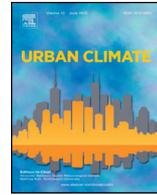




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# China's adaptation to climate & urban climatic changes: A critical review



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### ABSTRACT

Since the conclusion of the 2014 Climate Summit in New York and the 21st Conference of the Parties (COP21) in Paris, China has been actively advancing its national policies on climate change mitigation and adaptation since more unpredictable extreme weather events are expected, which may incur a heavy cost in terms of economics and public health. Since China is still in the process of urbanisation, the greatest challenge it faces is finding a balance between economic growth and keeping carbon dioxide and greenhouse gas emission rates at a manageable level. Cities in China play a key role in the implementation of the central policies and make concrete actions in response to climate change. With reference to a series of recent policy papers and action plans as the background, this paper attempts to provide a critical overview of China's climate change action plans from the national to the city and urban level. It seeks to understand whether the proposed responses to climate change and strategies for actions on greening and air corridors for cities and urban areas are appropriate. It is found that for China to advance its urban climatic adaptation strategy there is a need for (1) urban data, (2) a cross-disciplinary impact assessment, and (3) the development of a market and policy transformation mechanism.

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## 1. Introduction

In the face of global economic integration, there is a growing trend and need for the world community to deal with the growing environmental issues with joint efforts (Keohane, 2002; Chen, 2012). Global warming and climate change caused by greenhouse gas emissions are now at the top of the global agenda (UN-Habitat, 2011; IPCC, 2014). As the largest developing country in the region of East Asia, China contributes a dominant and increasing share of greenhouse gas (GHG) emissions. This has naturally attracted international attention and concern (Chen, 2012). Since 2014, China has actively embarked on a number of policies and action plans on the subject of climate change. However, it is never an easy task to understand China's climate change policies. They are not only related to the issues of national image, domestic and foreign policy, transnational co-operation, energy cost and economic growth, but also motivated or driven by other factors such as ecological protection, growing public awareness and civil society's attitude (Chen, 2012; Zhang, 2003; Economy, 1997; Economy, 1998; Hatch, 2003).

China is still in the process of urbanisation. The central government's 13th five-year plan predicts that the country's urbanisation level will reach 70% in 2050. Thus, the greatest challenge for China is to find a balance between economic growth and keeping carbon dioxide and greenhouse gas emission rates at a manageable level (Chen, 2012; Zeng et al., 2008). Cities in China play a key role in the implementation of the central policies and make concrete actions in response to climate change.

Unlike many other studies that attempt to explain China's climate change policies from a purely economic or political perspective, this paper aims to provide an overview of China's climate change strategies and actions to dissect its policy papers and action plans critically at both the national and city levels. Firstly, the paper examines China's climate change policy papers and plans not only in the context of global climate change, but also against its domestic contextual circumstances. Some of its key motivations may then be better positioned; some of its key claims of deliverables better contextualised; and a perspective of its path ahead better visualised. In so doing, the effectiveness of China's strategies and road maps may be better appreciated, and some of the many obstacles it is going to face may be better delineated. Secondly, China's National Climate Change Programme is outlined to provide a background and context of its adaptation plans. Thirdly, the paper analyses the 'China's Policies and Actions for Addressing Climate Change' report and five highlights from it. It is argued that since the priority of economic growth is set by the central government, and the multi-layer inter-governmental bureaucratic structure strictly follows China's top-down political system, it is very difficult to examine the performance of those adaptation plans and strategies. It is also hard to tell whether or not they can be followed and practiced in reality at the city level, because there is no specialised legislation and implementation mechanism to supervise and guarantee the performance of the climate change actions in China. Fourthly, the paper introduces China's recent effort to relate its climate change policies to urban climate and its series of policy papers and action plans for cities since 2014, all of which are related to the growing public awareness on environmental problems and the people's call for an improved quality of life. Among them, the Greening Masterplan and Air Corridor Masterplan are two key measures designated by the central government. Three selected examples of Wuhan, Macau and Hong Kong are introduced and discussed and an insight is offered into how local government and researchers can work together to evaluate urban climatic conditions and implement corresponding application strategies to local urban development in the adaptation to climate change. Lastly, based on the lessons learnt from the application in China, the paper concludes and highlights that there are three urgent needs in a country's response to climate change: 1) an available, accessible and standard urban database for cities in China; 2) cross-disciplinary collaboration and impact assessment; and 3) a market and policy transformation mechanism.

### 1.1. *International context: the 2014 climate summit*

The 2014 Climate Summit aimed to raise political momentum for a meaningful universal climate agreement in Paris in 2015 and to galvanize transformative action in all countries to reduce emissions and build resilience to the adverse impacts of climate change. So when UN Secretary-General Ban Ki-Moon gave the opening address in this Summit, the key message was "Humanity has never faced a greater challenge than climate change". On the same occasion, Chinese Vice-Premier Zhang Gao-Li, representing Asia's largest contributor to CO<sub>2</sub> emissions, made a response and promised that, "We will announce post-2020 actions on climate

change as soon as we can to markedly reduce carbon intensity, increase the share of non-fossil fuels and raise the forest stock.” (Sturmer, 2014).

Alongside international political negotiations and discussions, global CO<sub>2</sub> emissions were found to amount to 35.3 billion tonnes in 2014 (PBL and JRC, 2015). China's contribution was 23%, and Asia's contribution was 52% (Olivier et al., 2014). Asia's per capita CO<sub>2</sub> emission, at 3.8 t, was still low when compared to North America at 17.5 t and Europe at 8 t (Friedrich and Damassa, 2014). However, the rapid development and urbanisation in Asia means a sharp increase in its per capita CO<sub>2</sub>, and inevitably, given its huge population, the total amount of CO<sub>2</sub> it is going to emit is set to increase dramatically.

## 1.2. Climate change and its impact to Asian cities – IPCC, 2014

For Asia, the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) report (2014) summarises:

- (A) Warming trends and increasing temperature extremes have been observed, and an increasing numbers of warm days and decreasing numbers of cold days have been observed;
- (B) Water scarcity is expected;
- (C) Many regions will experience a decline in food productivity;
- (D) Increasing shifts in the phenologies;
- (E) Coastal and marine systems are under increasing stress;
- (F) Extreme climate events will have an increased impact on human living;
- (G) Multiple stresses caused by rapid urbanisation, industrialization, and economic development;
- (H) Studies of observed climate changes and their impacts are still inadequate.

While (B), (C), (D) and (E) have more to do with the ecological system and the resources human living needs, for cities, (A), (F) and (G) are particularly important for mayors and policy makers to note when it comes to city planning and its metabolism. Rightly pointed out in the IPCC report under (H), the need for further understanding is required especially when it comes to climate change's impact on human life in cities. It is also necessary to develop clearly formulated adaptation strategies.

### 1.2.1. Warming trends and increasing temperature extremes

According to the population projection by the United Nations, nearly 9% of the world's population will be living in 41 megacities by 2030 (UN, 2004). Many of them will be in the tropical and sub-tropical regions of Asia. Considering IPCC-2014-(A) (above in Section 1.2), the potential problems and corresponding impact caused by the warming trends and increasing temperature extremes are discussed and shown below:

Firstly, further temperature rises and more frequent hot days and nights will increase heat stress related mortality (Chan et al., 2012, 2011; Dang et al., 2016; Gao et al., 2015; Lin et al., 2011; Wu et al., 2013; Yan, 2000; Zeng et al., 2016). In those tropical cities, the ambient air temperature in summer is expected to increase in the face of global warming, and extreme hot weather events will become more frequent. The number of hot nights will increase faster than those of hot days. It is easy for people to ignore the potential health impact of hot nights. Generally speaking, an increase of 2% heat stress related mortality may be expected for every 1 degree rise in air temperature beyond the threshold level (Chan et al., 2012). A major challenge for developed cities is that most of their infrastructure and building stock are already there. Transforming existing buildings or urban spaces to take on the new climatic challenges is not easy. The institutional inertia and financial burden of upgrading efforts are two of the most commonly encountered obstacles.

