Danni Chen, Yuhuan Jia, Xiurui Guo*, Shuiyuan Cheng

Valuation of Health Benefit from the Air Quality Improvement in Beijing-Tianjin-Hebei and Surrounding Areas in 2020

Abstract: The Chinese government has defined the ambitious target of improving air quality during the 13rd FYP (Five-Year Plan). However, current knowledge of potential health benefits of air quality improvement remains insufficient. The paper aimed to evaluate the health impacts caused by the planning of air quality improvement in Beijing-Tianjin-Hebei (BTH) and surrounding areas by 2020, using the Poisson regression model. The results show that, the improvement in $PM_{2.5}$ levels in 2020 will result in substantial health benefits, for instance, 18,587 avoided premature deaths. The total economic value due to the decreased $PM_{2.5}$ concentration is 54.65 billion CNY, which is about 0.69% of GDP in 2013. And the health benefit is most massive in Beijing. The major health benefit is from the reduction of premature deaths and chronic bronchitis, which contribute to 88.63% of the total benefit. The results suggest that reduction of $PM_{2.5}$ concentration during the 13rd FYP in BTH and surrounding areas would benefit the public health substantially.

Keywords: air pollution control, health benefit, $PM_{2.5}$, BTH and surrounding areas.

1 Introduction

With the rapid economic growth in the past 30 years, China is suffering from severe air pollution, which caused an adverse impact on the health of residents, especially in mega-cities. It is proved that $PM_{2.5}$ is the representative air pollutant. A number of epidemiological studies have revealed that exposure to ambient $PM_{2.5}$ is associated with adverse health outcomes, especially mortality [1]. $PM_{2.5}$ -related premature deaths throughout the world have increased from 800,000 in 2004 to 3.2 million in 2010, with Asia accounting for 72% in 2010 [2].

The Beijing-Tianjin-Hebei (BTH) region, one of the most developed and densely populated areas in China, is experiencing serious air pollution and health damage [3].

*Corresponding author: Xiurui Guo, Key Laboratory of Beijing on Regional Air Pollution Control / College of Environmental & Energy Engineering, Beijing University of Technology, Beijing, 100124, China, E-mail: guoxiurui@bjut.edu.cn

Danni Chen, Yuhuan Jia, Shuiyuan Cheng, Key Laboratory of Beijing on Regional Air Pollution Control / College of Environmental & Energy Engineering, Beijing University of Technology, Beijing, 100124, China

Due to a large number of populations, even a slight decrease in $PM_{2.5}$ level in the future may lead to a substantial health benefit.

In order to address the severe particulate pollution, an action plan of Air Pollution Prevention and Control (APPC) was issued in 2013 [4], in which the target of specific $PM_{2.5}$ concentration was required to be achieved by 2017, such as the concentration in BTH region decreased by 25% compared to 2012. After that, MEP (Ministry of Environmental Protection of China) formulated the Implementation details of APPC in BTH and surrounding areas [5]. Considering that regional atmospheric pollution become increasingly serious, it would be more effective to take BTH and surrounding areas as a whole region to improve air quality. Related research [6] has shown that the transport among cross-city clusters outside BTH contributed 20%-35% of $PM_{2.5}$ emission in BTH. In fact, the deep mid- and long-term planning of air pollution control in BTH and surrounding areas is being drafted, in which the specific target of air quality improvement will be defined.

As we know, a critical and necessary component in the design and implementation of the air quality management policy is characterizing the impact on human health and the monetized benefits of air quality improvements [7]. The valuation of estimated health benefits would provide important information for the policymakers. Health impacts and benefits associated with air quality improvements have been studied by many researchers previously. Elena Boldo et al. estimated the benefits of implementing $PM_{2.5}$ control measures in Spain [8]. The results show that 1720 all-cause deaths in the over-30 age group and 1450 all-cause deaths in the 25–74 age group could be prevented with an average annual reduction of $0.7 \mu\text{g}/\text{m}^3$ in $PM_{2.5}$ levels. Richard et al. found that reducing the $PM_{2.5}$ exposure in Sydney in 2007 by 10% ($0.6 \mu\text{g}/\text{m}^3$) would result in about 650 fewer premature deaths, a gain of 3500 life-years and about 700 fewer respiratory and cardiovascular hospital visits over 10 years [9]. An increasing number of Chinese researchers began to focus on this subject in recent years. Zou et al. [10] and Cheng et al. [11] analyzed the variation of PM_{10} concentration over time and related health impacts in Beijing and China, respectively. Lina et al. projected that the annual mean $PM_{2.5}$ concentration decreasing by $20.41 \mu\text{g}/\text{m}^3$ in East China would generate at least 230 000 avoided deaths [12]. Ding et al. evaluated health benefit of emission control measures in Shanghai and found that the overall cost benefit of the improved air quality reached up to be 165 million CNY, with the avoided premature death contributing 90% of this figure [13].

