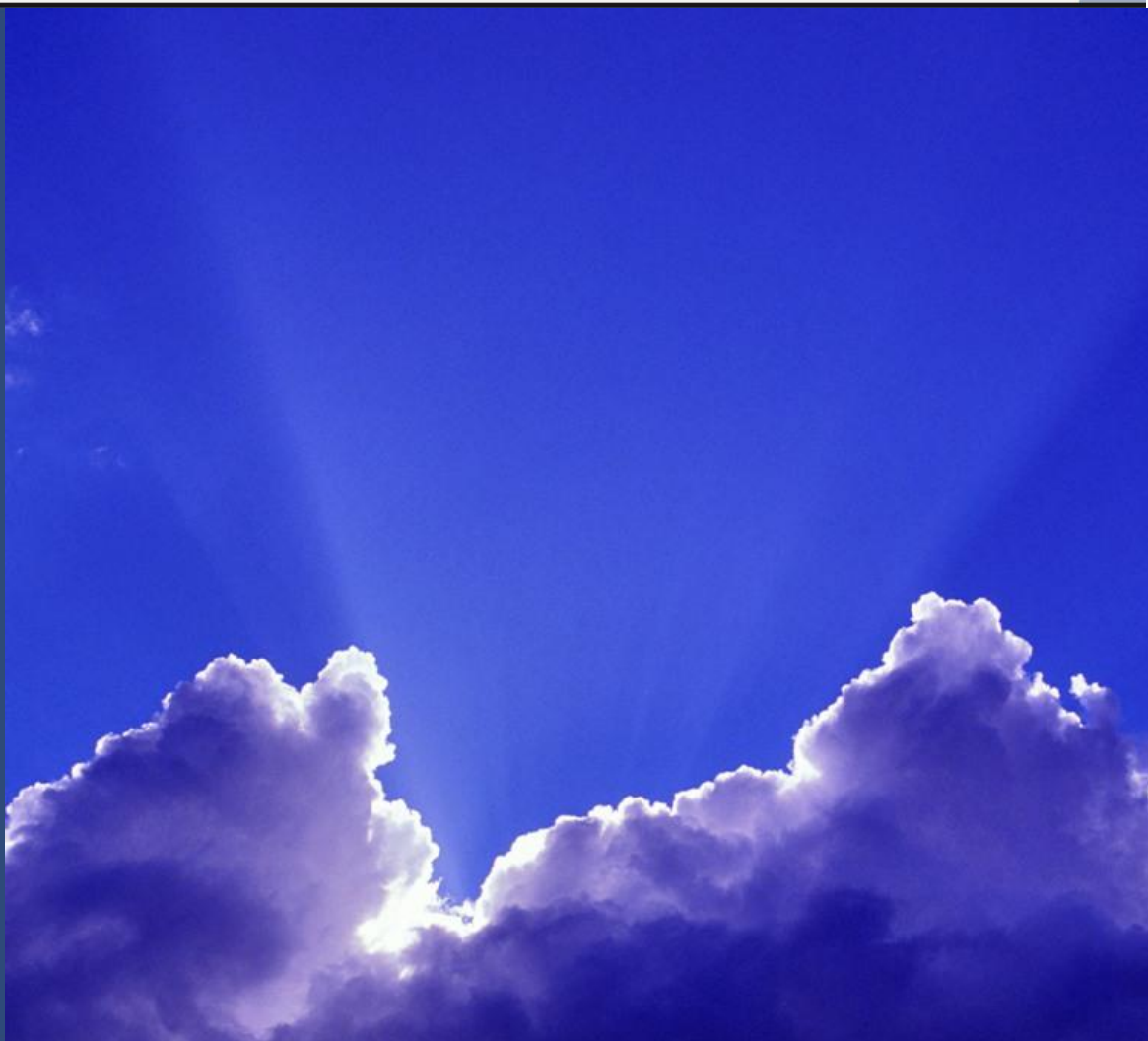


# Baseline survey of literature on environmental risk

Hans Martin Seip

VISTA ANALYSIS AS





## Document Details

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Vista Analysis AS	Report number 2013/38
Title	Baseline survey of literature on environmental risk
ISBN	978-82-8126-134-1
Author	Hans Martin Seip
Finished date	September 20, 2013
Project Manager	Haakon Vennemo
Quality Control	Kristin Aunan
Client	Chinese Academy of Environmental Planning
Access	Public
Published	pdf
Key words	Environmental risk, environmental planning, China

## **Preface**

This report gives an overview of major environmental problems related to the rapid economic growth in China both for accidents and continuous emissions based on literature from the last few years. Methods for evaluating risks and preventing accidents especially related to hazardous chemicals are described in several papers. Other major problems are caused by emissions of nitrogen compounds from industry, traffic and agriculture and emissions of heavy metals in particular mercury. A few recent studies using GAINS (Greenhouse gas–air pollution Interactions and Synergies) model or related methods are described. Among emerging issues production of unconventional gas, in particular shale gas, is considered briefly. Of the large number of recent papers only those considered most relevant for China are included. Many of the issues dealt with have special relevance for Jiangsu and Guizhou Provinces.

Haakon Vennemo

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Vista Analysis AS

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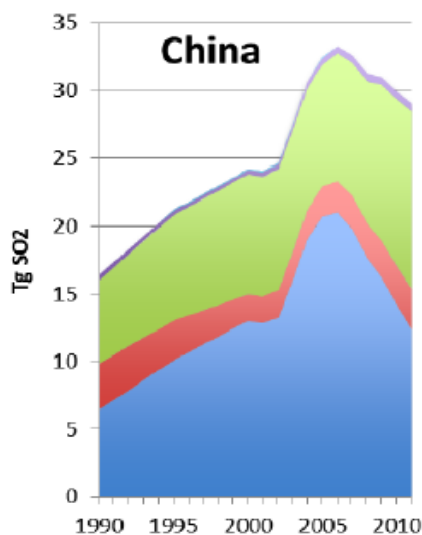
## 1 Introduction

According to the project description, the environmental planning phase II project follows up on the phase I project. The phase II project emphasizes training in CBA and SEA (Strategic Environmental Assessment) for environmental planning, and the application of CBA and SEA to planning for environmental risk reduction/prevention. In this report we will look at some recent developments based on publications for the last two-three years.

Recent development in environmental conditions in China is mixed. Although estimates differ, the total SO<sub>2</sub> emissions seem to have decreased since about 2005, see figure 1. Also, many areas report reduced concentrations of particulate matter (PM) and SO<sub>2</sub> concentrations in air. However, emissions of ammonia and nitrogen oxides have increased, see Fig. 2. Many observations of severe pollution episodes have been described especially in blogs such as Chinadialogue and mass media, and critique of lack of progress has been expressed. Links to some of these recent articles are given in Appendix 1.

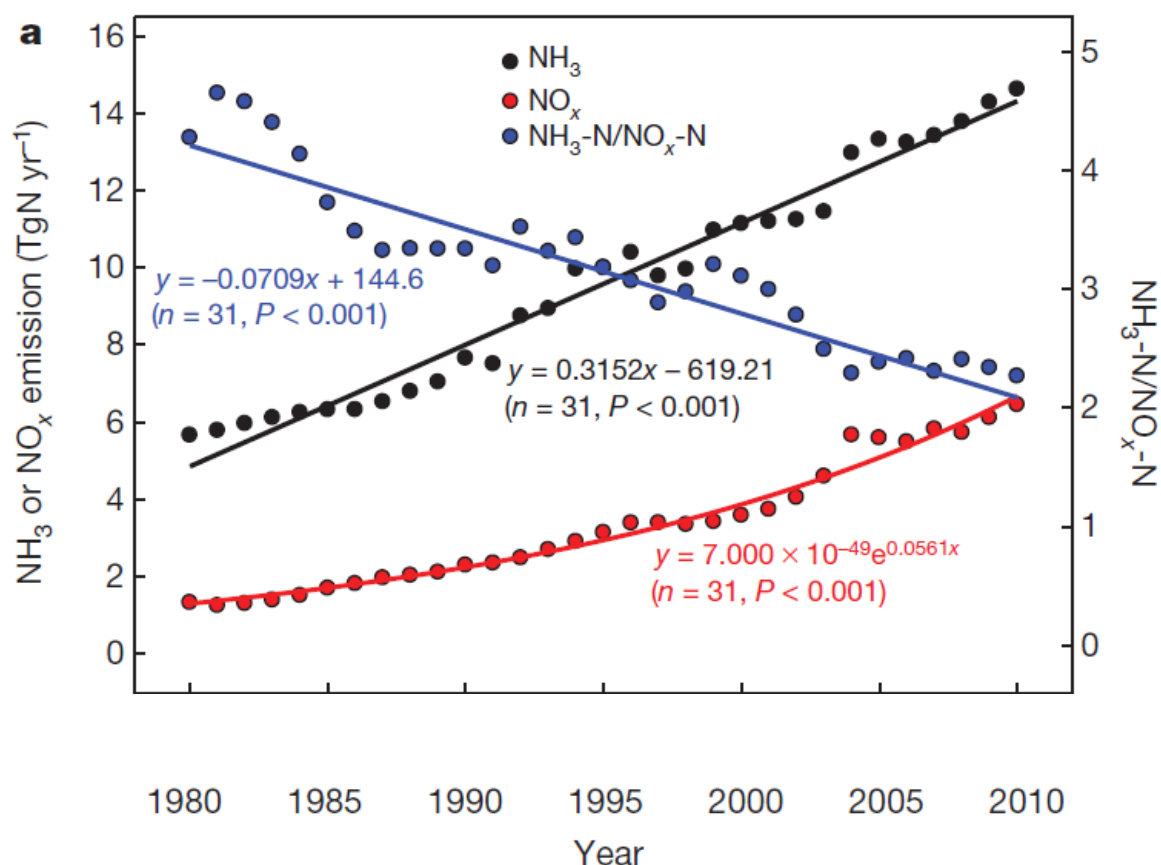
According to Global Burden of Disease Study 2010, outdoor air pollution contributed to 1.2 million premature deaths in China in 2010, nearly 40 percent of the global total.

