mainly yield losses caused by increased levels of SO_2 (European Commission, 2005). The function for effects on agriculture from SO_2, recommended in the ExternE methodology is adapted from Baker et al. (1986). The function assumes that yield will increase with increase of SO_2 from 0 to 6.8 ppb, and decline thereafter. It is used to quantify changes in crop yield for wheat, barley, rice, potato, sugar beet, oats etc. (see Table 1).

< Table 1 about here>

There also exist other dose-response functions to estimate yield losses due to SO_2. For instance, Spash (1997) argues that the critical load of SO_2 for indirect effects on agricultural crops is 30 μg/m^3, with agricultural crops generally less sensitive than natural vegetation and forests. Another example is the Air Pollution Emission Experiments and Policy (APEEP) analysis model employed by Henry III et al. (2011) to determine the damages caused by SO_2 emissions from the facilities governed by the Acid Rain Program – a traditional integrated assessment model of air pollution to account for damages to human health, visibility, crops, recreation and timber (Muller and Mendelsohn, 2007). However, the dose-response functions proposed by Baker et al. (1986) are most widely used to assess the yield losses due to SO_2 (European Commission, 2005; Krewitt et al., 1998; Mirasgedis et al., 2008; Wei et al., 2009; Czarnowska and Frangopoulos, 2012). The dose-response functions for yield loss assessments are considered universal (Ridker, 1967) and they have been applied to assess agricultural losses in different countries and regions (Van Dingenen et al., 2009 show satisfactory results for Europe, US, China, southern India and South-East Asia; Mauzerall and Wang, 2001 for US, Europe and Asia; Muller and Mendelsohn, 2007 for US; Wei et al., 2009 for China).

In the context of this analysis the exposure-response functions proposed by the ExternE Project (European Commission, 2005) have been used. Notwithstanding the fact that these functions were created by and for developed countries, some data can be transferred from the ExternE Project and other can be calculated or estimated in indirect ways when no local data are available or the information is incomplete (Carbonell et al., 2007). In 2008, the total output of staple crops, such as rice, wheat, maize and potato, in China was 478 million tons, accounting for 90.5% of the total output of farm products (National Bureau of Statistics, 2009). The three main crops, namely rice, wheat and potato, are covered by the dose-response functions in Table 1 and these functions are used with Chinese values per unit (to replace the European ones).

(4**) Cost**: this requires the economic valuation of the impacts; for example, multiplication by the cost incurred in the case of asthma.

The impacts and costs are summed up over all affected recipients. This involves a multidisciplinary systems analysis, with input from engineers, dispersion modellers, epidemiologists, ecologists and economists amongst others. For some impacts, for example visual intrusion, the passage from impact to cost is more direct, without the need for intermediate steps. The result of an IPA is the damage cost per impact, and if the results are for a specific source of impact that should be indicated. The IPA is a logically straightforward approach, but the details of its implementation differ between studies (Rabl and Holland, 2008).

Estimating the monetary value of food losses is normally done using the method of market value in the country area. We adapted the methodology of the ExternE project using China's grain prices. According to China’s grain buying pricing policy in 2008, the lowest buying prices were early indica rice (US$221.7/t, or RMB￥1540/t), white wheat (US$221.7/t, or RMB￥1540/t), red and mix wheat (US$207.3/t, or RMB￥1440/t). In this study, we use a price that is just above the lowest level, namely US$223.2/t (RMB￥1550/t) to define the price for the crop loss.

According to the above definition, we can estimate the agricultural economic loss (economic loss of crops) A in equation 1：

$$A=324\cdot G/S\cdot P\cdot(-u_{agriculture-so_2})/(1+u_{agriculture-so_2})\cdot N \qquad (1)$$

where S represents the area of a county with the monitored enterprise(s)[3]； G represents the crop production for the year from the county； P is the average crop price represented by US$223.2/t (RMB￥1550/t)； $u_{agriculture-SO2}$ is the rate of crop production under the influence of SO_2 and N is the number of enterprises monitored in the county; G/S is the average output of a county with the monitored enterprise(s), $u_{agriculture-SO2}$ is calculated by using the equation in Table 1 where the SO_2 concentration value is 0.06mg/m^3 (as explained above). Since G is the crop production affected by SO_2, we need

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[3] We use “area of a county” instead of “area of arable land of a county” as the neighbouring areas to polluting enterprises are not always arable land. For example, they can be other industrial or residential areas.

to correct for agricultural loss. $(-u_{agriculture-so_2})/(1+u_{agriculture-so_2})$ represents the rate of crop loss for G. Hence $324\cdot G/S\cdot P\cdot(-u_{agriculture-so_2})/(1+u_{agriculture-so_2})$ is the agricultural economic loss caused by one monitored enterprise[4].