Secondly, hot spell episodes will increase summer energy consumption for cooling (Eom et al., 2012; Fung et al., 2006; Jiang and Hu, 2006; Li et al., 2012; Santamouris et al., 2001; Zhou et al., 2013). Generally speaking, an increase of 5% to 10% in kWh of air conditioning energy use could be expected for every 1 degree rise in air temperature (Fung et al., 2006). More importantly, recent research has pointed to the “switching on” of air conditioner behaviour when air temperature reaches a certain threshold (Frankel et al., 2013; Hong and Lin, 2013). When the threshold is crossed, the increase in energy use is dramatic. For tropical and sub-tropical cities, when the ambient air temperature, especially in the evening, is very close to this threshold, it only takes a degree or two of temperature increase to change people's energy use behaviour.

Thirdly, and more seriously, temperature rises due to climate change could alter the spread of human diseases (Bai et al., 2013; Reiner et al., 2012; Tong et al., 2015; Yang et al., 2009). Many tropical diseases, such as Dengue Fever, Malaria, and other intestinal diseases like Brothers Mouth Disease, that were once epidemic in tropical cities, would migrate northward (Gething et al., 2010). New diseases, such as Severe Acute Respiratory Syndrome (SARS), would appear more often. This problem is compounded by the fact that most cities in the tropical and sub-tropical regions including China are ill-prepared in terms of disease control and prevention at the national, provincial, prefectural, and county level. Rapid urbanisation and large movements of immigrants also add to the complexity of the problem.

Last but not least, another issue that deserves attention is that a higher temperature would increase water usage and add to the problems identified in IPCC-2014-(B).

### 1.2.2. Extreme climate events

Considering IPCC-2014-(F) above, extreme events like severe typhoons will be more frequent (Chan and Liu, 2004; Lighthill et al., 1994; Whitney and Hobgood, 1997). Over 2 billion of Asia's population of 3.5 billion lives within 400 m of the coastline (Hinrichsen, 1998). The relatively poor sea wall defences of many low-lying Asian cities like Bangkok, Dhaka, Guangzhou, Ho Chi Minh City, Manila, Mumbai, Shanghai, and so on further add to their vulnerability. Properly designed sea walls are technically challenging and very expensive. The financial resources needed are well beyond the capacity of most developing Asian countries; the World Bank's US\$24 billion climate proofing projects in recent years is a drop in the ocean as reckoned by Preeti Bhandari of the Asian Development Bank (ADB)'s Climate Change and Disaster Risk Management Unit (Bhandari, 2015).

More importantly, even existing, well-constructed counter-measures could be rendered ineffective amid more frequent extreme events. A study by colleagues at the Hong Kong Observatory highlighted that the return period of a 4 m storm surge would decrease from 50 years to 2 years, and the city would need to brace itself for the possibility of suffering 5 m storm surges once every 50 years (Lee et al., 2010; Wong et al., 2003). Hence, even many developed cities in Asia are at risk.

Those living away from the sea are not safe either. On the one hand, extreme precipitation may cause more frequent landslides; this would affect settlements next to hillsides (Chiang and Chang, 2011). The risk is high due to the poor slope geo-technical management of many Asian cities; slope management is expensive. For example, Hong Kong, a small city territorially speaking, spends US\$250 million per year to maintain and upgrade its 60,000 man-made slopes in or next to the city. On the other hand, extreme precipitation may also lead to flooding. Many Chinese cities have invested in and worked towards an update of their water drainage systems since 2013. Both will cost more when heavier precipitation events due to climate change strike in the future.

### 1.2.3. Multiple stresses caused by rapid urbanisation

Considering IPCC-2014-(G) above, Asia is rapidly urbanising. Currently, East Asia has eight megacities with a population of over 10 million; over 120 large cities with 1 million to 10 million people; and more than 700 medium cities housing between 100,000 and 1 million people.

According to the World Bank's 2015 Report titled 'East Asia's Changing Urban Landscape', almost 200 million people moved to urban areas in East Asia from 2000 to 2010. China predicts that its urban-rural population ratio will increase from 50/50 to 70/30 in 2030 (World Bank, 2015). Urbanisation also means a growth in the urban middle-class population. This means a drastic 5 to 10-fold increase of per capita energy consumption (United Nations Department of Economic and Social Affairs, 2010).

According to another World Bank report in 2010, cities are highly vulnerable to uncertainties and extreme events that disrupt supplies (International Bank for Reconstruction and Development/World Bank, 2010). Once that happens, the scale of the problem would be exacerbated due to the close proximity of a large number of people. Social unrest, mass migration and terrorism may follow.

Apart from the problems caused by climate change, cities also face urban climatic problems, characterised by the change in interactions between the built up environment and regional climate (WMO, 1983).

Urban areas are warmer than rural areas because of the waste anthropogenic heat released from human activities, urban forms and the transformed environmental features. The resulting effect is known as Urban Heat Island (UHI). In some dense and compact tropical cities, an (air temperature) UHI intensity of 2 to 4 °C can normally be experienced during the day (Siu and Hart, 2013). Within a city, different districts warm up differently due to the differences in built environment conditions and human activities. It has been estimated that the number of hot days and nights would increase from 10 and 20 to 90 and 120 respectively due to a 3-

degree inter-urban air temperature differential (Ng, 2009). This could have a tremendous impact on public health, especially heat-related diseases, such as heat-related morbidity and mortality (Goggins et al., 2012).

The cause and effect behind climate change is complicated. Contributing factors are correlated and can even have an effect on each other. This means that when national and local governments draw up strategies in response to climate change, they must consider holistically with a long-term vision their commitment to greenhouse gas reduction, the impacts of climate change, levels of risks, the need to save energy, pollution control, and waste management (Meadowcroft, 2009; Ng, 2011; Bulkeley, 2010; Qi et al., 2008; Saavedra and Budd, 2009; USCOM, 2009; Zahran et al., 2008). With reference to the National Climate Change Policy in Asia, governments tend to treat each climate change impact individually to provide corresponding mitigation and adaptation strategies. However, many governments in Asia do not seem to be fully aware of the strategies' potential, or ready to deal with the unpredicted climatic disasters, since their urban expansion is very often unplanned or has gone out of hand. For example, there is no evidence to suggest that any of them, when working on their climate change preparation, adopted the World Bank's Urban Risk Assessment (WB, 2011) as a framework, or other similar frameworks (e.g. Urban Climate Change Research Network's ARC3.2 city planning framework (Rosenzweig et al., 2015)).

## 2. Post COP21 and China's climate change policies

Given the policy context and key issues outlined in the previous section, the paper continues to examine China's more recent developments since COP21.

COP21 was concluded in Paris in 2016. For the first time in over 20 years, 195 countries showed determination to achieve a legally binding agreement on climate change: to keep global warming below 2 °C. As the world celebrates this international political achievement, there is still a need for us to read further into what has been agreed upon. Ultimately, it is not a matter of “what is agreed”, but of “what can be achieved”.