This study aimed to obtain a better assessment regarding the health effects and the potential benefits of meeting the air quality targets in BTH and surrounding areas. The rest of this paper was organized as follows. In section 2, we introduced the methodology of our valuation and presented the data and variables. The results and discussions were presented in Section 3. We discussed the related uncertainties and limitations of this study in section 4. Finally, we drew our conclusions. The results would hopefully provide the impetus and scientific basis for relevant policy-making, and also enhance the public awareness of the health risk.

2 Methodology and Data

2.1 Study Area

The study area in this paper was defined as the BTH and surrounding areas, including Beijing, Tianjin and Hebei, Shanxi, Shandong, Henan and part of Inner-Mongolia. The BTH region is one of the most developed and densely populated areas in China. The Implementation details of APPC in 2013 defined BTH region and surrounding area as the focus of air pollution control in Northern China. The deep mid- and long-term planning of air pollution control in BTH and surrounding areas also defined this area as the foremost area to improve the air quality.

2.2 Method of Valuing the Health Benefit

1. *Assessment of health effects:* Based on the relative risk (RR) model in the form of a Poisson regression from the epidemiological studies, the log-linear exposure-response function below has been widely used to estimate the health impacts of air pollution [14].

$$I = I_0 \cdot \exp[\beta \cdot (C - C_0)] \quad (1)$$

$$\Delta I = I - I_0 = I \cdot \{1 - 1/\exp[\beta \cdot (C - C_0)]\} \quad (2)$$

where I is the mortality (morbidity) rate of the population exposed in the control year situation with concentration C and I_0 is the mortality (morbidity) rate of the population exposed in the baseline year situation with concentration C_0 . β is the coefficient of association between air pollution concentration and mortality (morbidity). By multiplying the lessened mortality (morbidity) rate (ΔI) with the population, the number of avoidable deaths (diseases) associated with improved air quality can be calculated.

2. *Monetization of health effects:* Monetized health effects provide quantified economic benefits to policy-makers for evaluating air pollution control strategies. Using the unit value for each health endpoint, the reduced health impact can be monetized to the health benefit as follows:

$$TV = \sum V_i \cdot E_i \quad (3)$$

where E_i is the impact for health endpoint i , V_i is the unit economic value of health endpoint i , and TV is the sum of economic change of health endpoints.

Three monetization methods including willingness to pay (WTP), cost of illness (COI), and human capital (HC) approach are commonly used in valuating environmental health. In general, WTP is the most widely preferred used method

because it takes intangible losses into account, such as pain, suffering and other adverse effects due to illness [15].

In this case, we calculated benefits of avoidable premature death using the VSL (value of statistical life) method, which represents the sum of what individuals would pay for reductions in their risk of dying that sum to saving one statistical life [16]. The unit value is generated from the original value for studies in reported city (Beijing) multiplied by the annual disposable income ratio per capita between Beijing and the source city [17]. Then the unit value for various currency years is adjusted to the year 2013 by multiplying by the annual consumer price index (CPI) in China.

For other health endpoints, we measure the benefits using the COI approach, formula is as follows:

$$C_i = C_{pi} + GDP_p \times T_{Li} \quad (4)$$

where C_i is the unit of health benefits of health endpoint i , C_{pi} is medical resources caused by health endpoints i , GDP_p is the daily mean value of per capita GDP, T_{Li} is the loss of working time.