3.2 Data collection

The data for the enterprises monitored for airborne pollution were obtained from the MEP's website (http://datacenter.mep.gov.cn/). This website provides a district code which allows to identify the county where each enterprise is located. Other county data, including agricultural value added, total output of crops, district areas, individual income, population etc. were obtained from the 2009 Statistical Yearbook of the cites and counties in China (National Bureau of Statistics, 2009). Using the number of enterprises monitored for airborne pollution, the agricultural losses in the 899 counties were calculated with the approach developed above (as show in Equation 1).

4. Results and discussion

4.1 Geographical distribution of the state-monitored heavily air polluting enterprises

The number of enterprises monitored for waste gases emissions in each county represents to a certain extent the level of airborne industry pollution generated there. In order to explore the geographical distribution of the enterprises monitored for airborne pollution, we conducted cluster analysis on the number (N) of enterprises hosted by each of the 31 provinces of China (excluding Hong Kong, Macau and Taiwan due to the unavailability of

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[4] The equation does not cover the situation when the aggregated area of impact from all monitored heavily polluting enterprises is bigger than the total area of the county, namely $324*N > S$. This is not the case for any of the 899 counties analyzed in this study. If this happen to be the case, then $A = S\Sigma G/S\Sigma P\Sigma(-u_{agriculture\text{-}SO2})/(1+u_{agriculture\text{-}SO2})$.

detailed data). The results are presented in Figure 1 and they show four groups of counties.

< Figure 1 about here>

Group 1：0≤N≤4

This group includes Beijing, Tianjin, Shanghai, Hainan and Tibet. It is logical to see the two extremes of development included in this group. Beijing, Tianjin and Shanghai’s geographical areas are small but economically well developed while Hainan and Tibet are still industrially underdeveloped.

Group 2：31≤N≤59

This group includes Liaoning, Jilin, Heilongjiang, Anhui, Fujian, Guangdong, Chongqing, Guihou, Yunnan, Gansu, Qinghai, Ningxia and Xinjiang. Geographically, these provinces are located in west China, northeast China and the southeast coastal part of China. The industrial development in the west regions is still at an early stage. Although the industrial foundation is better in the northeast part of China, it is developing at a slow rate. The industrial economy is more developed in the southeast coastal provinces, but these are mainly light industries which generate less pollution.

Group 3：78≤N≤103

This group includes Zhejiang, Jiangxi, Henan, Hubei, Hunan, Guangxi and Shaanxi. These provinces are located mainly in middle China. With the implementation of the rising middle China government strategy, the industrial economies of these provinces are undergoing fast development and this is regarded as more important than environmental protection.

Group 4：131≤N≤177

This group includes Hebei, Shanxi, Inner Mongolia, Jiangsu, Shandong and Sichuan. These provinces are known as large heavily industrial provinces with industries such as coal mining, iron and steel smelting, machinery building etc. Both energy consumptions and waste gases emissions in these provinces are enormous.

4.2 Frequency distribution of the state-monitored heavily air polluting enterprises

The situation with threatening airborne pollution in China’s counties is adverse, with 899 of the 2071 counties being home of the monitored enterprises. More than half of these 899 counties, namely 52% host more than 2 state-monitored enterprises and 6.8 % of them host 5 or more (see Figure 1). At the very extreme end of the spectrum, the county of Jiangyin in Jiangsu province hosts 26 enterprises which are predominantly in the field of thermal power and steel manufacturing.

< Figure 2 about here>

4.3 Agricultural losses caused by SO_2 emission

Using formula (1), the agricultural losses caused by the 2069 enterprises monitored for airborne pollution in each of the 899 counties were estimated. To better visually describe the geographic difference, they were merged into provincial agricultural losses, according to the enterprises’ district codes and the results are shown in Table 2. This aggregation includes only county-based heavy air polluters and does not include pollution from other city-based enterprises.