On top of the 2 °C limit, Article 2(2) of the COP21 Paris Agreement acknowledges that despite the common responsibility, the capabilities of the parties need to be differentiated. The Agreement articulates that “Each Party shall prepare, communicate and maintain successive nationally determined contributions that it intends to achieve. Parties shall pursue domestic mitigation measures, with the aim of achieving the objectives of such contributions.” (Paris Agreement, 2015). The Agreement continues in Article 2(4) to distinguish the actions expected from developed country parties and developing country parties.

There are 42 Asian countries in the Agreement. Many have a GDP of less than US\$10,000 per capita; among them are China, India, Indonesia, Philippines, Bangladesh, Pakistan, Vietnam, and Thailand (Table 1). These eight East Asian countries have a total population of around 3.4 billion – representing almost half of the world's population of 7.1 billion. Under Article 2(4) of the Agreement, these eight developing countries are only required to “enhance” their mitigation efforts, and are only “encouraged to move over time towards economy-wide emission reduction or limitation targets in the light of different national circumstances”.

**Table 1**

A comparison of GDP, population and annual CO<sub>2</sub> emissions for selected Asian countries (Ritchie and Roser, 2017; NDRC, 2016).

	CO <sub>2</sub> emission (tonnes per capita)	Population (millions)	Total CO <sub>2</sub> emission (kilotons)	GDP (US\$ capita)
World	5.0	7130	35,650,000	11,000
USA	16.5	320	5,280,000	53,000
China	7.6	1340	10,184,000	7500
India	1.8	1200	2,160,000	1700
Indonesia	1.8	240	432,000	3500
Pakistan	0.8	180	144,000	1500
Bangladesh	0.4	145	58,000	1300
Philippines	1.0	100	100,000	3000
Vietnam	1.9	90	171,000	2200
Thailand	3.9	85	331,000	5500
Japan	11	130	1,430,000	39,000
South Korea	13	50	650,000	26,000
Singapore	9	6	54,000	56,000
Hong Kong	7	7	49,000	39,000

The crucial point to note is: how does China see itself? On the one hand, from an economic and social development point of view, China is still very much a developing country; however, from a total energy consumption and CO<sub>2</sub> emission point of view, it is a major contributor, or even a global changer. The fact is, if China chooses only to “enhance” its mitigation efforts as in Article 2(4) of the Agreement, it is difficult to see how the 2 °C limit may be achieved.

Apart from mitigation, the Agreement also touches on the issue of adaptation. Article 7(1) of the Agreement spells it out clearly: “Parties hereby establish the global goal on adaptation of enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change, with a view to contributing to sustainable development and ensuring an adequate adaptation response in the context of the temperature goal referred to in Article 2.” The determinant of the adoption of any adaptation strategy is cost – and it remains to be seen how Article 9 of the Agreement on financial aids might be substantiated.

Thus, developing an adaptation plan is one thing, while implementing/adopting such an adaptation plan is another. Mitigation is developed to limit climate change by reducing the emission of GHGs to reduce ‘sink’ opportunities, while adaptation means that governments, industries and societies need to work together through a wide range of actions to lessen the adverse impacts of climate change (Füssel and Klein, 2002). It is very often found that adaptation is probably more challenging than mitigation measures given China’s top-down political system. It might be easy for a nation to develop an adaptation plan, however, a plan is only as good as its implementation and realisation. For many developing Asian countries, this, perhaps more than the need for mitigation measures, is the real challenge. Apart from the need to finance adaptation measures, the other challenge is technology. Both detection and facilitation technologies are needed, that is to say, knowing “where the problems are” and “how to tackle the problems” requires technological knowhow that may exceed the capability of many developing nations. This is where Article 10 and 11 of the Agreement on technology transfer may assist.

### 2.1. China's national climate change program

According to the historical data of CO<sub>2</sub> emissions from the World Resources Institute (Table 2), it can be seen that the industrialisation of China started late. However, since the turn of the twenty-first century, the process has rapidly picked up (Fig. 1). By 2005, it surpassed the USA as the world’s largest CO<sub>2</sub> emitter. By 2010, China’s annual CO<sub>2</sub> emissions were about 8200 t, and it is increasing rapidly at about 3% per year.

China issued its first National Climate Change Program in 2007 (National Development and Reform Commission [NDRC], 2007). In a nutshell, the 2007 Program set up six guiding principles (United Nations General Assembly, 2007):

1. To address climate change within the framework of sustainable development;
2. To place equal emphasis on both mitigation and adaptation;
3. To integrate climate change policy with other interrelated policies;
4. To rely on the advancement and innovation of science and technology;
5. To follow the principle of “common but differentiated responsibilities”; and
6. To actively engage in wide international cooperation.

The 2007 Program also set up a number of objectives (United Nations General Assembly, 2007):

1. To reduce energy consumption per unit GDP by 20%;
2. To increase the share of renewable energy to 10% in primary energy supply;
3. To stabilize nitrous oxide emissions from industrial processes at pre 2005 level;

**Table 2**

CO<sub>2</sub> emission (megatons per year) from 1850 to 2010. (Source: Friedrich and Damassa, 2014.)

	1850	1900	1920	1940	1960	1980	2000	2010
UK	122	420	470	475	583	578	533	478
USA	–	662	1871	1900	2858	4703	5747	5469
China	–	–	26	86	780	1465	3607	8159

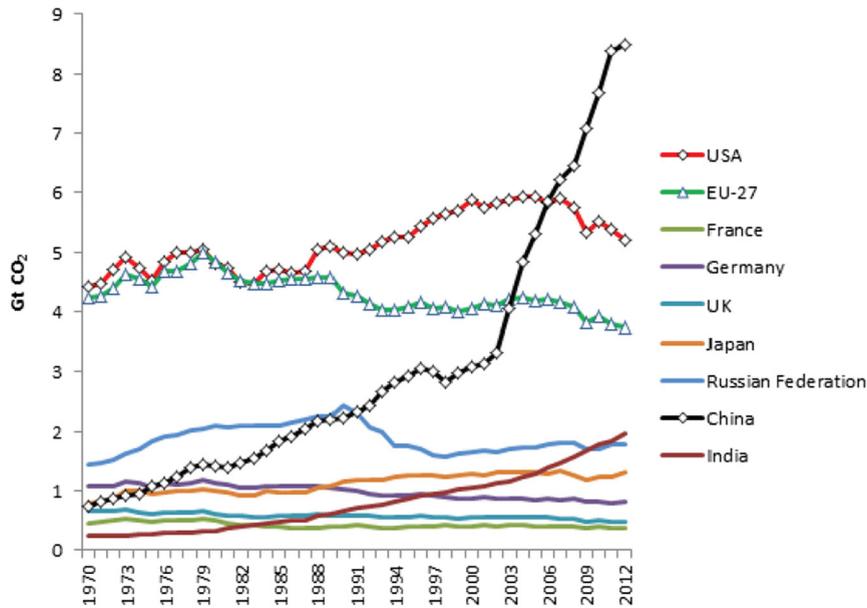


Fig. 1. Total CO<sub>2</sub> emissions of major emitters in 1970–2012. (Source: Liu, 2015.)

4. To control the growth rate of methane emissions;
5. To increase the forest coverage to 20%; and
6. To increase the carbon sink by 50 million tons over the 2005 level.