<http://www.thelancet.com/themed/global-burden-of-disease>



**Figure 1** Sectorial trend in SO<sub>2</sub> emissions from 1990 to 2011, Tg SO<sub>2</sub>.

Source: From Klimont et al., 2013. The GAINS (Greenhouse gas–air pollution Interactions and Synergies) model was used to calculate land based anthropogenic emissions for 2000, 2005 and 2010, while annual energy consumption data was used to scale these estimates for intermediate years and extending to produce a preliminary estimate for 2011



**Figure 2** **NH<sub>3</sub> and NO<sub>x</sub> emissions and ratios of NH<sub>3</sub>-N to NO<sub>x</sub>-N emission.**

Source: From Liu,X. et al., 2013.

This report will mainly build on articles published in international journals. Section 2 deals with pollution resulting from accidents. Analyses of previous accidents have been made and several schemes have been suggested for evaluating risks and prevent accidents. Several of these will be described. However, a detailed assessment of the schemes is beyond the scope of the report. In Section 3 some important environmental problems with special relevance for China are described. The section includes recent studies using the GAINS model or related methods. Of the large number of recent papers only those considered most relevant for China are included. Further some publications dealing with mercury and other heavy metals in China are discussed. Reasons for emphasis on mercury are that China has the largest Hg-emissions to the atmosphere in the world and Guizhou Province is the “Hg capital” of China. Section 4 describes very briefly some questions and problems related to unconventional natural gas production since this is by some predicted to become a major energy source in China.

## 2 Accident related pollution

An important paper was published by He-Da Zhang and Xiao-Ping Zheng at School of Economics and Management, Beijing University of Chemical Technology in 2012. They used data from official sources for 1632 hazardous chemical accidents (HCAs) occurring

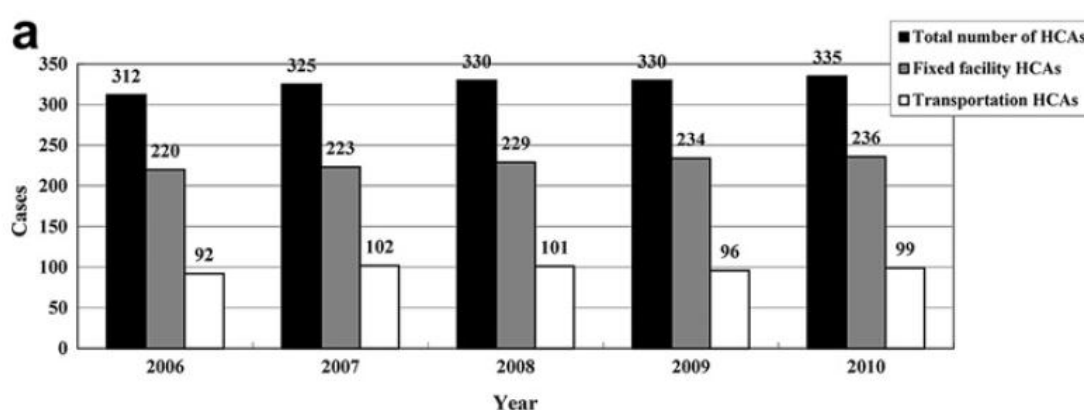


in China from 2006 to 2010, more than 2/3 in fixed facilities (see fig. 3). They found a slight increase in the annual number during the period. Zhao et al. (2012), on the other hand, reported a decrease in number of chemical accidents in China from 2004 to 2011 and also for the 2006 – 2010 period. However, their annual number of accidents is much smaller than reported by Zhang and Zheng so the selection criteria are clearly different. (See further discussion of the paper by Zhao et al. below.)

Zhang and Zheng give a table for the number of accidents in the provinces during the period, main hazardous chemicals involved, and main industries. For three provinces more than one hundred chemical accidents were reported (Jiangsu, Shandong, and Zhejiang). These provinces are economically developed regions with many petrochemical factories. The numbers for Anhui and Guizhou are 54 and 21, respectively. Altogether, 26.8% of the HCAs occurred in Jiangsu, Shandong and Zhejiang provinces due to their many petrochemical industries.

For fixed facility HCAs, nearly 90% of the cases occurred as a result of conscious rule-breaking behavior (e.g., breach of duty), whereas unconscious rule-breaking behavior (e.g., a careless operation or negligence) accounted for only 10%.

Important conclusions from the study include that in the efforts to prevent HCAs in China, enterprises should shift their focus from immediate human factors and concerns over advanced equipment requirements to the regulation of internal management issues (e.g., procedures constraints, training, inspection and equipment maintenance). The government should administer more external supervision and enforcement, particularly in remote townships and villages where illegal workshops remain. Furthermore, government should enforce real-time supervision in order to prevent non-qualified transportation of hazardous chemicals.



**Figure 3** Number of hazardous chemical accidents (HCAs) occurring in China from 2006 to 2010.

Source: From Zhang and Zheng, 2012.

Another important paper is by Jinsong Zhao at Department of Chemical Engineering, Tsinghua University and coworkers. (Process safety challenges for SMEs<sup>1</sup> in China, 2012)

The starting point is UNEP's "Responsible Production approach for Chemical Hazards Management along the Value-Chain", see Figure 4 and Appendix 2. A simplified PSM<sup>2</sup> approach targeted specifically at SMEs is suggested.



**Figure 4 Responsible production framework.**

Zhao et al. point out that the current trend in China of clustering all chemical companies in chemical industry parks points to increased challenges posed by the increased concentration of hazards, but also to opportunities for increased leadership and harmonization of safety practices across the chemical sector, with government and park management authorities playing a decisive role. By sharing common infrastructure and park management standards and requirements, enhanced opportunities are created for companies to share knowledge and best practice, towards the creation of a safety culture championed by more progressive companies.

Environmental risk assessment (ERA) with focus on industrial parks is also considered by Chaofeng Shao at Nankai University, Tianjin and coworkers (2013). They conclude: Unlike a single construction project, regional ERA and management are classified as new strategies in environmental risk management. These strategies resolve the multiple uncertainties of risk sources and their effects, non-additivity of the consequences of accidents, and other factors. In this study, a systematic analysis of the mechanisms underlying environmental risks was conducted, and an ERA method based on risk field theory was established. Theories and methods were proposed for environmental risk zoning in industrial parks.

The theories and methods of regional ERA and management remain in the development stage. In particular, the regional environmental risk spatial and temporal zoning, multi-risk coupling and risk-field superimposition as well as regional environmental risk capacity allocation are in the exploratory stage. Despite the establishment of the ERA

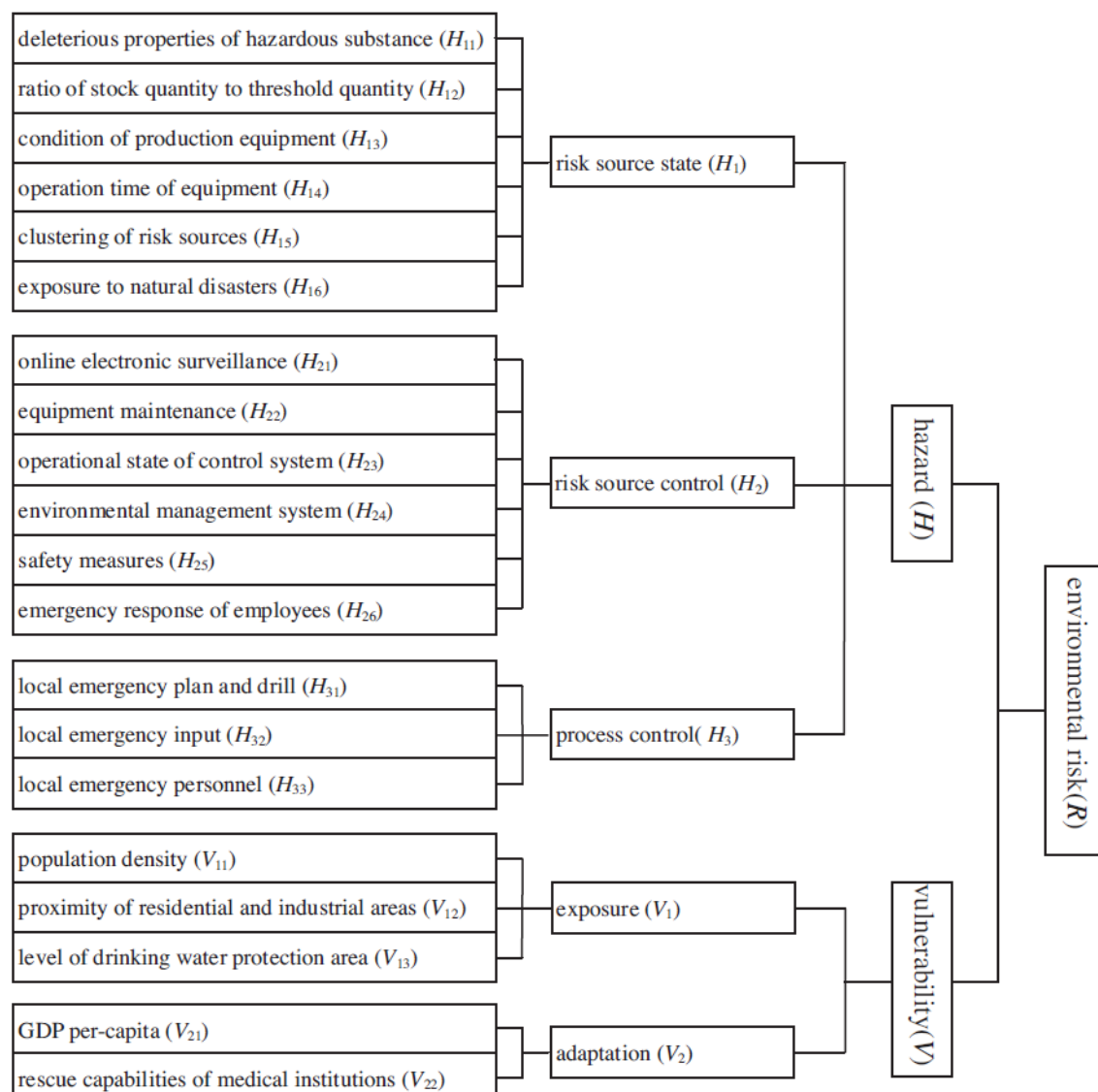
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<sup>1</sup> Small and medium sized enterprises