< Table 2 about here>

In 2008, the agricultural losses due to SO_2 are 1425.907 million US$, representing 0.66% of the agricultural value added in China in 2008. In the past few years SO_2 emissions had remained constant and in some provinces had even increased. The situation of the agricultural losses due to SO_2 is remaining to threaten the agricultural product. However, the losses also show obvious geographical differences. We try to analysis the relationship between economic growth and agricultural losses in different provinces which can provide relevant and valuable information of the hidden costs of growth and the future prospects of agricultural sustainability.

We use the ratio of agricultural losses to agricultural value added (RALAVD) as a measure for the agricultural sustainability of economic growth in each county. The value of RALAVD indicates the proportion of agricultural income losses caused by SO_2, as shown in Table 2. The 2008 fluctuation range of RALAVD is from 0.00% to 2.95% for the 31 provinces, the highest being for Shanxi and the lowest for Beijing.

We further examine the geographical distribution of agricultural losses across provinces. For the sample size (N=31), we use interval grouping. As proposed by Spiegel and Stephens (1999) and Frankfort-Nachmias and Leon-Guerrero (2008), we divide the counties into 4 groups according to the RALAVD average. The results from the grouping are presented on the map in Figure 3.

< Figure 3 about here>

Group1：0.00%⩽RALAVD⩽0.38%

This group includes 13 provinces (Beijing, Fujian, Gansu, Guagndong, Guangxi, Hainan, Heilongjiang, Hunan, Liaoning, Inner Mongolia, Tibet, Xinjiang and Yunan), whose RALAVD is below 0.38%. Most of them had lower number of the state-monitored heavily air polluting enterprises or higher agricultural value added.

Group 2：0.39%<RALAVD⩽0.86%

There are 12 provinces in this group (Anhui, Guizhou, Henan, Hubei, Jilin, Jiangxi, Qinghai, Shanghai, Sichuan, Tianjin, Zhejiang, and Chongqing), most of them located in middle China. There are large traditional agricultural areas in these regions, however agricultural development has been affected negatively by the rapid industrialisation.

Group 3：0.86%⩽RALAVD⩽1.47%

This group includes five provinces (Hebei, Jiangsu, Ningxia, Shandong and Shaanxi). Four of them host high numbers of enterprises monitored for airborne pollution. Although there are only 31 enterprises monitored in Ningxia, its agricultural value added is still very low (US$ 667.61 million).

Group 4：RALAVD≥2.95%

Only the province of Shanxi belongs to this group. It has the highest number of enterprises monitored for airborne pollution and a lower agricultural value added. The volume of SO_2 emitted by Shanxi in 2009, i.e. 12680 thousand tons, accounted for 25.9% of the national total[5].

Table 3 shows that air pollution was high across China’s counties, which resulted in significant agricultural damage. Figure 3 represents the geographical differences in RALAVD for the 31 provinces with group III and IV having low agricultural sustainability. The provinces in these two groups are located in middle and eastern China. They are also

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[5] http://www.stats.gov.cn/tjsj/qtsj/hjtjzl/hjtjsj2009/t20101201_402687113.htm.

the main grain and other crop output regions[6].

Agricultural production is the main source of income for most rural households. With industrialisation, the absence of stable compensation mechanisms always causes conflicts between the polluting enterprises and the affected farmers. Collective protest events often happen when environment conflicts cannot be properly solved. On some occasions, farmers had to protest many times to put pressure on the polluting enterprises and get the local government to start resolving the problems. It is necessary to establish stable proper and long-term compensation mechanisms for farmers who are affected by industrial air pollution.

4.4 Correlation between agricultural losses and regional industrial SO_2 emissions

The factors triggering agricultural losses by the state-monitored heavily air polluting enterprises are very complicated and also come with countless uncertainties, which make it hard to estimate the precise correlation between current data on the monitored concentration of SO_2 and the dose-response from SO_2 receptors. Considering that the agricultural losses caused by SO_2 are related to industrial waste gases emission in the regions, we analysed the correlation between the agricultural losses for each province and the respective volumes of industrial waste gas emissions to verify the accuracy of the loss estimates.