2.3 Data

1. *Improved $PM_{2.5}$ level in 2020:* We collected the mean yearly $PM_{2.5}$ concentration in the base year of 2013 from Environment Quality Bulletin of each city. According to Ecological Environmental Protection Planning for Coordinated Development of BTH [18] and the 13rd FYP of each city or province, the mean $PM_{2.5}$ target concentration of each city in 2020 was designed. We assumed that the mean $PM_{2.5}$ concentration will be controlled within $55 \mu/m^3$ in Beijing and Tianjin, about $60 \mu/m^3$ in Shijiazhuang, Tangshan, Langfang, Jinan and Zhengzhou, about $70 \mu/m^3$ in Baoding, Hengshui and Xingtai. And we also assumed that $PM_{2.5}$ concentration in Zhangjiakou, Chengde and Hohhot be controlled within the present Grade II annual $PM_{2.5}$ air quality standard (GB 3095-2012).
2. *Population projection:* There are many factors influencing the urban population scale, and some of the factors are not completely sure. Grey models prediction method can forecast the system containing known information and uncertain factors. By filtering random quantity, the Grey model turns the raw data into orderly sequence and analyzes the regularity of changes through time. Because of its less information requirement and higher precision, the Grey model is suitable for complex and difficult prediction. In this case, we use GM (1, 1) to project the population in 2020.
3. *Selection of ERCs and mortality/morbidity rates:* The health endpoints were selected based on the literature [19]: (1) those registered in Chinese cities and classified by ICD-10 (International Classification of Diseases) code; (2) those published in exposure-response studies; and (3) statistical data such as mortality/

morbidity incidence rates. Accordingly, we selected the health endpoints of mortality for respiratory and cardiovascular disease, hospital admissions for respiratory and cardiovascular disease, pediatric and internal outpatient visits, chronic and acute bronchitis, and asthma attack. As exposure-reaction coefficients (ERCs) establish the quantified relationship between the air pollution and health effect, selecting reasonable exposure-reaction coefficients is a key link in health effect assessment. In this case, those ERCs (Table 1) were selected through a comprehensive literature search to assess health impact. The annual incidence rates for each chosen health endpoint (in 2013) were obtained from the China health and family planning yearbook 2014 [20].

Table 1: ERCs and Annual Baseline Incidence Rates for Each of Health Endpoints

Health endpoints	β (95% CI)	Incidence rate in 2013
Mortality, cardiovascular	0.00053[21] (0.00015, 0.0009)	0.0028[20]
Mortality, respiratory	0.00143[21] (0.00085, 0.00201)	0.00076[20]
Hospital admission, cardiovascular	0.00068[21] (0.00043, 0.00093)	0.02[20]
Hospital admission, respiratory	0.00109[22] (0, 0.00221)	0.0099[20]
Outpatient visits, pediatric	0.00056[22] (0.0002, 0.0009)	0.12[20]
Outpatient visits, internal	0.00049[22] (0.00027, 0.0007)	0.28[20]
Chronic bronchitis	0.0075[22] (0.00025, 0.0135)	0.00148[19]
Acute bronchitis	0.0079[22] (0.0027, 0.013)	0.038[22]
Asthma attack	0.0021[22] (0.00145, 0.00274)	0.0094[22]

3 Results and Discussions

3.1 Physical Health Impacts

Table 2 listed the results of avoided health impacts from the strict $PM_{2.5}$ quality targets in BTH and surrounding areas in 2020. We conducted a statistical uncertainty analysis, but it is not comprehensive because we only calculated the 95% confidence interval for each health endpoint.

Table 2: The Health Impact from the Decrease of $PM_{2.5}$ Concentration in BTH and Surrounding Areas in 2020

Health endpoints	Health impact (thousand case)	95% CI
Mortality, cardiovascular	10907	3122-18317
Mortality, respiratory	7680	4645-10611
Hospital admission, cardiovascular	96678	61588-131252
Hospital admission, respiratory	78046	0-153108
Outpatient visits, pediatric	550739	198797-876312
Outpatient visits, internal	1132726	628135-1608423
Chronic bronchitis	67799	2778-104568
Acute bronchitis	1814050	716618-2617559
Asthma attack	140305	98746-179687