<sup>2</sup> Process Safety Management

technology and management mechanism in chemical industry parks, further tests, optimization, and upgrade, combined with application practices, are required, which should be based on the investigation and evaluation of risk sources in multiple chemical industry parks.

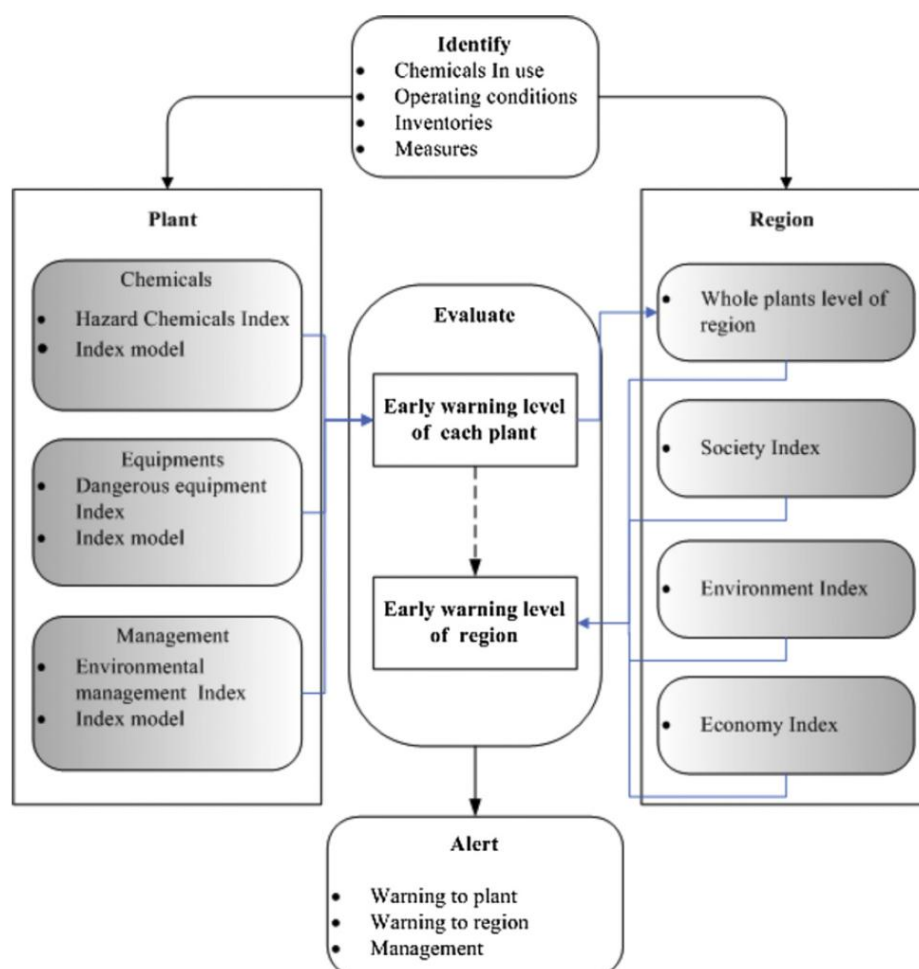
R. Z. Liu at Beijing Normal University and coworkers (2012) have outlined details of an Environmental Pollution Accident Risk Mapping (EPARM) approach for assessing and mapping such risk at the scale of a city. The EPARM approach consists of identifying suitable indexes, assessment of environmental risk at regional and national scales based on information on previous pollution accidents and the prevailing environmental and social conditions, and use of GIS to map the overall risk. EPARM is constructed according to a regional risk system for environmental pollution hazards due to accidents. The approach involves development of a mapping index system, evaluation of risk sub-indexes, calculation of higher-layer indexes, and zonal risk mapping. The mapping indexes are pertinent and complete, having been derived from the causative system of accidental environmental pollution risk, see figure 5.



**Figure 5      Regional scale mapping index system of environmental pollution accident risk**

Source: From Liu et al., 2012

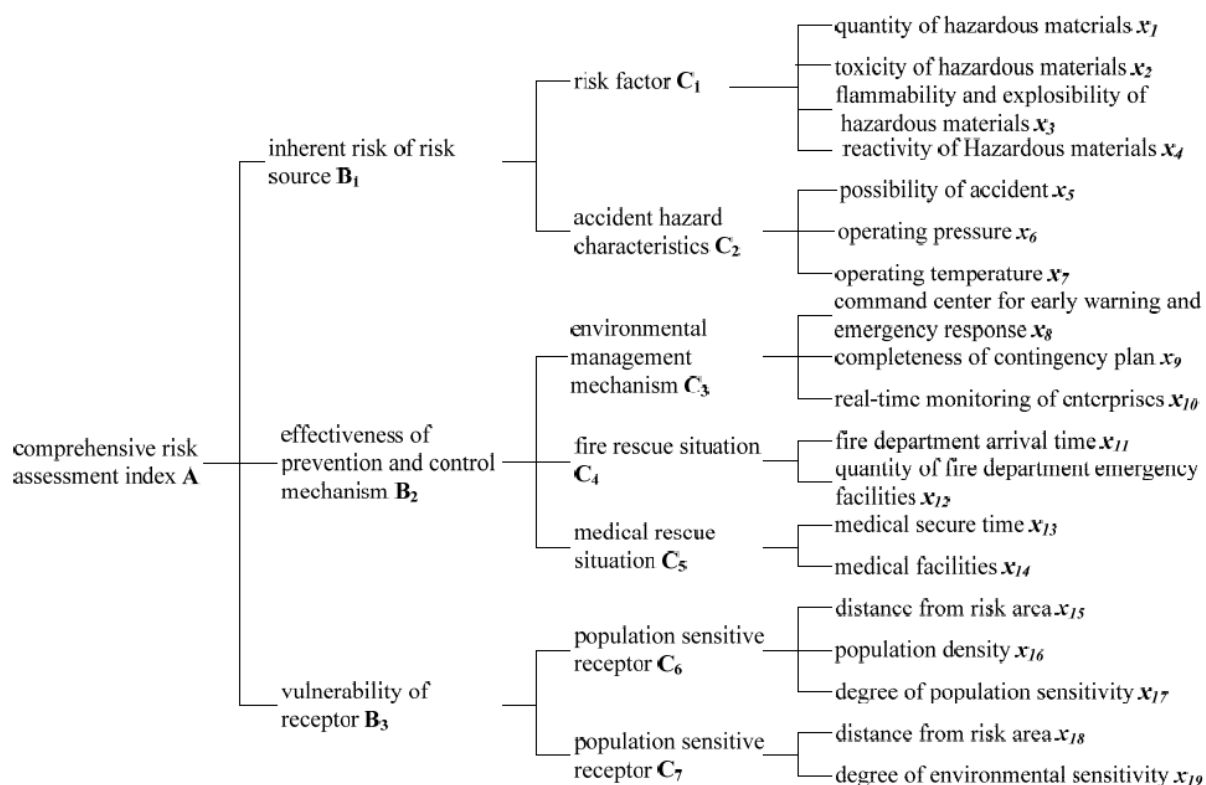
Lei Huang and coworkers (2011) developed a two-scale system to identify environmental risk of chemical industry clusters. A series of risk early warning indices both at the plant level and at the regional clusters level are used in this system. At the enterprise scale a risk early warning index is constructed using inputs such as the presence of hazardous materials, the operation of critical plant equipment and the efficiency of extant management techniques. Secondly, an index for quantifying risks on regional scales depends on environmental, economic, and social conditions as well as the specific enterprises' components. As an illustration, the system is applied to a case study involving a five-plant chemical industry cluster in Jiangsu province. The framework is shown in figure 6.



**Figure 6      Framework of the early warning system,**

Source: From Huang et al., 2011.