Table 3 indicates that there is significant positive correlation between agricultural

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[6] The map in Figure 3 is different from the 2008 acid rain map for China which shows that acid rain mostly affected the Yangtze River basin which has a high level of urbanisation. In addition to climate change, increasing urbanisation leads to higher car use in these cities and more SO_2 emissions subjecting them since 2000 to severe acid rain (Xie et al., 2009). Acid rain is also carried by strong winds and often this is towards the South of China where the highest precipitation rates are the highest.

losses and industrial emissions, including total volume of industrial waste gas emissions, total volume of industrial SO_2 emission and industrial dust emissions, as indicated by the Pearson and Spearman correlation coefficients. Although correlation results only indicate a linear relationship between the variables and does not imply causation, this is in line with the cognitive results and confirms that it is reasonable to estimate agricultural losses according to the emissions of the monitored enterprises.

The biggest values of the coefficients are for the correlation between the agricultural losses and total volume of SO_2 emission (with the Pearson Correlation being 0.695 and Spearman's Rho Correlation Coefficient being 0.771). This demonstrates that it is reasonable to consider SO_2 emissions as an important factor affecting crop production and causing agricultural losses.

< Table 3 about here>

As industry is a major source of pollution, the level of industrialisation is important in regional analysis. China’s fast industrialisation has been marred with pollution problems (Cao, 2007; Zhang, 2010), particularly because of the dominance of coal as an energy source. The increase in the share of industrial output has a direct influence on the total volume of SO_2 emissions and hence agricultural losses. This requires close attention to be given to the air pollution performance of industry and has been a main target of the government lead pollution control.

4.5. Correlation between the state-monitored heavily air polluting enterprises and socioeconomic indices in China’s counties

With the fast progress towards industrialisation, the share of agriculture in China’s economy is steadily decreasing. The proportion of the agricultural value added diminished from 28% in 2002 to 26% in 2005 and in 2008 it further dropped to 23%. As an economic sector which provides essential necessities for people’s life, the role of agriculture for the country’s socio-economic development cannot be ignored.

Airborne pollution generated by the strictly monitored enterprises has caused large agricultural losses. According to the above estimates, agricultural losses in China’s counties reached U$1.4 billion in 2008. This affects the socio-economic development in the counties. On the other hand, if the further development of the industrial economy in the counties continues to be dominated by coal (as it has been the case until now), there will be more enterprises and growing waste gas emissions, causing further airborne pollution and impacting environmental quality. In order to explore the relationship between the number of monitored enterprises and the counties’ socio-economic development, this study analysed the correlation between the number of enterprises and socio-economic indices. The calculation of the correlation coefficients is based on data for the 899 counties and per capita indices. The results are shown in Table 4.

< Table 4 about here>

The correlation between the per capita number of enterprises monitored for airborne pollution and per capita industrial and agricultural GDP is shown to be significantly positive with the correlation coefficient reaching 0.411 (Pearson or 0.316 Spearman). In addition, the correlation of the per capita number of enterprises monitored for airborne pollution and per capita industrial value added reached 0.416 (Pearson or 0.322 Spearman), which demonstrates that the industrial economy of China's counties still mainly follows an extensive developmental model. The economic development of the counties has been sustained by high consumption and highly polluting industrial enterprises, consequently the environmental damages caused by the emitted waste gases and other pollutants are very difficult to be restored.

We further conducted a correlation analysis between the per capita agricultural losses and per capita industrial value added in the 899 counties. The Pearson Correlation is 0.196, and Significance (2-tailed) is 0.000, indicating that industrialisation has a negative effect on agricultural development. However, the average of agricultural losses in the counties represents only 0.16% of the industrial value added, which is much lower than the average of RALAVD. This means that local governments have more incentive to promote industry development rather than reduce agricultural losses.

Despite the big output by the enterprises monitored for airborne pollution, the local governments should also emphasise reducing the impacts of enterprise pollution on agriculture, human health and the ecology. The policies may include encouraging industrial enterprises to adopt new technology and approaches to cut down the use of energy as well as strictly constraining the development of industrial projects that are likely to produce severe pollutants. In 1995, the Chinese government released Planning Outlines for National Ecological Demonstration Area (1996-2050) to improve the sustainability of the country's counties and between 2001 and 2006 MEP designated 528 ecological demonstration counties or cities. These counties have succeeded in overcoming the conflict between environmental protection, social development and economic growth, which proves that it is possible to balance pollution control and economy development. However, more work needs to be done to cut pollution across all counties and industrial enterprises in China.