Improvement in $PM_{2.5}$ levels in 2020 was estimated to result in 18,587 avoided premature deaths, 1.75×10^5 avoided hospital admissions for cardiovascular and respiratory disease, 1.68×10^6 avoided outpatient visits, 67,799 avoided chronic bronchitis, 1.81×10^6 avoided acute bronchitis, and 1.40×10^5 fewer cases for asthma attack, across the BTH and surrounding areas. One can see from the table that avoided deaths are much fewer than hospital admission cases and outpatient visits. Given the same population in 2020 we projected previously, the main reason for this difference lies in the diverse ERCs and the incidence rate in calculation.

Health impacts of each city are summarized in Fig. 1. Obviously, health effects due to improvements in $PM_{2.5}$ levels in Shijiazhuang, Beijing and Tianjin are larger than that in other cities. One reason is the rapid urbanization that these cities have experienced in recent decades, which led to a constantly growing population exposed to and affected by $PM_{2.5}$ pollution. Another reason is the extent of $PM_{2.5}$ concentration reduction. Compared to 2013, the $PM_{2.5}$ concentration in Shijiazhuang, Beijing and Tianjin have decreased by 59.6%, 38.5% and 44.8%, respectively, relatively higher than other cities.

Figure 1: Health impact from air quality improvement in BTH and surrounding areas

3.2 Economic Valuation of Physical Health Impacts

Combining the health impacts we calculated above and the unit economic value of each health endpoint, we estimated the health benefits of improved $PM_{2.5}$ levels (Table 3). Based on this strategy, the total economic value due to the decreased $PM_{2.5}$ concentration was estimated 54.65 billion CNY, about 0.69% of GDP in 2013. The health benefits were mainly from the reduction in premature deaths and chronic bronchitis, which contributed to 88.63% of the total benefit. Although the avoided cases of premature deaths and chronic bronchitis are much fewer than other health endpoints, their much higher unit values result in the larger benefits.

Table 3: The Economic Benefit from the Decrease of $PM_{2.5}$ Concentration in BTH and Surrounding Areas in 2020

Health endpoints	Benefit (million CNY)	95% CI
Mortality, cardiovascular	13066.33	3737.13-21963.24
Mortality, respiratory	9020.62	5449.29-12477.74
Hospital admission, cardiovascular	1179.16	750.73-1601.78
Hospital admission, respiratory	928.68	0.00-1826.36
Outpatient visits, pediatric	208.09	75.05-331.37
Outpatient visits, internal	439.01	243.31-623.71
Chronic bronchitis	26348.57	1063.00-41083.43
Acute bronchitis	3277.20	1280.73-4772.87
Asthma attack	184.33	129.54-236.40

Health benefits of each city are summarized in Fig. 2. Obviously, Beijing gained the largest economic benefits, which reached up to 10.53 billion CNY. The health benefit of Beijing is followed by that of Tianjin and Shijiazhuang, which account for 8.17 billion and 6.50 billion, respectively. This reflects that we can gain enormous health benefits if we implement strict air pollution control measures in the BTH region.

Figure 2: Health benefit from air quality improvement of each city in BTH and surrounding areas

We also calculated the GDP proportion and health benefits per capita of each city (Fig. 3). The highest estimated economic gain of health impacts is expected to be 618.67 CNY per capita in Shijiazhuang, which is about 1.34% of GDP in 2013. The second is Jinan, where the estimated economic gain is expected to be 520.95 CNY per capita and about 0.7% of GDP in 2013.

Figure 3: Per capita health benefits and GDP proportion of each city in BTH and surrounding areas

In summary, these numerical estimations indicated that improving air quality will have a positive impact on residents' health and the development of social economy. Our results are consistent with other studies in current literature. A Guangzhou study [13] found that by decreasing $PM_{2.5}$ concentration by $3.5 \mu\text{g}/\text{m}^3$, health benefit was estimated to be 165 million CNY, 0.02% of GDP in Guangzhou in 2010. Our result seemed a little bit higher than it, since the improvement of $PM_{2.5}$ level was more significant in our study. Lina et al. [12] conducted a study in East China found that at least 230,000 deaths could be avoided by a large reduction in $PM_{2.5}$ concentration ($20.41 \mu\text{g}/\text{m}^3$) by 2030. Another study [23] conducted in China found that a control investment of 101.8 billion USD (0.79% of GDP) and a gain of 1.17% of China's GDP from improving $PM_{2.5}$ pollution are projected in 2030. Though these studies had different reduction of $PM_{2.5}$ concentration, population sizes, and characteristics, they all suggested that significant health benefits could be gained by effective air pollution control measures.