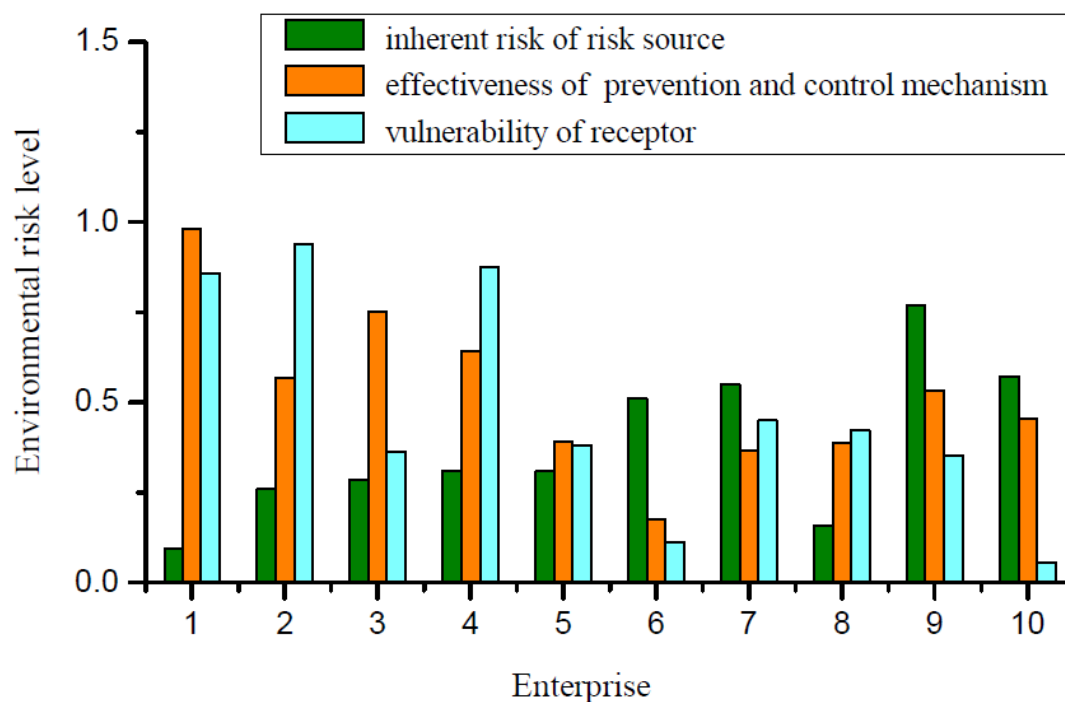
Yu Chen at Dalian University of Technology and coworkers (2012) have developed a comprehensive evaluation index system for risk assessment of chemical enterprises in Chemical Industrial Parks (CIPs) based on environmental risk systems theory. The three indices include the inherent risk associated with risk source, effectiveness of prevention and control mechanisms, and vulnerability of receptors. Among these, the inherent risk index associated with risk source is determined by multiple factors such as the stock, toxicity, flammability/explosibility and production process of hazardous substances. The effectiveness of prevention and control mechanisms is determined by the environmental management level and fire/medical rescue situation of the enterprise and the receptor vulnerability is calculated based on the density and structure of surrounding populations and the distance of sensitive targets from the enterprise, see figure 7.



**Figure 7** Comprehensive risk assessment index system for enterprises in chemical industrial parks

Source: Chen et al., 2012

Results for a case study are shown in figure 8.



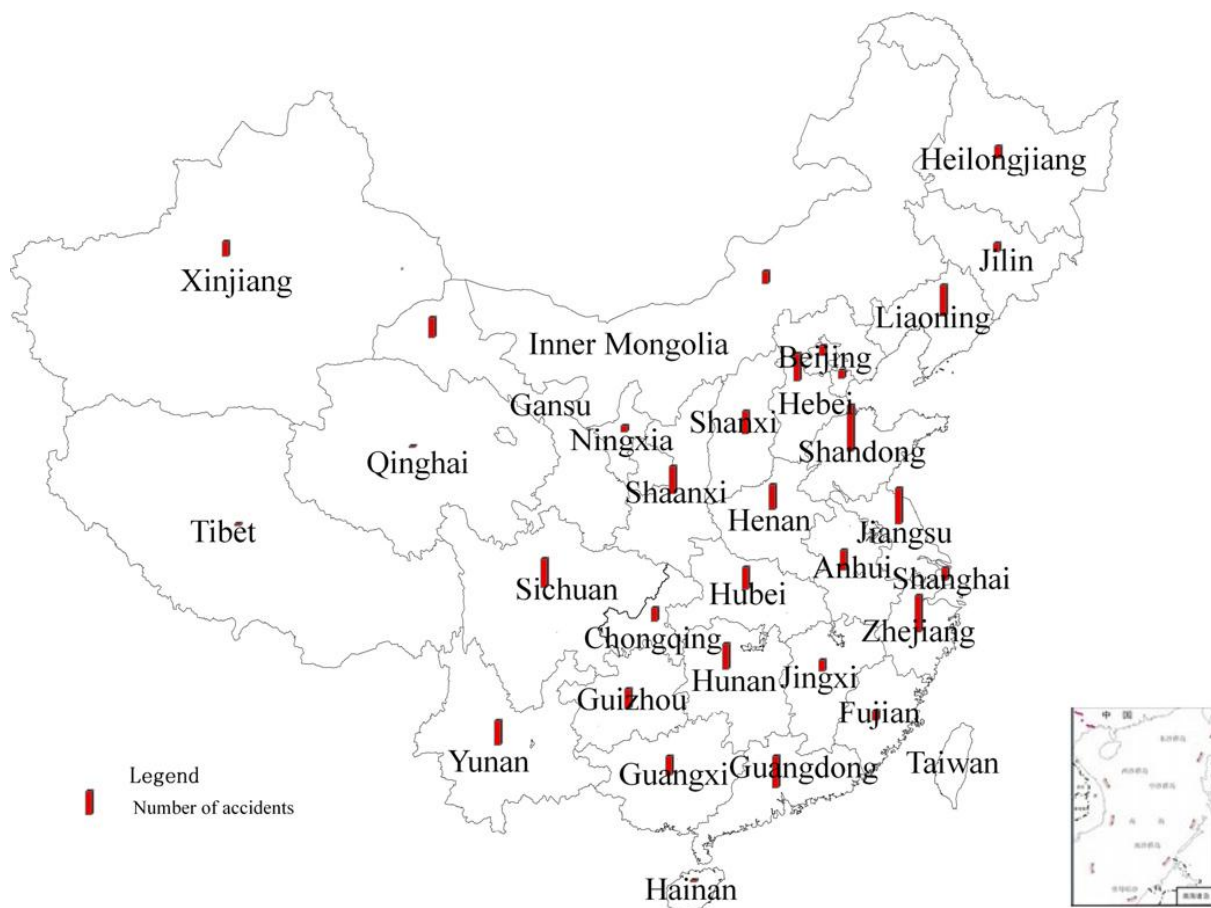
**Figure 8** Risk levels of layer B (see Figure 7) indices of chemical enterprises in Songmu Island Chemical Industrial Park Dalian, Liaoning province, which consists of syngas chemical, petrochemical, and fine chemical industries, with ten chemical enterprises.

Source: Chen et al., 2012

Yan Fu Wang at China University of Petroleum, Qing Dao, and coworkers (2013) proposed an accident analysis model to develop cost-efficient safety measures for preventing accidents. The model comprises two parts. In the first part, a quantitative accident analysis model is built by integrating the Human Factors Analysis and Classification System (HFACS) with a Bayesian Network (BN), which can be utilized to present the corresponding prevention measures. In the second part, the proposed prevention measures are ranked in a cost-effectiveness manner through Best-Fit method and Evidential Reasoning (ER) approach. A case study of vessel collision is analyzed as an illustration. The case study shows that the proposed model can be used to seek out accident causes and rank the derived safety measures from a cost-effectiveness perspective. The proposed model can provide accident investigators with a tool to generate cost-efficient safety intervention strategies.

Guizhen He at Research Centre for Eco-Environmental Sciences, Beijing and coworkers (2011) stated that the current chemical accident-related data system is highly fragmented and incomplete, as different responsible authorities adopt different data collection standards and procedures for different purposes. To contribute to the building of a more comprehensive, integrated and effective information system, they: (i) reviewed and assessed the existing data sources and data management, (ii) analyzed data on 976 recorded major hazardous chemical accidents in China over the last 40 years, and (iii) identified the improvements required for developing integrated risk management in China.

Among the conclusions are: For the sustainable development of a fast expanding chemical sector in China, it is strategically important to move from responding reactively to preventing proactively risks and accidents. This calls for a more coordinated management of comprehensive information system that gives more weight to environmental pollution information of the chemical accidents. A comprehensive and publicly accessible information system would not only increase the efficiency and effectiveness of accident prevention and responses, but also help raise public awareness and gain support from the society at large.



**Figure 9 Major dangerous chemical accidents in China, 1970–2009**

Source: from He et al., 2011

Yu Hou (2012) criticizes the Chinese policy regarding accidents causing serious damage to health and environment. He studied two accidents in China in 2006 that caused serious environmental problems in nearby communities and discusses the problems these accidents created and the resulting disputes among the concerned people. He stresses the importance of addressing the apparent weakness of oversight as shown by the continued operation of companies without environmental licenses.

