

Impacts and mitigation of climate change on Chinese cities

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China is experiencing rapid urbanization. The development of cities may be hampered by reduced access to resources and energy as well as natural disasters caused by climate change. In addition, the emission of greenhouse gases from construction and development may accelerate global climate change. In this review, we examine the effects of climate change and present possible solutions for Chinese cities. We also consider the development of low carbon cities as one option for reducing the emission of greenhouse gases. Finally, we discuss several issues related to climate change that merit further consideration.

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Introduction

Climate change is one of the most pressing global environmental issues [1,2]. Climate change has a significant impact on the environment and is expected to increase the frequency and intensity of natural disasters and create new hazards (e.g., rise in sea level) [3]. As densely populated and resource-intensive regions, cities will experience the enhanced heat island effect, flooding or water scarcity as a result of extremes in rainfall, and severe storms may devastate entire settlements [4,5]. Cities in developing countries are expected to face more severe challenges due to poverty and/ or the lack of urban facilities [6].

Although several studies have illustrated that in most cases per capita emissions from cities are lower than the average for the countries in which they are located [7,8], because of economies of scale and reduce costs of mitigation, cities can play an important role in reducing Greenhouse Gas (GHG) emissions [9]. With their concentration of industries, refrigeration plants, automobiles, stoves, etc., cities make a considerable contribution to green-

house gas emissions, one of the primary causes of global warming and climate change [10]. Roughly 75% of the world's carbon dioxide and 26% of direct greenhouse gas emissions come from urban areas [11,12].

Moreover, the proportion of gas emissions from cities is increasing continuously because of irrational urbanization. In many parts of the world, urban sprawl and energy-intensive development patterns are still seen as pathways to urbanization [13,14]. However, they rapidly increase greenhouse gas emissions and promote climate change.

China has become one of the most crowded and vulnerable countries in the world. The country is experiencing urbanization of unprecedented scope [15]. On the basis of remote sensing data, the urbanized areas of China increased by $8.25 \times 10^5 \text{ h m}^2$ in the 1990s as urban development gained momentum in western China [16,17]. By 2009, China's urbanization rate had reached 46.6% [18]. The recent *City Development Report of China 2009* published by the Association of Chinese Mayors (ACM) presents data indicating that 50% of China will be urbanized by 2020 and 75% of the population will live in urban areas by 2050 [18]. One inevitable result of this process is that more greenhouse gas emissions will be generated because energy consumption per capita in cities is about 3.5 times of that in rural areas in China.

Chinese cities are seemingly doomed to be at high risk because of climate change [19]. According to *China's National Assessment Report on Climate Change*, surface temperature in China will continue to rise. The average temperature will increase by 2.3–3.3°C by 2050 and by 3.9–6.0°C by 2100. Annual precipitation in China will increase by 5–7% by 2050 and by 11–17% by 2100 due to climate change [20]. However, this will not necessarily reduce water shortage problems. Rather, we will face more, and more serious, extreme weather events such as droughts and deluges [21]. The mean annual runoff will decrease by 2–10% in drought prone northern China while it will increase by more than 20% in flood prone southern China. The Yangtze River valley, China's largest urbanized zone, will continue to be the area experiencing the most irregular precipitation. Hazards such as unexpected floods, hail, and droughts will affect infrastructure and the urban population. In addition, rapid urbanization, high population densities, and poverty will aggravate the situation over the next few decades, particularly in urban centers.

The goal of this paper is to review recent research regarding how to mitigate the effects of climate change on Chinese cities. Scientists have made considerable

recent advances in this field. The low carbon city is a new model that was first presented by Chinese scholars. It is highly valued by scholars around the world.

Climate change is an irreversible process in the short-term and the most suitable action to address climate change should be taken to “adapt” to these changes [22••]. This is especially true for Chinese cities because the country is now in the initial stage of urbanization. Unreasonable emissions reduction targets may produce exactly the opposite results due to the shortage of funds, the lack of technology, and increases in the unemployment rate. As a result, China requires the implementation of practical “mitigation” strategies.

Adverse effects of climate change and possible solutions

According to *China's National Climate Change Program* released in 2007 by the National Development and Reform Commission (NDRC) of the People's Republic of China, the key areas for mitigating the effects of climate change are: energy expenditure, resource provisioning, and responses to natural disasters [23]. Related research has mainly focused on the following problems: (1) the effects of climate change on energy consumption in cities and how to resolve possible energy crises [10,24], (2) water shortages [25], and (3) measures for reducing the effect of natural disasters caused by climate change [26].