When examining the principles and objectives of the 2007 Program, it is not difficult to see that for China, the development of its economy has very much been the overarching concern. For example, given the average economic growth rate of 8% per year, achieving the CO<sub>2</sub> intensity target of 20% over five years means that more CO<sub>2</sub> will actually be emitted (Leggett, 2011). Indeed, in the years between 2005 and 2010, China's CO<sub>2</sub> emissions increased from 5935 megatonnes in 2005 to 8159 megatonnes in 2010 (Friedrich and Damassa, 2014). This represents an increase of 37%.

In 2011, a revised set of policies was published (NDRC, 2012). It set a target of a 17% reduction in CO<sub>2</sub> intensity over five years. Even given the slowdown of the Chinese economy, the undeniable fact is that China's total CO<sub>2</sub> emissions will still be on an upward trend since urbanisation and industrialisation in China are still ongoing.

A recent report by the Netherlands Environmental Assessment Agency highlights that China's CO<sub>2</sub> emission in 2014 was around 10,500 Mts, representing an annual increase of about 7% since 2010 (Olivier et al., 2014). In 2014 at the UN Climate Summit, China committed to peaking its total CO<sub>2</sub> emissions by 2030. This was in line with the earlier (November 2014) "US – China Joint Announcement on Climate Change and Clean Energy Cooperation". China has also set the goal of reducing its carbon intensity by up to 45% by 2020. How the promise is to be fulfilled remains a major question, but the most important fact is that China's CO<sub>2</sub> emissions, given an annual growth rate of around 5%, will, in 2030, be roughly 22,000 Mts. Unfortunately, this number alone will make COP21's two-degree target impossible. In the meantime, there is currently no specialised legislation to supervise and address China's climate change (domestic) policy, although it was firstly suggested by Dahe Qin, the former Secretary of China's Meteorology Administration in 2009 (Chen, 2015). More importantly, a corresponding implementation mechanism system is still lacking (Chen, 2015). This is a decisive factor as to whether or not China's targets on climate change will be successfully achieved.

## 2.2. China's key adaptation strategies at the national level

Given the ambiguity of power and duties regarding China's climate change (Chen, 2015), China has thus far focused only on mitigation. Adaptation measures and targets are needed and China is beginning to formulate them. However, so far there is no specialised legislation and corresponding implementation mechanism system to guarantee the proposed target can be realized. China's Policies and Actions for Addressing Climate Change published in 2011 reveals that the emphases are on water, health, land use, forestry, transport, air pollution, and industrial processes (IOSC, 2011). No specific target was set, and it is only mentioned that rises in sea levels will be analysed, and there are no corresponding detailed adaptation strategies. Subsequently, in 2013, a set of revised policies was published (NDRC, 2013). The five highlights are:

1. Disaster Prevention and Mitigation: The Ministry of Civil Affairs, Ministry of Agriculture, and Ministry of Water Resources now work closely together to build defensive infrastructure for extreme weather. Above all else is the production of flood risk maps and assessment mechanisms. However, given the vastness of China's territory, the task is challenging.
2. Monitoring and Early Warning: The China Meteorological Administration and the State Oceanic Administration are charged with providing the needed early warning and monitoring mechanisms.
3. Agriculture and Water Resources: The Outline of National Agricultural Water Conservation (2012 – 2020) promotes water-saving agriculture. Strictest Water Resources Management Systems have been developed for river basin protection.
4. Coastal Areas and Ecosystems: Overseen by the State Oceanic Administration, the coastal defences are being reinforced. The long coast lines and cities on or near the flood plains are the key challenges. A report by the Organization for Economic Cooperation and Development (OECD) reckons that a number of Chinese cities, including Guangzhou, Shanghai, Tianjin, Hong Kong, and Qingdao, are ranked in the top 20 most vulnerable cities (Pan et al., 2011).
5. Public Health: The impact of climate change on public health in the form of heatwaves has not been explicitly mentioned. Safe drinking water and PM2.5 are the focuses.

Despite the above highlights of China's action plans, a question remains: is China ready for climate change? For the Chinese Government, the riskiest challenges are agriculture and water resources (Darkin, 2008). Drought- and flood-related crop failure poses the highest impact not only socially and economically, but also politically. China's agriculture and water infrastructure is outdated. A lot of investment is going to be needed. Apart from building defensive measures, advances in agro-biological technology are also needed.

Given China's rapid urbanisation process, another key challenge is at the city and urban living level. Buildings and urban infrastructure needs to be planned and designed to cope with more frequent and more intense extreme heat events. The attention on adaptation needs to move down a scale from climate change to the consideration of urban climate. This focused concern will be further elaborated upon in the next section.

## 2.3. From climate change to urban climate – adaptation at the urban level

According to the report published by the Asian Development Bank in 2012, one-seventh of China suffers haze events, heavy air pollution and intensified urban heat island problems (Zhang and Crooks, 2012). Thus, improving urban living quality has become a matter of great concern among the general public. This has also turned out to be a driver for policy changes. In China, a politician can only work in the same position for at most 10 years. While 2030 or 2050 may be too far away for them, 2014 was not. Premier Xi Jinping in his opening address at the Asia-Pacific Economic Cooperation (APEC) meeting in Beijing in November 2014 reminded delegates of Beijing's air pollution and urban climate problems. He hoped that, as part of his "Chinese dream", one day China, especially the younger and future generations, would see "blue sky, green mountains and clean water". His address can be seen as a directive, setting off a chain reaction of subsequent policies and action plans.

The address was preceded by the National Plan on Climate Change 2014–2020 published in September 2014 (NDRC, 2014). The paper mentions, for the first time, policies related to urban climate and urban living. Keywords such as urban heat island, heat stress prevention, building design, transportation planning, open space provision, urban greenery, and water bodies have been included.

Almost immediately after Xi's address, China finally passed its 2009 draft of Design Standard for Thermal Environment of Urban Residential Areas (Ministry of Housing and Urban-Rural Development [MOHURD], 2013). It specifies that the urban heat island effect will be limited to 1.5 °C.

In May 2015, the 2011 draft of Technical Specifications for Climatic Feasibility Demonstration in the Urban Master Plan by the China Meteorological Administration was passed. As a major basis of city planning, the document mentions the need to calculate and quantify human thermal comfort, air pollution index, urban heat island intensity, mixing height, and so on.

In June 2015, the Ministry of Housing and Urban-Rural Development (MOHURD) published a draft policy paper titled National City Environmental Protection and Development Policies (MOHURD, 2015). It highlights the importance of Xi's "blue sky, green mountains and clean water". The key strategies are "city air corridors" and "urban greening". It recommends that China's major cities – and there are 291 of them – should complete their Greening Masterplan and Air Corridor Masterplan by 2017. Dovetailing urban climate and climate change considerations, the MOHURD's paper was followed by a joint MOHURD/NDRC paper in February 2016 on Climate Change Adaptation Action Plan for Cities (MOHURD and NDRC, 2016). It requires results to be realized by the local governments of 30 key cities.

### 2.3.1. Greening Masterplan and Air Corridor Masterplan

Apart from the landscape transformation, the associated human activities due to rapid urbanisation have modified cities' urban meteorological and climatic conditions. It is found that there is a linear trend of increasing haze events per year from 1960 to 2010 (Sun et al., 2014). Recent studies also demonstrate that there has been an explosive increase in haze events especially since 2000. In some extreme haze cases, the affected areas made up as much as 15% of the land in China (Wu et al., 2014), and the visibility distance was reduced to less than 1 km (Wu, 2011). Mitigating air pollution and improving urban ventilation have become the will of the people. Controlling air pollution emission sources means industrial transformation, and clean and green energy use. This is one of the biggest challenges, since economic growth is still the main pursuit for both central and local governments. Thus, improving urban ventilation by creating air corridors has become the first choice for politicians in the mitigation of air pollution, as they also help demonstrate their performance in the improvement of living quality (Ren, 2016).