### 3 Recent studies of environmental problems with focus on China

#### 3.1 Studies mainly based on GAINS

Fei Liu at Tsinghua University, Beijing and coworkers (2013) developed a city-scale emission model (GAINS-City) for Beijing based on the Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model. The GAINS-City model relies on a technology-based approach to evaluate the co-benefits of various policies. This approach allows for estimation of emission reductions of several pollutants (including SO<sub>2</sub>, NO<sub>x</sub>, PM) and CO<sub>2</sub> for individual policies and support evaluation of co-benefits. Liu et al. claim that the approach will have great potential to be applied in many large cities with local input data and/or minor structure modifications.

The emissions under three scenarios (*Baseline*, *Air Quality*, and *Strict Air Quality*) in base year (2005) and future years (2020 and 2030) were estimated. The results indicate a significant reduction potential. In 2030, implementation of *Air Quality* and *Strict Air Quality* scenarios could result in reductions of 39%-48% of SO<sub>2</sub> emissions, 38%-42% of NO<sub>x</sub> emissions, 37%-55% of PM<sub>2.5</sub> emissions and 5%-22% of CO<sub>2</sub> emissions respectively, compared with the Baseline scenario. The results demonstrated air quality policies and measures could also have co-benefits of reducing CO<sub>2</sub> emissions. However, there is no significant difference of reductions between the two policy scenarios, which indicates the limited further reduction potential in the stricter air quality case. This calls for a wider application of cleaner technologies, such as integrated gasification combined cycle and carbon capture and storage, and more aggressive air quality measures by neighboring provinces to control regional air pollution.

P. Rafaj and J. Cofala (2013) studied ancillary benefits of climate policies for the mitigation of atmospheric mercury emissions. The study provides an analysis of the impact of global climate policies on mercury emissions using the GAINS model in the time horizon up to 2050. The time evolution of mercury emissions is based on projections of energy consumption provided by the Prospective Outlook for the Long term Energy System (POLES) model for a scenario without any global greenhouse gas mitigation efforts, and for a 2°C climate policy scenario, which assumes internationally coordinated action to mitigate climate change. Outcomes of the analysis are reported globally and for key world regions: EU-27, China, India and the US. Scenario calculations for mercury emissions indicate significant scope for co-benefits made possible through climate policies. Atmospheric releases of mercury from anthropogenic sources under the global climate mitigation regime are reduced in 2050 by 45% when compared to the case without climate measures. Around one third of co-benefits for mercury emissions estimated world-wide in this study by 2050 are allocated to China. An annual Hg-abatement of about 800 tons is estimated for the coal combustion in power sector if the current air pollution legislation and climate policies are adopted in parallel.

Since nitrogen emissions are an increasing problem in China, the recent study by Hans J. M. Van Grinsven and coworkers (2013) may be of interest although it is for Europe. The paper, which partly is based on GAINS, provides a critical and comprehensive assessment of costs and benefits of the various flows of N on human health, ecosystems and climate stability in order to identify major options for mitigation. A good treatment of uncertainties is given.



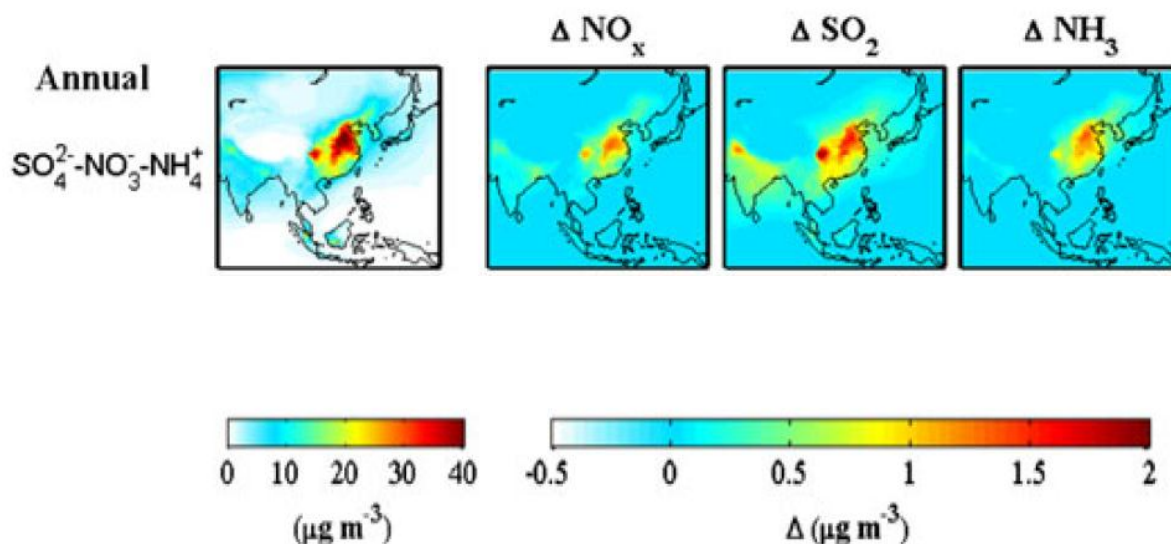
### **3.2 Haze and other air pollution**

Litao Wang at Hebei University of Engineering, Handan and coworkers (2012) studied haze pollution over the Hebei area using an air quality model. They found that approximately 65% of the PM<sub>2.5</sub> in Shijiazhuang and Xingtai originated from the local emissions of the southern Hebei area, followed by Shanxi Province and the northern area of Hebei (13.8% and 7.3% to Shijiazhuang and 10.4% and 5.2% to Xingtai, respectively). Moreover, an analysis of a typical pollution episode indicates that the contributions from the Shandong and Henan provinces are also significant. Further investigations are still required because of the complexity of the haze pollution over the southern Hebei area.

K. Huang at Fudan University, Shanghai and coworkers (2012) studied the impact of anthropogenic emission on air quality over a megacity by an intensive atmospheric campaign during the Chinese Spring Festival. The study demonstrated that organic aerosol was the largest contributor to aerosol extinction at 47 %, followed by sulfate ammonium, nitrate ammonium, and EC (elemental carbon ) at 22 %, 14 %, and 12 %, respectively. The results indicated the dominant role of traffic-related aerosol species (i.e. organic aerosol, nitrate and elemental carbon) on the formation of air pollution, and suggested the importance of controlling vehicle numbers and emissions in mega-cities of China as its population and economy continue to grow.

Another similar study by the same group on pollution characterization and source analysis in Shanghai before, during, and after the 2010 World Expo has been carried out, but so far only an abstract seems to have been published (Huang et al., 2013).

S. K. Kharol at Dalhousie University, Halifax, Nova Scotia, Canada and coworkers (2013) used a chemical transport model and its adjoint to examine the sensitivity of secondary inorganic aerosol formation to emissions of precursor trace gases from Asia, see figure 10. Sensitivity simulations indicate that secondary inorganic aerosol mass concentrations are most sensitive to ammonia (NH<sub>3</sub>) emissions in winter and to sulfur dioxide (SO<sub>2</sub>) emissions during the rest of the year. However, persistent sensitivity to NO<sub>x</sub> arises from the regional abundance of NH<sub>3</sub> over Asia that promotes ammonium nitrate formation. Satellite observations corroborate the NH<sub>3</sub> abundance. The authors encourage more attention to NO<sub>x</sub> controls in addition to SO<sub>2</sub> and NH<sub>3</sub> controls to reduce ground-level East Asian aerosol.

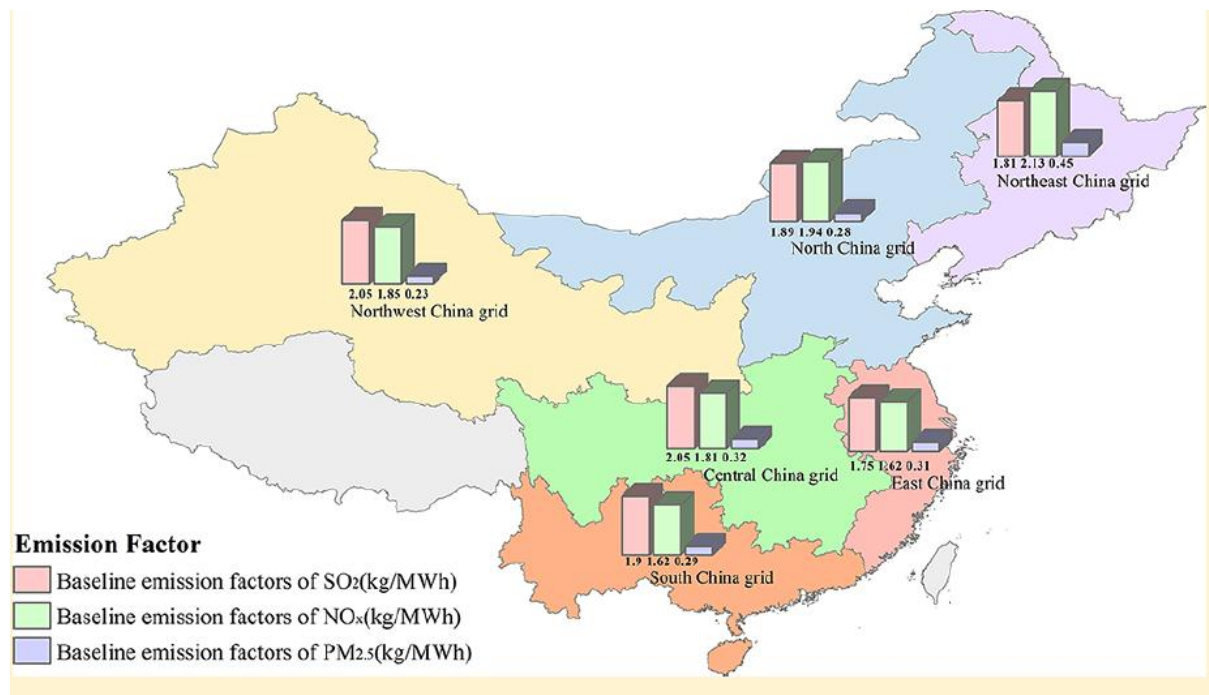


**Figure 10** The left map indicates the spatial distribution of annual mass concentration of secondary inorganic aerosol for 2006. The remaining maps indicate the sensitivity of the aerosol to a 10% increase in precursor emissions ( $\text{NO}_x$ ,  $\text{SO}_2$ , or  $\text{NH}_3$ )