The exploitation and utilization of energy will increase in the future because global warming causes frequent extreme fluctuations in temperature and the heat island effect. These in turn place more demands on refrigeration and air conditioning systems. Taking Guangzhou city as an example, a 1°C in the average maximum temperature will increase electricity consumption by 2.02% in industrial contexts and by 1.25% in residences [27•]. Accelerating the development of alternative power sources and popularizing power-saving technologies to meet the growing energy demand are two pathways for adapting to climate change.

More than 400 of China's 669 cities have water shortage problems [28]. This is especially true for cities located in northern and eastern China. Taking Beijing as an example, the water deficit in this typical northern city exceeds $4 \times 10^8 \text{ m}^3$ every year. A study indicates that Beijing will face more serious water shortages over the next 50 years due to climate change if no measure is taken to improve the efficiency of water use [29•]. Water consumption per person in Beijing is 210 m^3 , 2.5% of the world average [30]. Yet every year more than 500,000 move to Beijing. The *Beijing City Overall Plan (2004–2020)* estimated that the current population of Beijing should be no more than 18 million [31]. However, Beijing currently has a population approaching 20 million. Fortunately, the South-to-North Water Transfer Project will

supply $1 \times 10^9 \text{ m}^3$ fresh water to Beijing when completed [32]. In addition, the popularization of water-saving techniques will help water resources in the city adapt to climate change [25].

The disaster bearing capability of most Chinese cities must be improved because natural disasters will become more frequent and more serious as a result of climate change [19,21,33]. In addition to droughts in northern and western China, floods, storms, debris flows, and landslides affect many southern and eastern cities [21,34]. Researchers studying the impact of climate change on urban agglomerations along China's coast have recommended reinforcing embankments in order to cope with the rise in sea level and frequent storm tides driven by climate change [35•]. There is also a need to develop an early warning and response systems for tidal disasters in coastal areas. An emergency rescue system should also be implemented as soon as possible. In addition, plans for mitigating the effects of climate change should be tested first. Successful programs can then be applied to other cities [36].

Climate change may also lead to major epidemics in densely populated cities [37]. Climate is one of the main factors influencing the transmission of infectious diseases. A warmer climate may encourage the growth of insect-borne infectious diseases such as malaria, schistosomiasis, viral encephalitis, and dengue [38]. In addition, extreme changes in temperature may weaken peoples' immunity [39]. Extreme fluctuation in temperatures may lead to the transmission of bacillary dysentery in China's temperate and subtropical cities [40]. Thus, action should be taken at this stage to reduce future risks taking into consideration local climatic conditions and population characteristics [40]. A warmer climate may also raise the temperature of the sea and consequently increase the incidence of waterborne diseases such as cholera and mussel poisoning [41,42]. Financial support to public health programs should be enhanced in order to promote preventative measures to reduce the transmission of infectious diseases.

Low carbon cities

The low carbon city program was launched by China's Ministry of Construction and the World Wide Fund for Nature in 2008. Scientists consider the development of low carbon cities a feasible means of mitigating the effects of climate change [11]. A low carbon city follows several guidelines: (1) developing a low-carbon economy, (2) promoting a low carbon lifestyle among residents, and (3) developing and implementing laws to promote a low carbon society [43].

More specifically, a low carbon city is characterized by less pollution, low emissions, and high energy efficiency [43,44]. Shanghai and Baoding were chosen for pilot

studies regarding the implementation of low carbon cities in China [43]. In Shanghai, the energy consumption of large commercial buildings will be surveyed and property managers will be trained to implement methods for increasing energy efficiency. In Baoding, the National Renewable Energy Industrial Production Base will be built. The pilot was initiated at the end of 2009 and is expected to be completed within five years. The program will focus on the popularization of low carbon cities.

Considerable research has been conducted in fields related to the development of low carbon cities [45,46]. One of the main conclusions of this research is that China's cities should focus on the spreading of low carbon ideas and economic structural adjustment. The low carbon cities includes a synthesized development model with building a low carbon society as final target and three transitional paths: the model with developing a low-carbon industry as the driving force, the model with developing the low-carbon industry as the backbone and the model by popularizing the pilot demonstration projects for developing low carbon cities [44]. Policies related to the reduction of greenhouse gas emissions can be implemented only if they do not interfere with economic and social development. A successful model will involve collaboration among government, the private sector, and civil society [47]. So, the choosing of development path for low carbon city should be according to local conditions. However, no matter which pattern is adopted, cities should focus on the spreading of low carbon ideas and accomplish the target of a low carbon society with a long-term strategic vision and a reasonable comprehensive urban planning.