The National City Environmental Protection and Development Policies document (MOHURD, 2015) stipulates that city officials and planners need to take on urban ventilation corridor- and greening planning seriously. The suggested work must include:

1. Completing the conservation and development plan of suburban greenery areas as oxygen sources as well as urban ventilation corridor plans in town planning at accelerated rates with aims to improve fresh air supply capacity;
2. Allocating large green plots and urban ventilation corridors in the densely populated urban areas, to promote vertical greening to mitigate urban heat islands
3. Creating ecological forest belts based on the existing road and water systems;
4. Transforming areas close to natural green spaces;
5. Promoting multi-layer planting and to increase the proportion of trees along the roadside;
6. Creating green belts in suburban areas to protect downtown air quality.

Thus, planners and government officials must have: (A) an investigation of the city's air mass movement and its clean air sources, (B) a mapping of the air ventilation functions of its green spaces, (C) an understanding of the city's urban heat island characteristics, (D) an understanding of the impact of urban forms and land use on urban air temperature distribution patterns. Based on the above understandings, it is possible for them to develop a strategic plan for the layout of the city's air corridors and a conservation plan of its green spaces.

The MOHURD policy document requires the above to be achieved by all district level cities by 2017. The document highlights 3 mega-areas: the Beijing region, the Changjiang River Delta region and the Pearl River Delta region. The cities within each of these three regions need to be considered together. To do that, mesoscale studies covering an area of a radius of a hundred kilometres must first be conducted. Initial studies have been carried out (Meng et al., 2011; Miao et al., 2009; Sang, 2012; Zhang et al., 2010). These and many others to follow will provide the needed atmospheric boundary conditions for further fine scale studies to extract useful data for policy makers and planners operating at the city, district, urban and neighbourhood scales of development planning (Wang et al., 2013a, 2013b).

The initiative for the Chinese Government to move towards planning its cities based on climate and urban climatic knowledge is further demonstrated by the publication of the ‘Technical specifications for climatic feasibility demonstration in urban master plan’ (Beijing Meteorological Office, 2015). The guideline highlights a number of considerations for planners at the master planning and urban planning scales of development. The meteorological data needed includes wind speeds and directions, air temperature, humidity, shortwave and longwave radiations. Demographic data, planning and urban morphological data, anthropogenic heat data, as well as air pollution data are also needed. The human thermal comfort model is used to evaluate the model simulation results, and various planning options will then be compared.

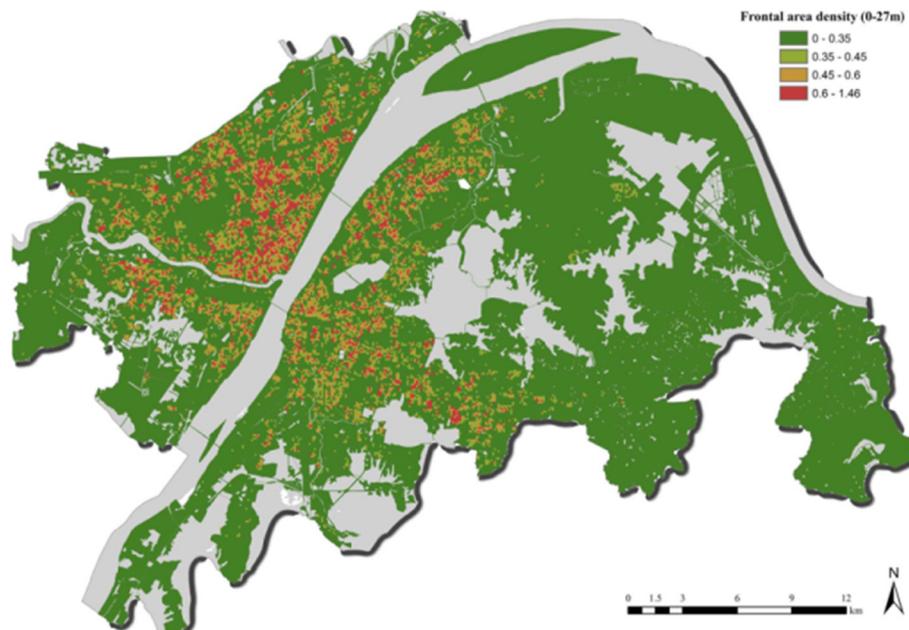
Another set of guidelines underway by MOHURD is tentatively titled Green Eco-city and Building Design Guideline provides further guidance to planners and architects. It is still at the consultation stage as of June 2016. The guidelines aim to bridge the understanding of UHI at the urban scale and the building design and system design scales of property developments.

As far as the action plan is concerned, Sections 5.2 to 5.4 below highlight three examples of Wuhan, Macau and Hong Kong. Local urban climatic application cases are introduced and discussed and an insight is offered into how local government and researchers can work together to evaluate urban climatic conditions and implement its corresponding application strategies to local urban development in the adaptation to climate change.

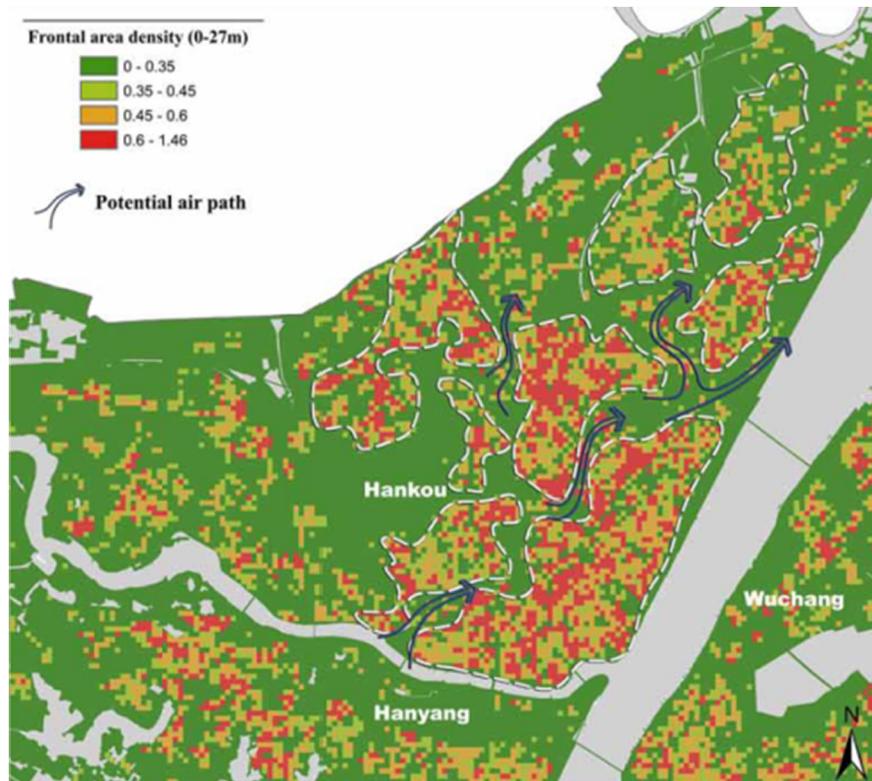
### 2.3.2. The city of Wuhan planning its air paths to improve urban climate

As of June 2016, 36 cities in 17 provinces in China that have already conducted different kinds of studies related to the urban climate (Ren, 2016). The city of Wuhan is a pioneer in the field of urban climatic application in mainland China. The local planning and land resources bureau started practicing the air corridor plan in 2006. Wuhan is located inland over the Yangtze River, 700 km west of Shanghai. It has more than 10 million inhabitants. The city's climate is humid subtropical (Köppen Cfa). It has very hot and humid summers with a calm wind situation. The city, however, is well endowed with about 200 lakes in and around the city.