Source: From Kharol et al., 2013

Based on a chemical transport model, Y. Wang at Tsinghua University, Beijing, and coworkers (2013) suggested that the  $\text{SO}_2$  emission reduction target set by the 12th FYP, although effective in reducing sulfate-nitrate-ammonium (SNA) aerosols over South China (SC) and Sichuan Basin (SCB), will not be successful over North China (NC), where  $\text{NO}_x$  emission control needs to be strengthened. If  $\text{NH}_3$  emissions are allowed to keep their recent growth rate and increase by +16% from 2006 to 2015, the benefit of  $\text{SO}_2$  reduction will be completely offset over all of China due to the significant increase of nitrate, demonstrating the critical role of  $\text{NH}_3$ . The effective strategy to control SNA and hence  $\text{PM}_{2.5}$  pollution over China should thus be based on improving understanding of current  $\text{NH}_3$  emissions and putting more emphasis on controlling  $\text{NH}_3$  emissions in the future.

Wenjia Cai at Tsinghua University, Beijing and coworkers (2013) estimated baseline emission factors for  $\text{SO}_2$ ,  $\text{NO}_x$  and  $\text{PM}_{2.5}$ , see figure 11. (Not using GAINS) It was estimated that in 2010, every 1%  $\text{CO}_2$  reduction in China's power generation sector resulted in co-reductions of 1.1%, 0.5%, and 0.8% of  $\text{SO}_2$ ,  $\text{NO}_x$ , and  $\text{PM}_{2.5}$ , respectively. Wind is the best technology to achieve the largest amount of co-abatement in most parts of China. This methodology is recommended to be used in making comprehensive air pollution control strategies and in co-benefits analysis in future CDM approval processes.



**Figure 11 Emission Factor**

Source: from Cai et al., (2013).

Kyung-Min Nam at Massachusetts Institute of Technology and coworkers (2012) investigated the costs of achieving the reductions in SO<sub>2</sub> and NO<sub>x</sub> in China's Twelfth Five Year Plan (FYP) and the implications of doing so for CO<sub>2</sub> emissions. The analysis was extended through 2050, and emissions policy targets were either hold at the level specified in the Twelfth FYP, or reduced gradually. They applied a computable general equilibrium model of the Chinese economy that includes a representation of pollution abatement derived from detailed assessment of abatement technology and costs. They found that China's SO<sub>2</sub> and NO<sub>x</sub> emissions control targets would have substantial effects on CO<sub>2</sub> emissions leading to emissions savings far beyond those we estimate would be needed to meet its CO<sub>2</sub> intensity targets. However, the cost of achieving and maintaining the pollution targets can be quite high given the growing economy. Actually the Twelfth FYP pollution targets can be met while still expanding the use of coal, but if they are, then there is a lock-in effect that makes it more costly to maintain or further reduce emissions. That is, if firms were to look ahead to tighter targets, they would make different technology choices in the near term, largely turning away from increased use of coal immediately.

Jiahai Yuan and coworkers (2011) review energy conservation (EC) and emissions reduction (ER) in China. Lessons from the 11th FYP periods are drawn and factors underlying and limiting the policy formulation and implementation are discussed to probe problems and solutions. Rationality and feasibility analysis on the 12th FYP EC and ER target is also addressed. Policy suggestions are proposed for long-term successful implementation of EC and ER in China.

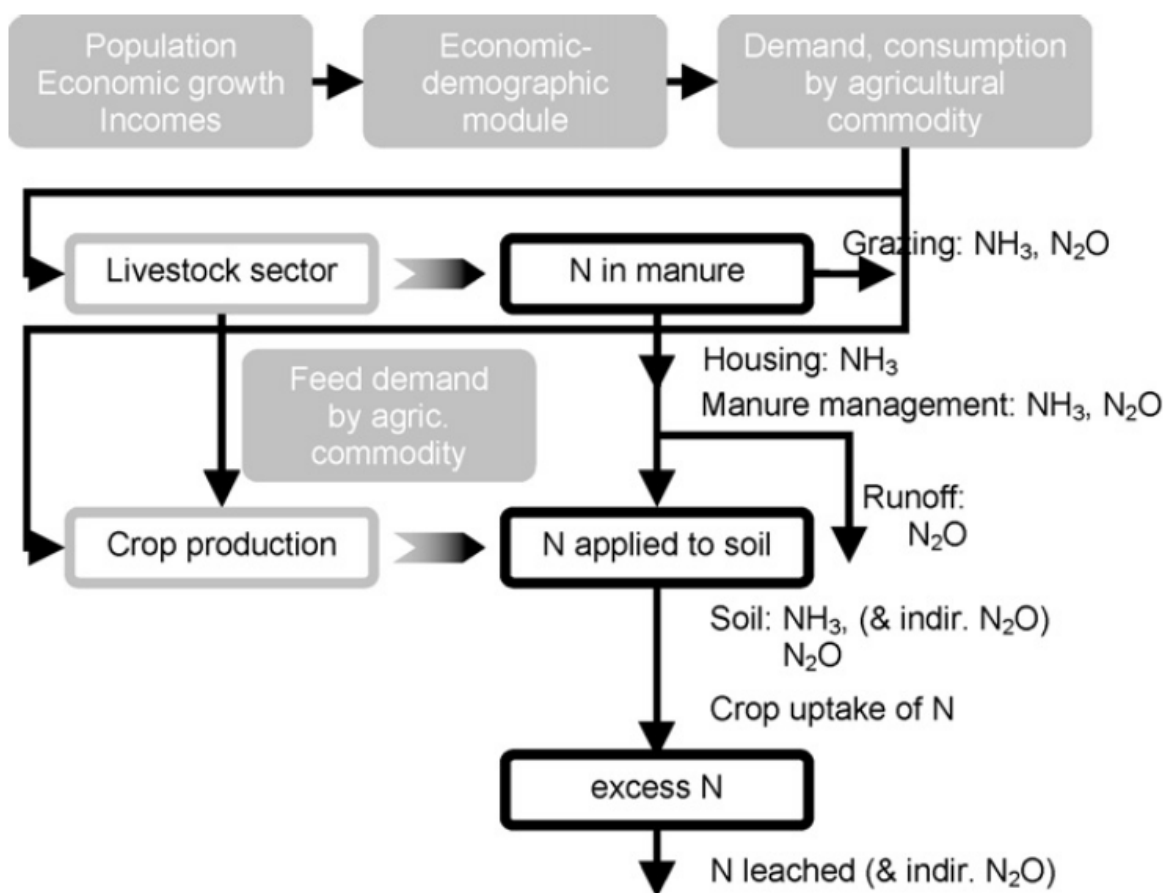
Since the NO<sub>x</sub> emissions are a key to ozone formation one should note that recent predictions of ozone damage to important crops indicate that this may become larger than several earlier predictions, see Amin et al., 2013.

Another paper on effects of air pollution of special interest for cost-benefit analyses has been published by Jie Cao and coworkers (2011). It describes association between long-term exposure to outdoor air pollution and mortality in China.

### ***3.3 Studies with emphasis on agriculture***

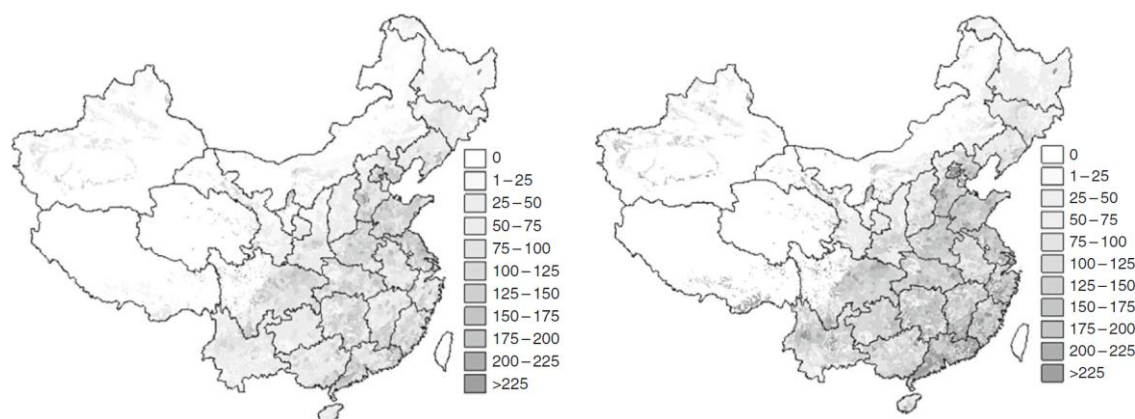
Agriculture is a major source of water, air and soil pollution. Pollution rates are often linked to intensification of agricultural activities, i.e., large-scale livestock production and excessive fertilization of crops.