The correlation coefficients between the per capita number of state-monitored heavily air polluting enterprises and the other two indices, including per capita agricultural value added and per capita crop production, are both negative. Although some correlation coefficients are not significant, the negative coefficients reflect that the monitored enterprises have definitely caused a certain level of loss in crop production for agriculture. The significant positive correlation between RECGDP1 and per capita number of monitored enterprises can even better show the aggressiveness of polluting enterprises for the agricultural sector. The higher the number of enterprises, the higher the agricultural losses, therefore the development of counties' economy has been achieved at the price of sacrificing agriculture.

The correlation coefficients between per capita number of enterprises monitored strictly for waste gases and other socio-economic indices, including per capita financial income, per capita bank balance and urbanisation rate are all positive. The increasing number of monitored enterprises represents the growth of the industrial economy in counties, which potentially improves people's quality of life and can promote development and progress in society. Comparing the correlation coefficients, the influencing effect of the increase in the number of monitored enterprises on the increase of governmental revenue reached 0.347 (Pearson, or 0.360 Spearman) which is significantly higher than the effect on improving the level of people's income (Pearson 0.171, Spearman 0.29). This has resulted in more willingness by the counties' governments, than by the public, to host monitored enterprises. In addition, the state-monitored heavily air polluting enterprises have attracted a significant number of rural labour force. The loss of rural labour creates further challenges for the agricultural sector.

5. Policy implication

Despite using only SO_2 emissions as representative of the industry created airborne pollution, the results from the above analysis are alarming. The correlation between per capita number of state-monitored enterprises and other socio-economic indices show the negative impacts of industrial air pollution on agricultural development in the regions. The study found a direct link between industrial SO_2 emission and agricultural losses in the context of recent regional development in China. Hence, it is not enough to measure the burden and monitor SO_2 emissions and effluents, the important issue we raised here is the urgency of implementation of the cleaner production policy to avoid or mitigate the burden due to the air pollutant emission (Shi et al., 2008; Taylor, 2006).

The pathway to implement the cleaner production policy in China's counties is a complex area where the interests of industry are often competing with those of the general public with government stepping in when needed and possible. There is a large range of policies and initiatives, including voluntary (such as ISO 14001) and regulatory compliance at a local, national or international level, that aim at reducing pollution and adopting cleaner production. However, lax environmental enforcement is one of the top three barriers to adopt the cleaner production in the small- and medium-sized enterprises in

China (Shi et al., 2008). Many argue that direct regulation is the main driver behind cleaner production which works better than economic or voluntary measures (Testa et al., 2012), or internal technical and managerial barriers (Shi et al., 2008). Miller et al. (2008) describe the history of pollution prevention in the US leading to the Pollution Prevention Act adopted in 1990, but stress that in recent times there are declining public sector support (compared to areas such as education, healthcare, war and terrorism), rival business priorities (such as increasing market share through marketing and new product development) and lack of documenting the progress made (including no legal requirement to report, no comprehensive data collection systems, inability and costs associated with such data gathering). By comparison, China had air pollution prevention and control (1995) and water pollution prevention and control (1996) laws which in 2002 were replaced by the Cleaner Production Act (a world first). Nevertheless, legislation alone has not been very successful in reducing pollution and the country faces a similar range of challenges as described by Miller et al. (2008). There needs to be a focus on what makes industry take action and according to Higgins (1999), this includes pollution inventories, information on enterprise performance, environmental management systems, negotiated agreements and government-industry partnerships. The monitoring of enterprises is an important component in curbing pollution but there needs to be further efforts in negotiating agreements and building partnerships which can secure not only waste reduction but also minimal impact on agricultural production. Location of large industrial plants should be decided through negotiating agreements and partnerships, in a way that compromises the least any agricultural production systems. Furthermore, public-private partnerships are seen as preferred policy instrument for achieving cleaner production (Shin et al., 2008).

Economic activities are fundamental in lifting people out of poverty and increasing human standards of life (Shin et al., 2008). Industrialisation and industry development are part of this process. However if an enterprise is generating pollution that negatively impacts on the lives of other sections of society, and farmers in particular, there are two ways of mitigating any damage: by stricter environmental regulations or through offering compensations to those affected. The patchy evidence about strengthening discharge standards in China (Wang et al., 2011) shows that while there might be some improvements, including in SO_2 emissions, not all pollution is being arrested. Compensation hence should be introduced for rural workers whose livelihoods are being affected by industry. Further improvements in environmental legislation to drastically adopt cleaner production are also needed. The US experience shows that industry-related environmental management programs should be performance based (Zarker and Kerr, 2008) and China has made the first step by closely monitoring the key polluters.