The first version of its air corridor plan was made in 2006 as a conceptual design. Local planners hoped to designate six large green belts so that fresh air and wind from the outside would be introduced from six directions into the downtown areas. However, due to the lack of strong scientific-evidence-based support, local



**Fig. 2.** The FAD map of Wuhan downtown areas.  
(Source: Yuan et al., 2014.)



**Fig. 3.** Using the FAD map of Wuhan, the existing air paths through the city may be defined. They need to be protected. (Source: Yuan et al., 2014.)

officials commissioned Hong Kong researchers to conduct the 2nd version of the air corridor plan and explore the urban morphology's impact on local ventilation in 2012. Thus, the Frontal Area Density (FAD) of Wuhan was calculated as the basis of its air corridor assessment (Fig. 2). Potential air corridor locations at the urban and neighbourhood scales are then identified (Fig. 3) (Yuan et al., 2014). The results provide a useful initial basis for planners, especially in urban renewal and new town plans.

For China, the city of Wuhan has a complete and well-managed digital urban database in Geographical Information System (GIS), so it is easy for local government and researchers to work together to conduct scientific research and quantify how urban morphology and development intensity affects the urban climate and local environment. However, it is not easy to replicate its success and experience in other cities in China. A number of challenges and research opportunities lie ahead. The need for technical and professional understanding of the urban climate is well documented in Grimmond's and Mill's seminal papers presented in the World Climate Conference 3 gathering in Geneva in 2009 (Grimmond et al., 2010; Mills et al., 2010). China is beginning to amass the technical knowledge of how to gather data and generate scientific understanding. This area of capabilities as Grimmond et al. have outlined in their 2010 paper is not that difficult to acquire. However, the challenge lies in the institutional translation of technical understanding into policy and action. Mills et al. have put together in their 2010 paper the framework and checklist for policy makers and professionals. However, there is still plenty of room for improvement in China's multi-layer bureaucratic governance structure and professionalism to actually push things forward.

### 2.3.3. The city of Macau using air ventilation study to improve its land development policies

The shortage of suitable land for urban development is a challenge for many Asian developing cities. Macau's problem is more acute. Its economy is booming, but it has an area of just 30 km<sup>2</sup> to accommodate



**Fig. 4.** A map showing the locations of the reclamation areas as related to the existing city areas. (Source: DSSOPT, 2013.)

its population of 650,000 and all its activities. The Government of Macau therefore decided to expand the city with an ambitious reclamation plan, adding 12% to the city's land area. The 350 ha will accommodate up to 350,000 people (Fig. 4).

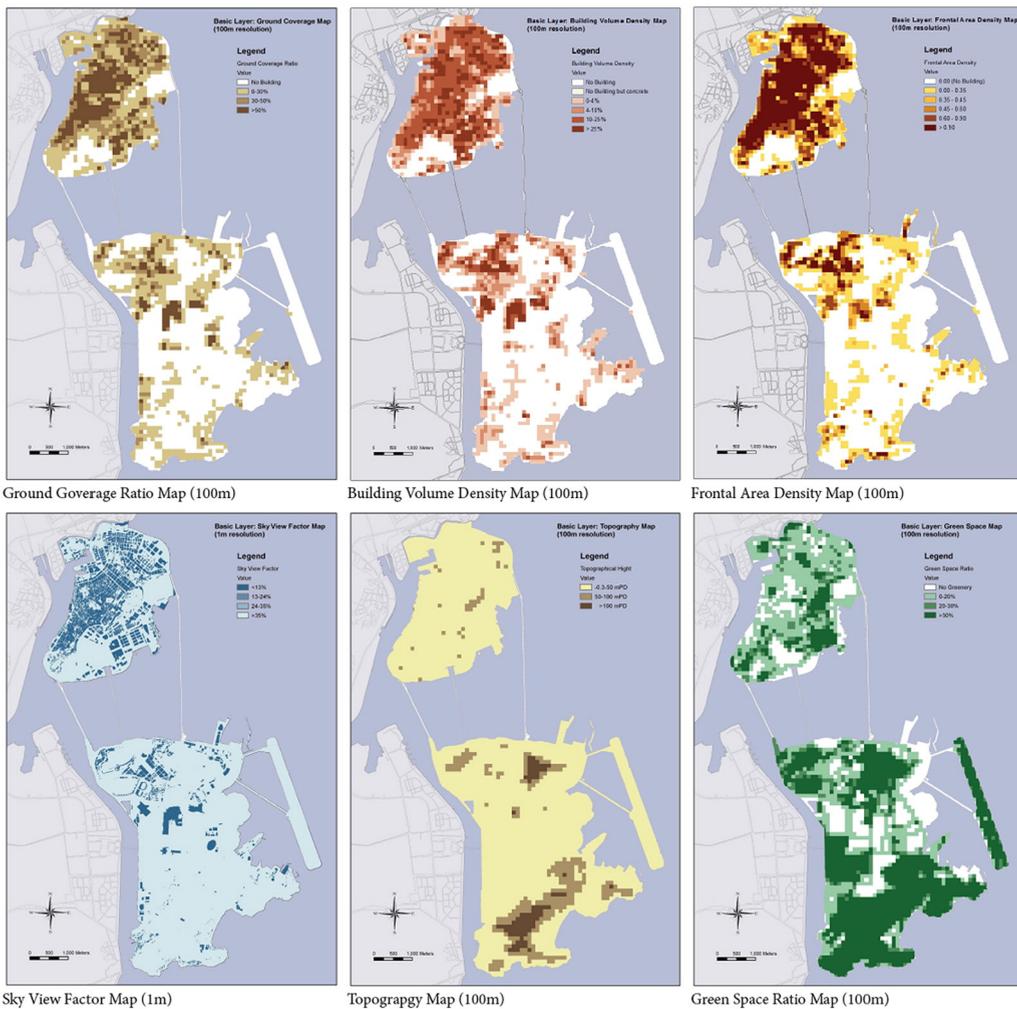
Since the announcement of the plan in 2009, public consensus mandated that the master plan must include, among others, the consideration of the environment, green areas and water bodies, and coastal areas. In addition, a key request from the general public was that the newly reclaimed areas must not adversely impact the urban climatic living environment of the existing metro areas and townships. The task fell on the Public Works and Transport Bureau (DSSOPT). Commissioned by DSSOPT, researchers developed the GIS-based urban climatic maps of Macau (Fig. 5) (Gong et al., 2015; Ren et al., 2015). A 10-year high resolution (100 m × 100 m grid) wind field study was conducted using WRF and CALMET (Yim et al., 2007). In addition, a large domain fine grid LES study was conducted to test the wind flow characteristics of the territory with and

without the land reclamation (Fig. 6) (Keck et al., 2014). A set of planning guidelines on improving urban ventilation and greening was developed for planners and policy makers (Ren et al., 2015).