G. Fischer at International Institute for Applied Systems Analysis (IIASA) and coworkers (2010; 2012) developed a concept of a spatially and temporally explicit model for sustainable agriculture production planning, which operates at a detailed spatial scale and integrates demand and agricultural production activities at national and sub-national levels, see figure 12. It distinguishes environmental loads and sources of agricultural pollution originating from two main agricultural activities: livestock raising and crop production. The indicators used to reflect the impacts of agricultural production comprise of fluxes to air (emissions of ammonia and nitrous oxide) and water (nitrate leaching). Risk functions indicate the degree of risk associated with agricultural production. Alternative production scenarios are compared in terms of human exposure to risk, i.e., the number of people in different risk classes. In this way the model allows for assessment and testing of strategies for mitigating agricultural pollution. Application of the integrated model is illustrated by a case study of agricultural production development in China. Results for ammonia emissions are shown in figure 13.



**Figure 12** Schematic structure of the model used by Fischer et al.

Source: Fisher et al.



**Figure 13** Ammonia emissions from agriculture (kg ammonia/ha cultivated land) in 2000 (left) and estimated for 2030 (right).

Source: from Fischer et al., 2012.

### 3.4 Water pollution

Jian Sha at Nankai University, Tianjin and coworkers (2013) described a modeling approach for quantifying the source apportionment of dissolved nitrogen (DN) and associated tools for examining the sensitivity and uncertainty of the model estimates. Results were assessed for the Sha He River (SHR) watershed in China. The SHR is representative of many watersheds in the region because of its main environmental issue, excess nitrogen. Because it is the main natural recharge source of the Yu Qiao Reservoir (YQR, the source of drinking water for Tianjin City), the water quality of the SHR is of critical concern.

The Regional Nutrient Management model (ReNuMa) was used to infer the primary sources of DN in the SHR watershed. This model is based on the Generalized Watershed Loading Functions (GWLF) and the Net Anthropogenic Nutrient Input (NANI) framework, modified to improve the characterization of subsurface hydrology and septic system loads. Hydrochemical processes of the SHR watershed, including streamflow, DN load fluxes, and corresponding DN concentration responses, were simulated following calibrations against observations of streamflow and DN fluxes.

### 3.5 Heavy metals with emphasis on mercury

Yan Lin at Norwegian Institute for Water Research, Oslo and coworkers (2012) have written a review on environmental mercury in China. China is the country that contributes most to atmospheric mercury (Hg) emissions and has the greatest intentional (industrial) use of Hg. Mercury in the Chinese environment is generally elevated, particularly in air and water bodies. Remote areas in China also show elevated Hg levels in air and water bodies compared to other rural regions in the world. Large river estuaries are often heavily affected by upstream industrial sources. Mercury is also elevated in sediments, a direct result of contamination in river systems. Regardless of the few heavily polluted sites, the urban environment in Chinese cities is comparable to

that of other megacities in terms of Hg pollution, considering the size and rapid development of Chinese cities. Studies on Hg in fish showed generally low levels of contamination resulting from low bioaccumulation of Hg in the mostly short food chains. Mercury in rice has recently received increased research interest; elevated concentrations have been reported from rice grown in contaminated areas and may pose a threat to people dependent on such locally grown food. However, for the general population, Hg exposure from rice is small (Table 1). In addition, Hg hair concentration in the Chinese population showed generally low levels of exposure to Hg, except for people with special occupational exposure. Some values for Hg in water, soils and sediments are given in Table 2.

**Table 1** Mercury concentrations in rice in China (from Lin et al., 2012).

Location	Total mercury ( $\mu\text{g kg}^{-1}$ dry wt)	Methylmercury ( $\mu\text{g kg}^{-1}$ dry wt)
Nationwide	3.3 (<LOD–31)	
Wanshan, Guizhou	10–1,120	1.61–174
Wanshan, Guizhou	4.9–215	1.9–27.6
Wanshan, Guizhou	7.4–508	1.2–44
Wuchuan, Guizhou	6.0–113	3.1–13.4
Qingzhen, Guizhou	2.53–33.5	0.71–28.0

**Table 2** Environmental Hg concentrations in China: Heavily contaminated sites (Lin et al., 2012).

Location	Water ( $\text{ng L}^{-1}$ )	Soil ( $\text{mg kg}^{-1}$ dry wt)	Sediment ( $\text{mg kg}^{-1}$ dry wt)	Pollution sources
Second Songhua River	173–233		0.219–1.12	Chemical plant
Baihua Reservoir	6.9		0.26–38.9	Chemical plant
Wuhan	105.42–3,067.18	0.01–1.126	2.45–8.63	Chemical plant
Zhuzhou		1.28–2.89		Pb–Zn Smelting
Huludao		0.129–28.182	0.5–48	Zn Smelting and Chlor alkali
Guangxi		0.06–1.94		Pb–Zn mining
Beijing		0.22–76.27		Industrial
Baoji		0.197–2.105		Coal fire power plant
Xunyang	120–21,000	1.3–752	60–2,100	Hg mining
Chatian		0.087–424		Sb mining
Lanmuchang	24.8–7,020	8.4–610		Hg mining
Wuchuan	22–360	0.33–320		Hg mining
Hezhang	12–691	0.14–0.86		Artisanal Zn Smelting
Qingzhen		0.06–321.38		Chemical plant
Wenling		0.2–654.1		E-waste recycling
Wanshan	20–10,580	8.1–156	30.1–115	Hg mining and smelting
Wanshan	15–9,300	5.1–790	90–930	Hg mining and smelting
Wanshan	19–12,000	8–130	1.1–480	Hg mining and smelting



Yonghua Li at Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing (2013) describes a field survey of mercury pollution in environmental media and human hair samples obtained from residents living in the area surrounding the Chatian mercury mine (CMM) of southwestern China. Health risks of mercury to local residents were evaluated. Mine waste, and tailings in particular, contained high levels of mercury and the maximum mercury concentration was  $88.50 \mu\text{g g}^{-1}$ . Elevated mercury levels were also found in local surface water, paddy soil, and paddy grain, which may cause severe health problems. The mercury concentration of hair samples from the inhabitants of the CMM exceeded  $1.0 \mu\text{g g}^{-1}$ , which is the limit recommended by the US EPA. The average daily dose (ADD) of mercury for local adults and preschool children via oral exposure reached  $0.241$  and  $0.624 \mu\text{g kg}^{-1}$  body weight per day, respectively, which is approaching or exceeds the provisional tolerable daily intake. Among the three oral exposure routes, the greatest contributor to the ADD of mercury was the ingestion of rice grain. Open-stacked mine tailings have resulted in heavy mercury contamination in the surrounding soil, and the depth of appreciable soil mercury concentrations exceeded 100 cm.

Sai Liang at Tsinghua University, Beijing and coworkers (2013) studied the drivers of mercury emissions in China from 1992 to 2007. Mercury emissions in China have increased by 164% during 1992– 2007. They examined the underlying drivers and their contributions to the change of mercury emissions. Results show that changes in per capita GDP and GDP composition led to increased emissions which offset the reduction of emissions made possible by technology-induced decrease of mercury emissions intensity and changes in final demand mix. In particular, changes in final demand mix caused decreasing mercury emissions from 1992 to 2002 and increasing emissions from 2002 to 2007. Formation of fixed capital was the dominant driver behind the increase of mercury emissions, followed by the increasing urban population and net exports. The authors claim that such a systems-based examination of socioeconomic drivers for China's mercury emission increase is critical for emission control by guiding policy-making and targets of technology development.

Quan-Ying Cai at the Agricultural University, Guangzhou and coworkers (2013) studied the heavy metal concentrations of soil and dust samples from roadside, residential areas, parks, campus sport grounds, and commercial sites in Guangzhou, South China. Elevated heavy metal concentrations were found in urban soils and dusts in Guangzhou, especially for Cd, Pb, and Zn. Mean concentrations in urban dusts were remarkably higher compared to those in urban soils. Individual heavy metals behaved in a different way in roadsides, residential areas, parks, and sport grounds. Eighty-nine percent of park soil and all residential area soils were classified as lowly–moderately polluted; 86 % of roadside soils and 91 % of sport ground soils exhibited a moderate integrated pollution index, while all dusts were classified as highly polluted.

Changsheng Qu et al. (2012) presented a procedure for health risk assessment of heavy metal pollution based on a U.S. Environmental Protection Agency model and using Monte Carlo simulation techniques. A case study was conducted in the Qixia lead and zinc mining area in Jiangsu province. Based on the magnitude of heavy metal contamination in the mine factory, vicinal Qixia scenic site and village, the potential health risk calculated for a lifetime of exposure (through ingestion and dermal contact) was determined as the cumulative carcinogenic and non-carcinogenic risk for workers, tourists, and local residents (including children and adults), respectively. The risk



assessment indicated that the carcinogenic risk is not significant. However, Pb poses a significant cumulative non-carcinogenic risk, which tends to be serious for workers. Additionally, local children are more vulnerable than adults to the risks associated with heavy metal contamination. Accordingly, risk alleviation and preventive measures should be taken, especially for children and workers.

#### **4 Unconventional natural gas – an emerging problem?**

The use of unconventional gas, in particular shale gas will according to some analysts cause an energy revolution. It seems relevant to mention this here since there are ongoing projects both in Jiangsu and Guizhou provinces (Gao, 2012; Zhao et al., 2013).

