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Environmental, health and economic benefits of using urban updraft tower to govern urban air pollution

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ABSTRACT

Air quality in the Chinese urban areas has been worsened severely in the past few years and serious haze problems have been experienced frequently. Here, filter-contained urban updraft tower (FUUT) is proposed to be an approach to govern the air pollution and generate electricity. Due to buoyancy with the help of urban heat island (UHI), the air with air pollution can flow into the tower, and the air pollution mainly being particulate matters less than 10 μm in diameter (PM_{10}) is then intercepted by the filter. FUUTs are assumed to be introduced in the typical metropolitan city in China, i.e., Beijing in 2012, and then the methods to predict the performance and estimate the health and economic benefits are established. Under these conditions, the design value of air velocity in FUUT is 5.00 m/s. The initial yearly mean PM_{10} concentration is 109 μg/m^3, and the reduction is 6.72 μg/m^3 in the first year brought by one FUUT, which contributes to the reduction in premature mortality to 227.8 and in respiratory hospital admissions to 1051.9 and the equivalent economic benefits estimated to be 211.48 million RMB yuan in total. It would take 3.45, 7.81, and 13.22 years to meet the second- and first- class China national ambient air quality standards (CNAAQS), and the standard regulated by the World Health Organization (WHO) guideline. Furthermore, the economic capability analyses of FUUT, including the levelized electricity cost (LEC) and return on investment (ROI) on different factors, are also conducted.

1. Introduction

In the past decades, with the boosted growth of the economy, China has suffered from environmental pollution. The livelihood and health of people in this country have been seriously affected by environmental pollution and the resultant economic losses were estimated to reach more than 100 billion US dollar every year [1].

Environmental protection is one of Chinese basic national policies. Since the environment in China is facing more and more serious challenges, the investment on environmental protection has been increasing. The total amount of investment on environmental protection was 16.62 billion RMB yuan in the sixth Five-Year Plan (from 1981 to 1985) and became 2160 billion RMB yuan in the eleventh Five-Year Plan (from 2006 to 2010), while the investment share of the total GDP increased from 0.51% to 1.44% (Table 1) [2,3].

Although the Chinese government has attached importance to the environmental problems and a series of standards, policies and laws about air pollution have been put in place in China, air quality especially in the urban areas has been worsened severely and air pollution events have occurred frequently. Only one percent of the five hundred biggest Chinese cities have met the World Health Organization (WHO) air quality standards and seven of the world's top ten most polluted cities are in China [4]. The World Bank (WB) estimated the health costs associated with atmospheric pollution in China in 2003 to be 1.2% of China's GDP by using the cost of illness (COI) approach or 3.8% by using the willingness to pay (WTP) approach [1]. In the recent years, haze has become a major livelihood issue, and often troubles people in urban areas. Typically, the number of haze days in China in 2013 was 35.9, which was 18.3 more than that in 2012 and reached the maximum over the past 52 years [5]. In January 2013, a hazardous haze choked northern and eastern China covering 1.4 million km^2, and affected more than 800 million people. In Beijing, this terrible haze lasted for 25 days of January affecting more than 20 million citizens directly [6,7]. The resultant direct cost on health and transportation due to this haze event was estimated to be 23 billion RMB yuan [8]. Haze in China is becoming such a tough issue

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Table 1
Historical investment on environmental protection in China.

Five-Year Plan	Period	Investment on environmental protection (billion RMB yuan)	Total GDP (billion RMB yuan)	Investment shares of total GDP (%)
Sixth	1981–1985	16.62	3240.18	0.51
Seventh	1986–1990	47.64	7303.67	0.65
Eighth	1991–1995	130.66	19303.05	0.68
Ninth	1996–2000	351.64	42344.36	0.83
Tenth	2001–2005	839.51	70877.38	1.18
Eleventh	2006–2010	2162.00	150138.90	1.44

that has to be in control, and it is even more horrible than the SARs epidemic [6,9].

Particulate matters (PMs), including $PM_{2.5}$ and PM_{10}, are found to relate tightly to the formation of the haze [10]. $PM_{2.5}$ made a major contribution to the serious haze in January 2013 [11]. As verified by epidemiological studies, particulate matters are also the most fatal to human health among the common atmospheric pollutants [12]. The research by the WHO for 3211 cities worldwide indicated that the number of premature mortality caused by outdoor PM_{10} was about 799,000 in 2000, and 487,000 of them took place in the Asian-Pacific region [13,14]. In China, as the result of the increase in the urban population exposed to air pollution, the impact of PM_{10} on health and economy became more enormous. According to statistics, although the annual mean PM_{10} concentration decreased from 116.4 μg/m^3 (in the year 2001) to 85.3 μg/m^3 (in the year 2011), with the annual decrease rate of 3 μg/m^3, the total number of premature deaths increased from 41,800 to approximately 514,000 [15]. Moreover, the decrease rate has obviously slowed down and the ratio of $PM_{2.5}$ concentration to PM_{10} concentration becomes higher in the recent years. The evaluation on health losses caused by $PM_{2.5}$ in China is scanty. A report [16] jointly released by the organization of Greenpeace and the Peking University estimated the losses in four typical cities, i.e., Beijing, Shanghai, Guangzhou and Xi'an. It turned out that the total number of premature deaths caused by $PM_{2.5}$ in the four cities was 7770 in 2010 and 8572 in 2012 and led to the economic losses of 6.17 billion RMB yuan in 2010 and 6.8 billion RMB yuan in 2012, respectively.