An essential characteristic of cleaner production in industry is the principle for “reduction at source” which also leads to improved economic performance, particularly in terms of profitability (Cagno et al., 2005; Nishitani et al., 2011; Shadiya et al., 2012). This should encourage companies to regularly examine their manufacturing processes, particularly if there are financial payments for ecological compensation triggered by pollution. Companies’ own pollution minimisation policies and strategies can also play a key role in reducing their environmental impact (Driussi and Jansz, 2006), including negative effects on agriculture.

After experiencing a prolonged period of significant economic growth China is yet to realise that only a development that does not destroy the environment can be a source for long-term sustainability. This is something that the globalised economy and international professional community are also struggling with, in spite of numerous sustainable development initiatives (Lozano et al., 2011). There are however some positive examples from transition economies, such as Poland, where companies are increasingly responding to pressure from social and actors (Kronenberg and Bergier, 2012). The Chinese counties that are currently industrialising may have the opportunity to avoid repeating previous mistakes, particularly if local governments are strict about pollution prevention.

6. Conclusion

This paper assessed the agricultural losses caused by the 2069 enterprises (located in 899 counties), identified by the Chinese government as requiring strict monitoring for airborne pollution because of their high industrial waste gas emissions. The analysis shows that in 2008 close to US$ 1.5 billion (or 0.66% of the total agricultural value added) was lost due to industrial air pollution. These alarming results emphasise the urgent need for effective environmental policies and strategies related to cleaner production.

Although there are regional differences, the economic development of China’s counties has come at a high cost for the environment and the large agricultural losses should not be ignored. In China, the wheat-production loss ratios in the Beijing districts are between 6 and 15%, which is considered medium range in most regions (Zhang and Wang, 2010). If the damage caused to agriculture by air pollution continues to rise, the Chinese people will face the risk of food supply shortages and contamination. Cleaner production hence becomes a crucial issue for the Chinese counties. There is mounting evidence that the growing environmental challenges cannot be solved by technological or societal sciences alone, and an integrated, multi-disciplinary and multi-stakeholder approach, including governmental policies, educational programs, technical assistance programs and many other initiatives is needed (Klemes et al., 2012; Lozano García, 2006).

Regional governments have played a leading role in promoting cleaner production (Geng et al., 2010). Since industrial development in many counties is inevitable, proper standards and instructions to restrict the pollution emission by the industrial enterprises are needed. The counties of central and west China, in particular need to avoid pollution intensive industries to be shifted from the east for the purpose of economic development. If the environment is sacrificed in the pursuit of large industrial projects, the damages caused to crop production will soon wipe off any real economic benefits.

Despite the reasonable methodology and findings of this study in assessing the agricultural losses due to industrial SO_2 emission, the accounting procedure involves many uncertainties. They accompany each step of the adopted impact-pathway approach (Mirasgedis et al., 2008). For example, as there are no specific data available for the ambient concentrations of SO_2 for all of the 2069 enterprises monitored for airborne pollution in the 899 counties, the estimated results may not reflect exactly the differences of agriculture losses caused by each enterprise. Also, the dose–response function for agricultural losses based on the ExternE methodology may not represent well the crop yield response to SO_2 in China. Furthermore, as there are not quality data available this study does not include ground-level ozone and NO_x influences on the crop yield and these are expected to be manifold larger. Even without accounting for these factors, the outcomes of the study are already indicative of the significance of the problems and the need for policy reaction.

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Table 1 Quantification of agricultural impacts due to SO_2 [a]

Impact category	*Dose-response functions*	*Crop*
Yield loss	$0.74x_{SO2}-0.055x^2_{SO2}(0<x_{SO2}<13.6ppb)$ $-0.69x_{SO2}+9.35(x_{SO2}>13.6ppb)$	Sunflower, wheat, potato, rice, rye, oats, tobacco, barley, sugar beet

[a] The information presented in this table has been mainly derived by *coSenseLE*, European Commission (2005).