Gao (2012) writes that although various sources have estimated that China has one of the largest technically recoverable unconventional gas resource bases in the world, very little exploration has been carried out to confirm its detailed characteristics and productivity capacity. It should therefore be emphasized that, despite a potentially larger resource base, estimates of how much can be produced and at what cost level may change significantly when further assessments are conducted because the unconventional gas industry, and especially the shale gas sector, is still in its infancy.

Gao also writes that environmental challenges to unconventional gas have so far not been considered a significant issue in China in contrast to European countries which have raised concerns about the potential damage from intensive drilling and fracturing.

Problems and questions related to unconventional gas production are numerous. Yunhua Chang et al. (2012) write that China is now embarking upon substantial development of shale gas extraction but the question of major public concern is whether or not the Chinese government will try to learn from the US experience not only to benefit from the new engineering techniques but also to minimize the negative impacts of this technology on environmental and human health. Further, they write that more data have recently emerged in North America: (i) fracturing requires tens of million liters of water; and the threat of associated damage such as water pollution and earthquakes has become clearer; (ii) using Life Cycle Assessment, leakage of methane gas from the fracking process has been estimated to form a greater carbon footprint than coal or conventional natural gas in some studies; (iii) shale gas extraction has negatively affected local air quality in some regions as a result of the release of nitrogen oxides (NO<sub>x</sub>) and volatile organic compounds (VOCs), two air pollutants with significant respiratory and cardiac health effects.

Especially the methane leakage is causing a heated debate. In a very recent paper by LaFranci et al., (2013) describe a more sophisticated method to estimate the leakages than commonly used. They claim that some of the earlier estimates are considerable overestimates. In a case study they estimated the leakage to 1.7 % of the total natural gas production in the region.

Brian G. Rahm et al. and coworkers (2013) suggested that nations, states, and regulatory agencies facing new, unconventional shale development recognize that pace and scale of well drilling leads to commensurate wastewater management challenges. They also suggest nations, states, and regulatory agencies implement wastewater reporting and tracking systems, articulate a policy for adapting management to evolving data and

development patterns, assess local and regional wastewater treatment infrastructure in terms of capacity and capability, promote well-regulated on-site treatment technologies, and review and update wastewater management regulations and policies.

It should also be noted that there is an ongoing discussion about the resources and economy of producing unconventional gas. Thus Hughes (2013) writes that the general predictions are wildly optimistic given the fundamentals of producing these hydrocarbons.

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## **Appendix 1. Some recent articles on environmental problems in China in blogs and mass media.**

*Politics of pollution: China's oil giants take a choke-hold on power*

<http://www.reuters.com/article/2013/02/02/us-china-pollution-oilcompanies-idUSBRE9110F620130202>

*Mainland editorial declares war on water pollution*

<http://www.scmp.com/news/china/article/1150179/mainland-editorial-declares-war-water-pollution>

*Worse Than Poisoned Water: Dwindling Water, in China's North*

<http://rendezvous.blogs.nytimes.com/2013/02/05/worse-than-poisoned-water-dwindling-water-in-chinas-north-and-west/>

*Chinese struggle through 'airpocalypse' smog*

<http://www.guardian.co.uk/world/2013/feb/16/chinese-struggle-through-airpocalypse-smog>

*China's environment ministry an "utter disappointment"*

<http://www.chinadialogue.net/article/show/single/en/5788-China-s-environment-ministry-an-utter-disappointment->

*Shanghai's dead pig story stretches back upstream*

<http://www.chinadialogue.net/article/show/single/en/5820-Shanghai-s-dead-pig-story-stretches-back-upstream>

*Air pollution tops the agenda at China's parliament*

<http://www.chinadialogue.net/article/show/single/en/5791-Air-pollution-tops-the-agenda-at-China-s-parliament>

*In China, Breathing Becomes a Childhood Risk*

[http://www.nytimes.com/2013/04/23/world/asia/pollution-is-radically-changing-childhood-in-chinas-cities.html?pagewanted=2&r=1&nl=todaysheadlines&emc=edit\\_th\\_20130423](http://www.nytimes.com/2013/04/23/world/asia/pollution-is-radically-changing-childhood-in-chinas-cities.html?pagewanted=2&r=1&nl=todaysheadlines&emc=edit_th_20130423)



*Illustration from chinadialogue.*



## **Appendix 2. The Awareness and Preparedness for Emergencies at Local Level (APELL) programme and Responsible Production Approach**

The APELL programme was developed under the auspices of United Nations Environment Programme (UNEP) in 1986 following various industrial accidents that harmed surrounding communities and the environment. The APELL Handbook was written to assist decision-makers and technical personnel in improving community awareness of industrial hazards and in preparing response plans for chemical accidents. ....Although the initial focus of the APELL programme was on chemical hazards, the methods and concepts used are also applicable to natural hazards. The programme's emphasis on integrated hazard and risk assessment and emergency planning is suitable for the development of comprehensive emergency plans that consider both industrial and natural risks, as well as some aspects of the interaction between the two.

As a part of the program a *UNEP APELL Multi-Hazard Training Kit For Local Authorities - For Community Vulnerability Reduction, Prevention, and Preparedness* has been developed. The Training Kit shall assist local authorities in increasing their preparedness and reducing their vulnerability in the face of natural and industrial disasters. It is based on UNEP's APELL process, which has been promoted in many communities around the world to increase preparedness for industrial accidents. It consists of 15 modules among them are: Multi-Hazard Matrix for Self Assessment, Risk Analysis, Emergency Planning, Risk Communication, Fixed Industrial Installations, Transportation of Hazardous Materials, and Small and Medium Sized Enterprises.

### *Assessment of the current situation*

Among the first steps in the APELL process is the collection of information and data regarding current hazards and the level of community preparedness for emergencies. This information can be used to identify strengths, abilities, and aspects of emergency preparedness that can be improved.

Potentially valuable information includes:

- **Identification**

of agencies with a potential role to play in emergency planning and response

- **Identification**

of hazards that could produce an emergency situation

- **The current state**

of community planning and coordination for emergency preparedness

- **Identification**

of existing points of contact and responsibilities of stakeholders in case of an emergency

- **List**

of available equipment and materials to be used in an emergency

- **The existing organizational structure**

for handling emergencies

- **The presence or absence**

of specialized emergency response teams for hazardous materials releases

- **The current state**

of the emergency transportation network, including evacuation

routes and access roads

- **Procedures**

for protecting citizens in emergencies (i.e., asking them to remain indoors, respond to emergency sirens in a specific fashion, take shelter in designated buildings, etc.)

- **Establishment**

of a mechanism to enable responders to exchange information during emergencies

It should be noted that the list above is for indicative purposes only, and not all of this information will be available or applicable for a given community. The objective of this step is only to develop a good idea of what resources do or do not exist within the community, and does not imply that all the information above is required to begin creation of a plan

## **Ten Step Process for Improving Emergency Preparedness**

After the existing information has been gathered and reviewed, local authorities and the Co-ordinating Group should have a qualitative understanding of the community's ability to deal with an emergency. At this point, the following 10-step process can be used to increase emergency preparedness.

1. Identify emergency response participants and establish roles, resources and concerns
2. Evaluate risks and hazards that may result in an emergency situation
3. Have participants review existing emergency plans, identify weaknesses

4. Identify response tasks not covered by existing plans
5. Match tasks to resources available from identified participants
6. Make changes necessary to improve existing plans and integrate into overall emergency plan and gain agreement
7. Commit integrated plan to writing, obtain local government approvals
8. Educate participating groups about the integrated plan and ensure all emergency responders are trained
9. Establish procedures for periodic testing, review and updating of plan
10. Educate general community about the integrated plan

<http://www.unep.fr/scp/publications/details.asp?id=DTI/1289/PA>

<http://www.unep.fr/shared/publications/pdf/DTIx1289xPA-APELLMulti-HazardTrainingKit.pdf>

**A Framework for Chemical Hazard Management for Small and Medium Sized Enterprises. Responsible production handbook, see**

[http://www.unep.org/resourceefficiency/Portals/24147/scp/sp/saferprod/pdf/Responsible\\_Production\\_Brochure.pdf](http://www.unep.org/resourceefficiency/Portals/24147/scp/sp/saferprod/pdf/Responsible_Production_Brochure.pdf)

## 5 Appendix 3. Assessing results of Chinese Environmental policy

In a recent report Jing Wu at Institute of Real Estate Studies, Tsinghua University, and coworkers analyze incentives and outcomes of: China's environmental policy.

In the abstract they write that data from 2000 to 2009 show that spending on environmental infrastructure has visible positive environmental impact. However, city spending is strongly tilted towards transportation infrastructure. Investment in transportation infrastructure correlates strongly with both real GDP growth, a measure of tangible economic growth relevant to city-level Party and government cadres' promotion odds, and with land prices, which affect city governments' revenues from land lease sales. In contrast, city governments' spending on environmental improvements is at best uncorrelated<sup>3</sup> with cadres' promotion odds, and is uncorrelated with local GDP growth and land prices. These findings suggest that, were environmental quality explicitly linked to a cadre's chance of promotion, or were environmental quality to affect land prices substantially, city-level public investment in environmental improvement would rise.

Wu, J., Deng, Y., Huang, J., Morck, R., and Yeung, B., 2013. Incentives and outcomes: China's environmental policy. National Bureau of Economic Research. Cambridge, MA 02138, USA. <http://www.nber.org/papers/w18754>

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<sup>3</sup> In fact the correlation is significantly negative.



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