4 Uncertainties and Limitations

The data of this case study included air quality data, exposed population, ERCs, mortality/morbidity incidence rates, and monetary valuation functions. Each of these data can affect the final results to different extents. The accuracy of results is interpreted cautiously in the following discussion.

Air quality data and mortality/morbidity incidence rates were obtained from reliable data sources—the national/local statistics institute. In the process of population projection, we use the Grey models, which can accurately predict the population over the next five years, relatively. The validity of health impact results depends basically on the selection of ERCs. Compared with the foreign literature, there are few studies on the relationship between $PM_{2.5}$ and health impact for Chinese cities. This study selected domestic ERCs and considered regional differences as much as possible. Meanwhile, in the evaluation process, the 95% CI of health outcomes were used to reflect the error range.

Furthermore, uncertainty exists when using different unit values for monetization. The domestic studies and statistical data on the unit economic value for each health endpoint are relatively insufficient. Considering unit value varies greatly in the different regions and is generated by different monetization methods, we try our best to achieve accurate measurements. In this case, we select VSL to measure health benefits of avoided premature deaths, which can reflect people's willingness. And we obtain the unit value for each city in BTH and surrounding areas by adjusting result of Beijing with the annual capita disposable income

5 Conclusions

In summary, we can conclude that a reduction of $PM_{2.5}$ concentration in the BTH and surrounding areas could cause significant health benefit. Improvements in $PM_{2.5}$ levels due to the planning were estimated to result in 18,587 avoided premature deaths, 1.75×10^5 avoided hospital admissions for cardiovascular and respiratory disease, 1.68×10^6 avoided outpatient visits, 67,799 avoided chronic bronchitis, 1.81×10^6 avoided acute bronchitis, and 1.40×10^5 fewer cases for asthma attack, across the BTH and surrounding areas. Based on this estimation strategy, the total economic value due to decreased $PM_{2.5}$ concentration is 54.65 billion CNY, which is about 0.69% of GDP in 2013. The major health benefit is from the reduction in premature deaths and chronic bronchitis, which contributed to 88.63% of the total benefit.

Acknowledgment: This study was supported by the Natural Sciences Foundation of Beijing (Project No. 9152001) and the Ministry of Environmental Protection Special Funds for Scientific Research on Public Causes (No. 201409007). Many thanks for the anonymous reviewers for their valuable comments.

References

- [1] Hoek G., Krishnan M.R., Beelen R., Peters A., Ostro B., Brunekreef B., et al. Long-term air pollution exposure and cardio-respiratory mortality: a review[J]. *Environ. Health*, 2013, 12: 43.
- [2] Apte J.S., Marshall J.D., Cohen A.J., Brauer M. Addressing global mortality from ambient $PM_{2.5}$ [J]. *Environ. Sci. Technol.*, 2015, 49: 8057–8066.
- [3] Zhang L., Chen X., Xue X., Sun M., Han B., Li C., et al. Long-Term Exposure to High Particulate Matter Pollution and Cardiovascular Mortality: A 12-Year Cohort Study in Four Cities in Northern China[J]. *Environ. Int.*, 2014, 62: 41–7.
- [4] State Council, The notice on the action plan of the Air Pollution Prevention and Control from the State Council (in Chinese). http://www.gov.cn/zwggk/201309/12/con-tent_2486773.htm. Accessed 12 March 2016.
- [5] Ministry of Environmental Protection of China, Implementation details of the action plan of Air Pollution Prevention and Control (APPC) in Beijing-Tianjin-Hebei and surrounding areas. Ministry of Environmental Protection of China (in Chinese). http://www.mep.gov.cn/gkml/hbb/bwj/201309/t20130918_260414.htm. Accessed 12 March 2016.
- [6] Wang Z., Li J., Wang Z., Modeling study of regional severe hazes over Mid-Eastern China in January 2013 and its implications on pollution prevention and control[J]. *Science China: Earth Sciences*, 2014, 57: 3–13, (in Chinese).
- [7] National Academy of Sciences (NAS), Improving health in the United States: the role of health impact assessment[M]. Washington, DC: The National Academies Press, 2011.
- [8] Boldo E., Linares C., Health impact assessment of a reduction in ambient $PM_{2.5}$ levels in Spain[J]. *Environment International*, 2011, 37: 342–348.
- [9] Broome R.A., Fann N., The health benefits of reducing air pollution in Sydney, Australia [J]. *Environmental Research*, 2015, 143: 19–25.
- [10] Zou W., Zhang S., Economic Valuation of Health Impact of PM_{10} Pollution in Beijing from 2001 to 2006[J]. *Chinese Journal of Population, Resources and Environment*, 2010, 2: 68–74.