Table 2 Agriculture losses due to the strictly monitored enterprises, 2008

Province	Number of enterprises monitored for airborne pollution in the county	Agricultural losses [a] (million US$)	Agricultural value added [a] (million US$)	RAL AVD (%)	Class
Beijing [b]	0	0	608.203	0	1
Fujian	32	7.615	5904.244	0.13	1
Gansu	33	6.333	2216.056	0.29	1
Guangdong	44	10.585	9075.310	0.12	1
Guangxi	96	29.152	9713.026	0.30	1
Hainan	2	0.374	658.420	0.06	1
Heilongjiang	35	14.848	5929.672	0.25	1
Hunan	91	57.679	15203.345	0.38	1
Liaoning	45	29.841	10061.896	0.30	1
Inner Mongolia	132	20.443	7705.983	0.27	1
Tibet	1	0.035	15.236	0.23	1
Xinjiang	59	3.762	4480.555	0.08	1
Yunnan	34	7.780	3206.457	0.24	1
Anhui	34	40.441	6059.207	0.67	2
Guizhou	52	18.516	3518.732	0.53	2
Henan	78	92.893	10857.443	0.86	2
Hubei	88	58.742	11380.713	0.52	2
Jilin	40	34.400	7564.477	0.45	2
Jiangxi	88	56.057	7211.675	0.78	2
Qinghai	34	3.378	682.992	0.49	2
Shanghai	3	2.287	450.184	0.51	2
Sichuan	131	99.435	14088.532	0.71	2
Tianjin	4	3.209	702.193	0.46	2
Zhejiang	94	63.165	8199.469	0.77	2
Chongqing	38	29.984	4968.587	0.60	2
Hebei	177	174.951	14852.475	1.18	3
Jiangsu	146	163.498	15863.546	1.03	3
Ningxia	31	9.806	667.608	1.47	3
Shandong	175	266.200	25454.401	1.05	3
Shaanxi	103	45.246	4650.429	0.97	3
Shanxi	149	75.251	2553.027	2.95	4
National Total	2069	1425.907	214504.092	0.66	-

[a] US$1=6.948RMB (data from the Bank of China, http://www.boc.cn).

[b] As Beijing has no strictly monitored enterprises, the values of the related variables are zero.

Table 3 Correlation between agricultural losses and the industrial waste gas emissions

Industrial waste gas emissions		Total Volume of Industrial Waste Gas Emission	Total Volume of Sulphur Dioxide Emission by Industry	Total Volume of Industrial Dust Emission by Industry
Agricultural losses	Pearson Correlation [a]	0.688**	0.695**	0.468**
	Sig., 2-tailed)	0.000	0.000	0.009
	Spearman's rho Correlation Coefficient [a]	0.731**	0.771**	0.711**
	Sig., 2-tailed)	0.000	0.000	0.000

[a] ** Correlation is significant at the 0.01 level (2-tailed).

Table 4 Per capita number of enterprises monitored for airborne pollution and socio-economic indices correlation coefficient

Variables	Per capita number of monitored enterprises	
	Pearson Correlation [a]	Spearman's Rho Correlation Coefficient [a]
Per capita industrial and agricultural added value	0.411^{**}	0.316^{**}
Per capita industrial value added	0.416^{**}	0.322^{**}
Per capita agricultural value added	-0.005	-0.029
Per capita crop production	-0.033	-0.103^{**}
RECGDP1 [b]	0.262^{**}	0.306^{**}
Per capita revenue	0.347^{**}	0.360^{**}
Per capita bank balance	0.171^{**}	0.293^{**}
Urbanisation rate	0.319^{**}	0.358^{**}
Agricultural labour participation rate	-0.223^{**}	-0.356^{**}

[a] ** Correlation is significant at the 0.01 level (2-tailed).

[b] RECGDP1 is the ratio of the agricultural losses caused by the enterprises monitored for airborne pollution to agricultural GDP.

Figure 1 Cluster analysis results for Chinese state-monitored heavily air polluting enterprises