The problems with severe air pollution in urban areas of China owing to industrialization are similar to – or worse than – the ones in developed countries in the last century. For example, the famous great smog event occurred in London in December 1952 [17,18]. The main pollutants are sulphur dioxide (SO_2) and dark smoke, mainly created by burning coals. The event led to the increase in deaths of about 4000 [17,18]. The UK government took a serials of measures to abate the air pollution. More monitoring stations were built and extensive legislation was introduced, the most important being the Clean Air Act of 1956 [19]. The measures for controlling smoke include prohibition of dark smoke from chimneys, and requirement that new furnaces shall be so far as practicable smokeless. The measures for controlling grit and dust from furnaces include requirement that grit and dust from furnaces shall be minimized, requirement that new furnaces shall be fitted with plant to arrest grit and dust, measurement of grit and dust emitted from furnaces, furnishing information about furnaces and fuel consumed, and sufficient height of chimneys, and so on; additionally, setting smoke control areas is another measure [20]. The concentrations of the two main pollutants underwent a long-term decrease for several decades [11,21].

Since 1973, EU paid great attention to environmental pollution. In order to control the aggravating air pollution, EU introduced the legislation to limit the emissions of air pollution from pollution sources, for example, the industrial plants, the coal-fired power stations, the solid waste combustion, and transportation [11,22]. In the USA, air quality degraded quickly after the industrial revolution again, mainly resulting from coal burning. The famous air pollution events in the USA include the five-day episode in Donora, PA in 1948, several dangerous episodes in New York in 1960s, and many pollution episodes due to the increase in industry and automobile usage in Los Angeles from 1960-70s. These air pollution events gave rise to passing the Clean Air Act of 1970, which empowered the USA federal government to establish standards of emissions to the atmosphere [23]. Nevertheless, based on the above measures, it still took very long periods of several decades to make the air quality improved to approach the standards.

In September 2013, the Action Plan on Prevention and Control of Air Pollution, which included ten measures, was issued by Chinese government and about 1.75 trillion RMB yuan would be invested to prevent and control air pollution in China [24,25]. However, the haze events have occurred frequently till now (Fig. 1).

Similar to the measures taken by the developed countries since 1950s, the measures will not be obviously helpful in improving Chinese air quality in the next few years, but beneficial to essential alleviation of Chinese air quality in the long future. In addition, the need to balance economic growth and environmental protection determines a long-process challenge for improving air quality significantly. It is very difficult to alter the situation that Chinese cities are densely populated and the people are choked by dense haze in the next few years unless special effective measures to alleviate the haze problem are taken.

Some bold measures have been proposed for governing the haze in China. Artificial rain was proposed to reduce the air pollution, but the effect was yet suspected [28,29]. A method of spraying water into the atmosphere (like watering gardens) to scavenge air pollution have been proposed [29,30]. Six urban wind passages was another plan to channel wind to blow away air pollution and disperse the haze [29]. However, these methods were thought not to be practical, because they may be too great undertaking and miraculous for megacities and of high cost or of high energy consumption, besides they may not effectively disperse the haze [29].

Zhou et al. [29] proposed solar updraft towers (also called solar chimneys) to effectively disperse dense haze over cities to higher and farther distance. The device operates in the metropolis due to buoyancy with the help of urban heat island (UHI) effect instead of the traditional solar collector effect, which was called urban updraft tower (UUT) instead of solar updraft tower in this paper. This approach of UUT is of

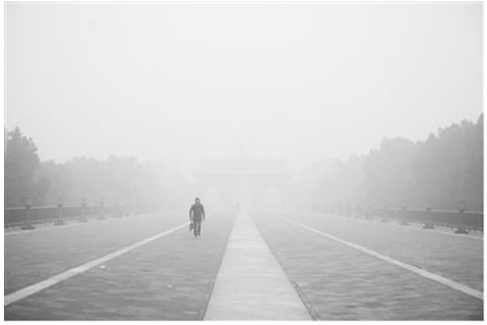

Fig. 1. Temple of Heaven Park shrouded in a heavy haze, Beijing, December 6, 2015 [26]. The haze settled over Beijing since October 2015. Nine warnings of serious haze days from October 5 to December 14 in Beijing were issued. Most seriously, the $PM_{2.5}$ concentration was over 900 μg/m^3 in some regions of Beijing in October 30 [27].