- [11] Cheng Z., Characteristics and health impacts of particulate matter pollution in China (2001-2011) [J]. *Atmospheric Environment*, 2013, 65:186-194.
- [12] Madaniyazi L., Projecting Fine Particulate Matter-Related Mortality in East China[J]. *Environ. Sci. Technol.* 2015, 49: 11141–11150.
- [13] Ding D., Evaluation of health benefit using BenMAP-CE with an integrated scheme of model and monitor data during Guangzhou Asian Games[J]. *Environ. Sci.*, <http://dx.doi.org/10.1016/j.jes.2015.06.003>
- [14] Gao J., Yuan Z., Liu X., Xia X., Huang X., Dong Z. Improving air pollution control policy in China-a perspective based on cost-benefit analysis[J]. *Sci. Total Environ.*, 2016, 543: 307–314.
- [15] Robinson L.A., (2011) Valuing the health impacts of air emissions. In: Nriagu, J.O. (Ed.), *Encyclopedia of Environmental Health*[M], Burlington: Elsevier, 2011: 619–627.
- [16] Pope C.A. III, Cropper M., Coggins J. & Cohen A. Health benefits of air pollution abatement policy: Role of the shape of the concentration–response function[J]. *Journal of the Air & Waste Management Association*, 2015, 65:5, 516-522.
- [17] Huang D., Xu J., Zhang S., Valuing the health risks of particulate air pollution in the Pearl River Delta, China[J]. *Environ. Sci. Pol.*, 2012, 15: 38–47.
- [18] Ministry of Environmental Protection of China, Ecological Environmental Protection Planning for Coordinated Development of Beijing-Tianjin-Hebei region. Ministry of Environmental Protection of China (in Chinese). http://www.gov.cn/xinwen/201512/30/content_5029650.htm. Accessed 20 May 2016.
- [19] World Bank, China SEPA, Cost of pollution in China. Economic estimates of physical damages. http://siteresources.worldbank.org/INT/TEAPREGTOPENVIRONMENT/Resources/China_Cost_of_Pollution.pdf. Accessed 31 March 2016.
- [20] National Health and Family Planning Commission of China, China health and family planning yearbook 2014. The Minister of Health of China, Beijing. <http://tongji.cnki.net.libproxy.bjut.edu.cn/kns55/Navi/Ye arBook.aspx?id=N2014120147&floor=1>. Accessed 22 March 2016.
- [21] Xie Y., Chen J., Li W., An Assessment of PM_{2.5} Related Health Risks and Impaired Values of Beijing Residents in a Consecutive High-Level Exposure during Heavy Haze Days[J]. *Environmental Science.*, 2014, 35(1): 1-8.
- [22] Huang D., Zhang S., Health benefit evaluation for PM_{2.5} pollution control in Beijing-Tianjin-Hebei region of china[J]. *China Environmental Science*, 2013, 33(1): 166-174.
- [23] Xie Y., Dai H., Dong H., Economic Impacts from PM_{2.5} Pollution-Related Health Effects in China: A Provincial-Level Analysis[J]. *Environ. Sci. Technol.*, 2016, 50: 4836–4843.