It is self-evident that planning for low carbon cities would be a best way to address the urban challenges faced by fast growing cities in the developing countries. To be sustainable, in the specific context of Dhaka, implementation of related plans, such as Dhaka Metropolitan Development Planning (DMDP) Area Integrated Transport Network, analysis of potential alternatives and securing stakeholder involvement have been thought essential. Transportation planning for the Mumbai transport system was done with restrictions on CO₂ emissions. Under each level of CO₂ mitigation target the vehicular mix and the emission of other pollutants is monitored [48]. Some of these techniques, such as reduction of travel distance, are adaptive measures, and addressable through integrated planning [49]. Others, such as clean technology, are mitigation measures in that they are interventions to reduce the sources of greenhouse gas (GHG) [50].

Policies that do not support economic and social development may hamper city development and lead to the loss of city functions and the ability to reduce greenhouse gas emissions. The development of low carbon cities in

China should take resource availability and socio-economic characteristics into consideration [51]. China is currently in the preliminary stage of urbanization. Thus, the development of low carbon cities should be a long-term goal that also permits urbanization and economic development [52]. In China, energy-intensive cities are largely located in the cooler, central and western regions [53]. Thus, energy efficiency is greater in the developed cities. One way of increasing energy efficiency depends on the technological progress.

There are also scholars focusing on concrete measures for reducing greenhouse gas emissions [9,24,54]. Researchers have recommended the implementation of a system dynamics model in order to reduce CO₂ emissions by public transportation [55]. Accelerating the development of railways, slowing the extension of highways, and imposing fuel taxes will reduce CO₂ emissions by 26–32% [56]. Results from a case study in Xiamen city indicate that clean energy substitution is most effective in terms of saving energy and reducing greenhouse gas emissions [57]. In contrast, the industrial sector has the greatest potential employing for abatement policies [57].

Discussion and conclusions

Many studies regarding the adaptation of cities to climate change have been undertaken in China [58–60]. The impact of climate change on Chinese cities and the development of low carbon cities have been discussed accordingly. However, a complete research system has yet to be established and many core issues have yet to be considered. It is still unclear whether low carbon cities will work in practice. The following issues require further consideration:

- Causes of climate change and the role and contribution of cities to this process.
- Trade-off between adaptation to and mitigation of the effects of climate change on cities.
- Impacts of climate change on different cities across the country.
- Cost of developing low carbon cities.
- Urban heat island effect and its impact.
- Coordinating emission reduction and urbanization/economic development.
- A detailed data set and canonical modeling framework applicable to cities.

Anyway, developing low carbon cities allows the dissociation of greenhouse gas emissions from economic development and urbanization. The idea that the increase in greenhouse gas emissions is a condition to economic growth and urbanization is denied under the new city developing mode. Therefore, China could move on to more intensive stages in regards to climate change without inhibiting economic development and urbanization. China should not, for instance, necessarily try to

repeat the unattainable standards of energetic consumption of the industrialized countries in order to assure its rapid economic development and urbanization.

Thus the increase in greenhouse gas emissions originated from higher levels of economic development and urbanization does not necessarily need to be based on and conditioned by the increase in energy supply. The direct or indirect reduction of greenhouse gas emissions, especially through developing low carbon cities, can play an important role toward this.

The importance of strategies such as developing low carbon cities lies in the fact that investments in developing and applying the new technologies of greenhouse gas emissions reduction are as scarce as they are necessary. This way, the enterprises destined to suspend production due to the discharge of greenhouse gas exceeding the stipulated standards would revive and generate more social and economic returns [61]. In addition, a set of institutions and policies needs to be formulated to mitigate and adapt to climate change for Chinese cities.

Currently, the goal of low carbon cities in China is the reduction of greenhouse gas emissions [51,62]. And the planned popularization of low carbon city in China will be rather radical in the next three or four years. However, the understanding of the real causes of climate change is still incomplete and the performance of greenhouse gas emissions reduction in mitigating climate change is unpredictable. Thus, adaptation should also be considered.

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