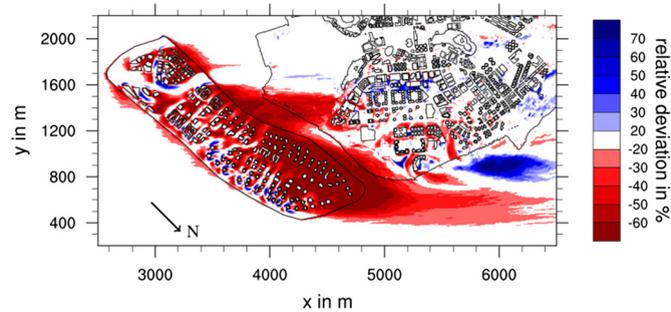
Further studies have been planned to extend the understanding of the future situation using the results of a downscaled General Circulation Model (GCM), to optimise neighbourhood scale designs with localised modelling research, and to assess the public health impact of different planning and design options.

### 2.3.4. Hong Kong using air ventilation assessment (AVA) and urban climatic study to improve its land development policies

Hong Kong is a special administrative region of China. Local urban climatic application and its corresponding policy and guidelines can be traced back to 2003, when SARS broke out. It was a wake-up call for the government and local people. A series of technical studies and consultancy projects such as the 'Air Ventilation Assessment (AVA)', 'Urban Climatic Map (UCMap)' and Standards for Wind Environment – Feasibility Study', 'Sustainable Building Design Guidelines', and 'micro-climatic study for public housing' was then



**Fig. 5.** Based on the GIS platform, maps of Macau's urban morphological characteristics are layered to be the input layers of the Macau urban climatic maps. (Source: Author)



**Fig. 6.** The differences between wind speed in m/s at 2 m above ground before and after the land reclamation when wind is from the south-east [prevailing wind direction in the summer months]. Note the effects of the land reclamation on the urban air ventilation performance of the existing city are minimal due to the sea channel in between – the width of this channel had earlier been optimised. (Source: Author)

commissioned. Among them, the results of the UCMaP formed the basis of local climate change policy in Hong Kong, mentioned in the ‘Climate Change Report in 2015’ published by the Environment Bureau (Environment Bureau, 2015). The report, with an emphasis on climate change mitigation and adaptation, was prepared for COP21 in Paris. It (A) summarises the achievement so far, (B) discusses the impacts of climate change on city living, (C) highlights the energy saving targets, and (D) reveals the actions needed (Environment Bureau, 2015). On city planning, the report states that the government will formulate an Urban Climatic Planning Recommendation Map to provide a scientific basis for assessing urban climatic and air ventilation impacts of major developments. The report also states that the government will develop its Greening Master Plan and the Sustainable Building Design Guidelines further.

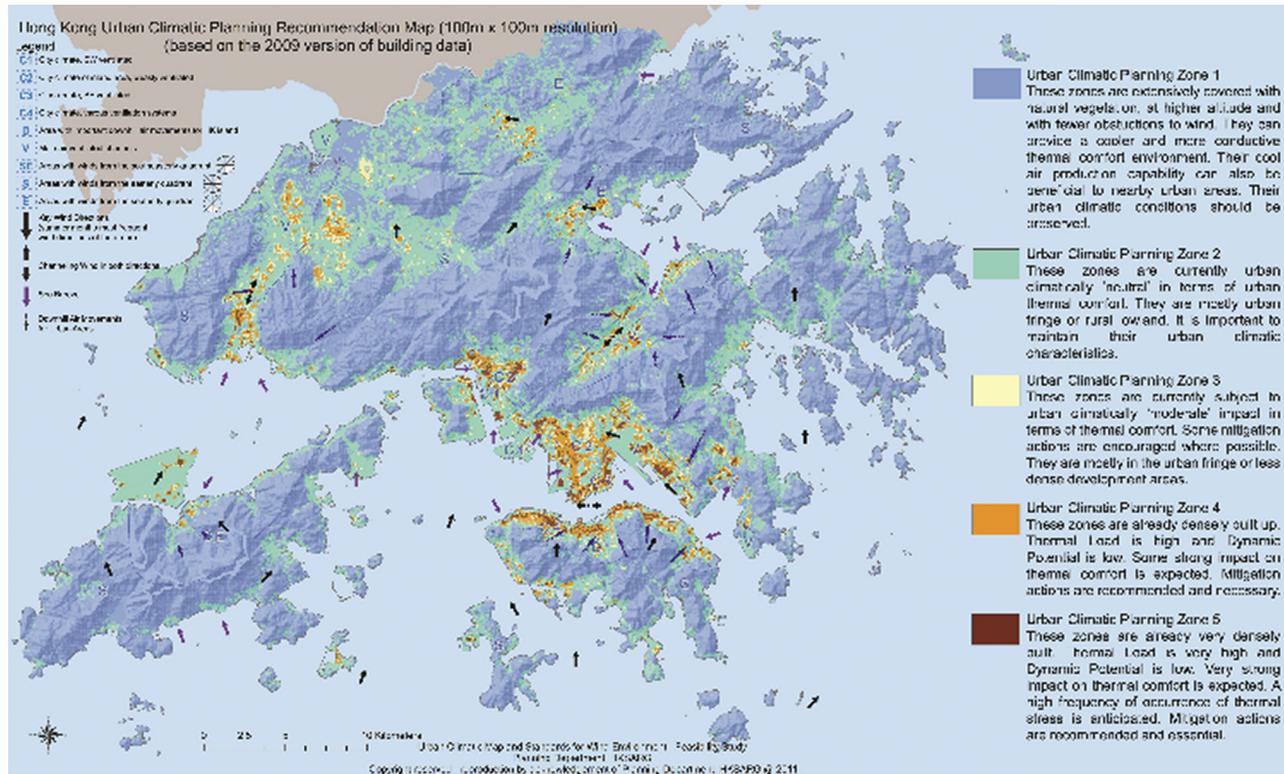
The Hong Kong Urban Climatic Maps are the results of 6 years of studies by researchers and governmental officials in Hong Kong (Ren et al., 2011). On the one hand, they provide a comprehensive scientific evaluation and information on the spatial distribution of the local urban climate (Planning Department, 2012); on the other hand, it builds a link between urban planning and its corresponding impact on the local urban climate. All of this can provide local planners and governments with quantitative references for their daily practice (Fig. 7).

In the recently published ‘Hong Kong 2030 +: Towards a Planning Vision and Strategy Transcending 2030’ (“Hong Kong 2030 +”), it is suggested that the UCMaP and its results on urban climatic evaluation and climatic-responsive planning recommendations be referred to in guiding the future town planning of Hong Kong towards a liveable, healthy, high-density city. Urban climatic and air ventilation considerations will be strengthened in the planning and design of new development areas. Due regard to the proposals in the Hong Kong Urban Climatic Planning Recommendation Map (HKGov., 2016) will also be made in the regeneration of some densely developed urban areas. The UCMaPs provide a “prevailing” and “criticality” understanding to planners and policy makers so that professional judgement based on the scientific evidence may be made (Ng, 2012). This is in line with the planning and design understanding as summarised in the recently published UCCRN-ARC Report (Rosenzweig et al., 2015) (Fig. 8).