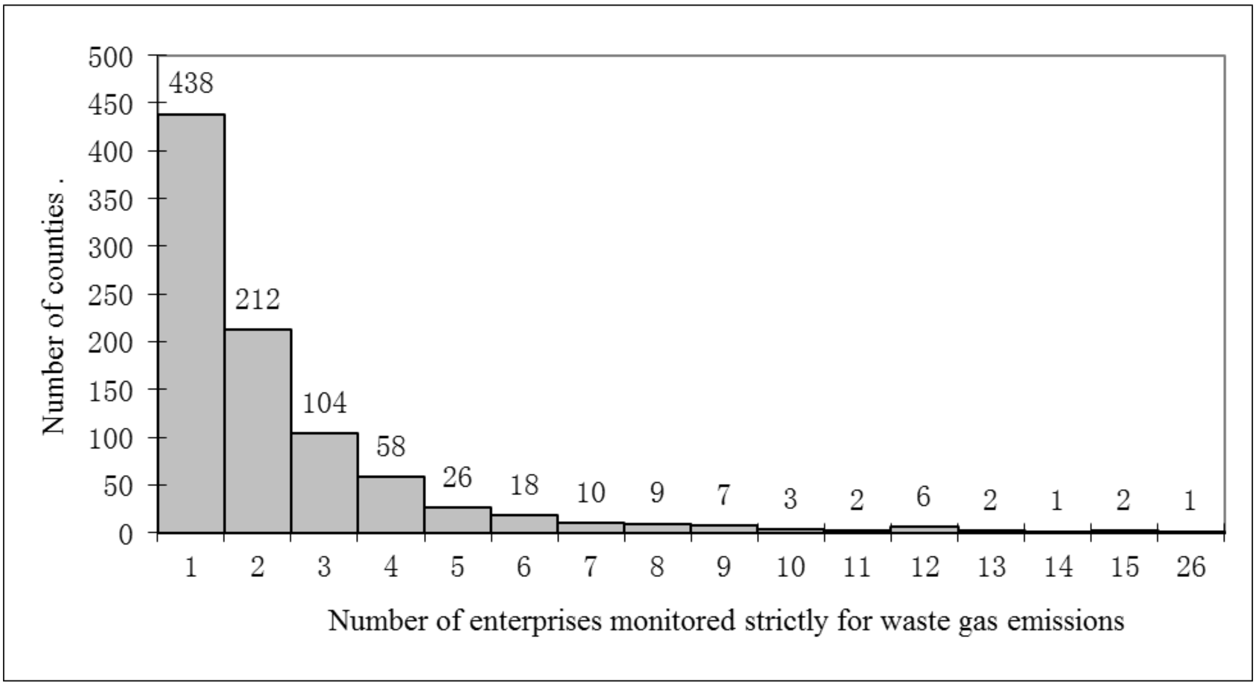

Figure 2 Distribution of the number of enterprises strictly monitored for waste gas emissions

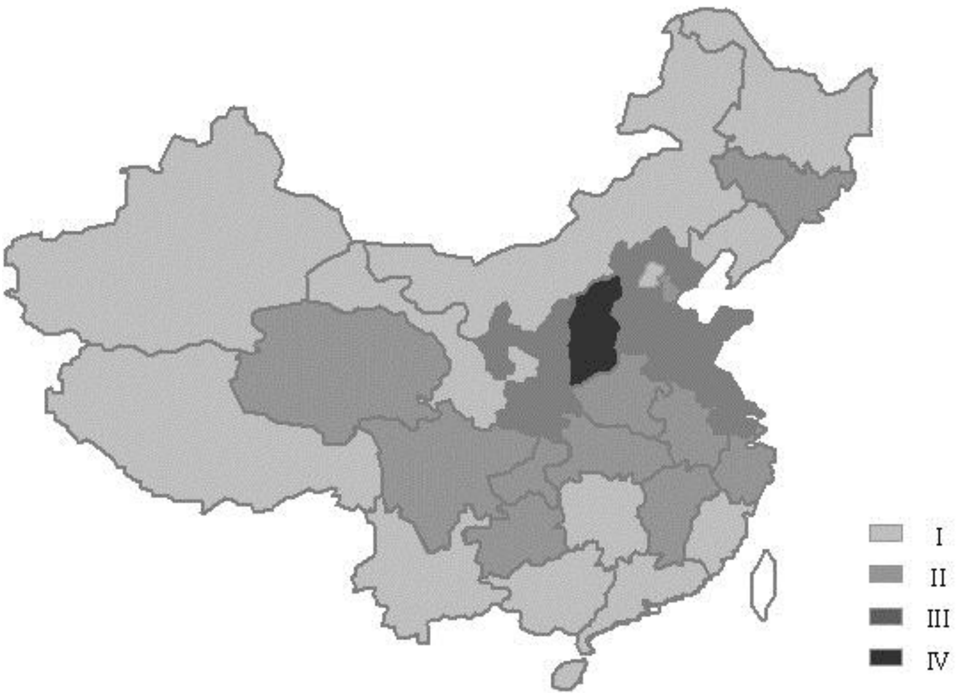

Figure 3 Groups of counties in China according to RALAVD