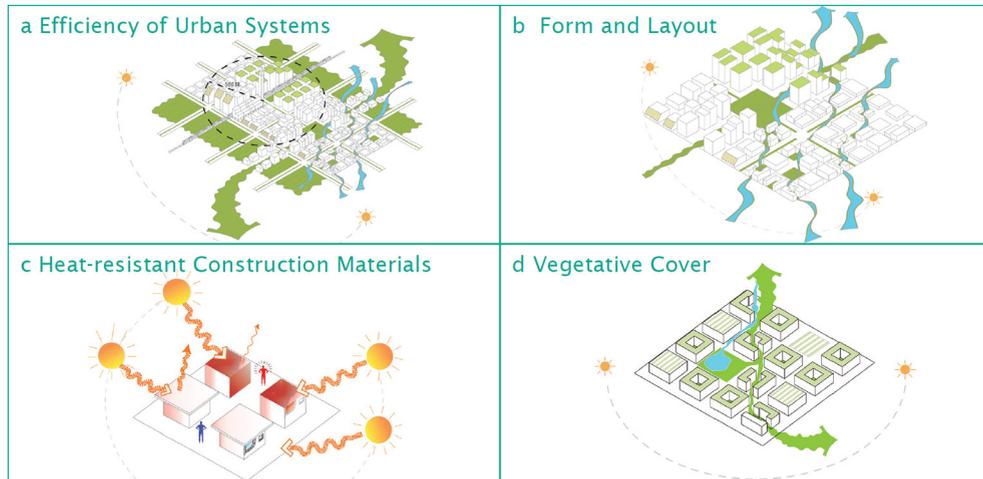
### 3. The urban climate challenges ahead

Given the global climate change challenges and the need for long term sustainable policies, China needs to adapt its cities in the mid- and short term to address the issue. The three examples of urban climate adaptation plans outlined above provide a glimpse into China’s realisation efforts at the urban level. The experience gained so far highlights a number of needs in order to cope with the challenges ahead. They are highlighted in the following section.

Mills and other researchers have highlighted the need for perspectives on the way forward for urban climatic application (Mills et al., 2010). For scientific knowledge to be transferred to practical application, the process must include: purpose, timing, subsidiarity, complexity, economic viability, sustainability, benefits, and integrated problem solving. The schema applies to all cities in the world.



**Fig. 7.** The Hong Kong urban climatic planning recommendation map of the Hong Kong SAR Government. The five colour coded categories indicates the five difference types of planning actions needed. The arrows on the map show the prevailing wind directions of the territory during the summer months. (Source: Planning Department, HKSAR Govt.)



**Fig. 8.** The diagrams summarise the larger regional scale understanding as in (a), the district understanding as in (b) and (d), and the building scale understanding as in (c) (Rosenzweig et al., 2015).

Against Mills' framework, experiences gained from project implementation in China highlights three important needs: (1) urban data, (2) a cross-disciplinary impact assessment, and (3) development of a market and policy transformation mechanism.

### 3.1. The need for urban data and the WUDAPT initiative

In Asian cities, accessible and standardised urban data are often unavailable or lacking. In the process of creating urban climatic knowledge for Wuhan, Macau and Hong Kong, it is apparent that the availability of urban morphological data at a suitable resolution is crucial. It precedes all subsequent modelling and assimilating works. In this respect, the recently initiated WUDAPT framework by Gerald Mills, Jason Ching, Chao Ren and others is worth noting (Ching et al., 2016).

For China, the first challenge to overcome must be the technical capability to quickly complete the initial assessment (WUDAPT level 0) of detailed urban morphological data for all 290 cities. As of today (Jun 2017), at the Chinese University of Hong Kong, Professor Chao Ren's team has already finished mapping most major cities in China to WUDAPT Level 0. Her team will complete all 290 Chinese cities by the end of the year. The harmonised database will provide the much-needed basis for an air corridor assessment of these cities. Based on the dataset, Ren's team will be able to quickly assemble the urban climatic maps of all the cities in China (Ren et al., 2011). Planning advice may then follow.

### 3.2. The need for cross disciplinary impact assessment

Once the key urban climate characteristics of cities have been established, the next task is to find ways to understand the implications. Fundamentally, there are three key concerns by local government, design stakeholders and as well as the general public. Firstly, it is about the city's need for energy and resources. Secondly, it is about the health impact on city dwellers. Thirdly, it is about the changing lifestyles.

To fully and holistically address the concerns, there is a need for cross disciplinary impact assessment. Scientific disciplines need to talk to their counterparts in other disciplines. For example, what is the new definition of "heat waves"? What health impact would it have? How can we better design our cities and buildings? And how can the community adjust its activities and lifestyles to cope with it? These and many more questions are cross-disciplinary in nature. Big Data techniques and its potential to cope with the variety of data from different disciplines may offer a way forward.

Developing an impact assessment schema is one thing. The potential the schema has on action is another. The framing of any impact assessment schema must be action oriented. It is necessary not only to tell the

“what”, but also to indicate the “how”, and when it comes to the “how”, solutions can only be contextually based. That is to say, they must relate to the professional, market, and policy practices of the city.

### 3.3. *The need for market and policy transformation*

The challenge is more difficult because it is beyond science. It has to do with the political will and, more importantly, the administrative capability for professional planners to take on the scientific information and merge it into their day-to-day practice of city planning. According to Professor Ingegård Eliasson, the challenge is conceptual, knowledge-based, institutional, and technical (Eliasson, 2000). The call has been echoed by Professor Gerald Mills and his co-authors (Mills et al., 2010). Two fundamental qualities of the needed information are their “criticality” and that they are “prevailing” (Mills, 2006; Ng, 2012). It is important to cross the river by feeling the stones – that is to say, there must be monitoring and feedback mechanisms in place to allow achievements to be measured, and more importantly, adjustments to the course to be made. When it comes to policy, the benefits must be beyond the environment. Economists have a role to play here especially when one is dealing with a capitalist economy. The short-term and the long-term payback and cost benefits must be quantified and communicated. In addition, sociologists are needed to help elaborate the qualitative and community benefits to the society. A win-win situation may not be found all the time, but there must be platforms that allow trade-offs and the balancing act to be negotiated among various parties.

## 4. Conclusion

Against the context and a critical reading of the 2014 Climate Summit and COP21, China's urban climatic adaptation strategies on greening and urban air corridor plans are reviewed. Premier Xi's “blue sky, green mountains and clean water” provides the much needed political impetus for recent actions. A few pilot projects have been attempted and a number of lessons have been learnt. This paper highlights three needs: (1) urban data, (2) a cross-disciplinary impact assessment, and (3) the development of a market and policy transformation mechanism. As China's urban transformation unfolds and more projects are attempted, it is certain that more needs and obstacles will be uncovered.

China's policy makers are aware of the difficulties ahead. A draft national standard titled “Technical specification for climatic feasibility demonstration in urban master plan” has been circulated. Prof Chao Ren is a lead author of the standard. Based on her published book on Urban ventilation (Ren, 2016), the national standard will address some of the “needs” this paper has highlighted. It will provide the much-needed standardisation of format, process, and methodology of data needed for urban climatic studies; it will give the fundamental principles of impact assessment, and it will put together an institutional framework of practice.

## 5. Epilogue

The recent conclusion of the COP21 in Paris is a starting point. Mitigation and adaptation measure are needed. China has laid out its targets. The recent rapid urbanisation processes in China adds to the complexity of the problems that need to be resolved. City dwellers are vulnerable, and they need to respond to the challenges. Cities and buildings need to be adapted or re-designed. Changing the city's infrastructural layout and provisions is a long process. The old saying that “Rome wasn't built in a day” still applies. What can be added is that changing what has been built will take even longer and require the firm commitment of all parties and stakeholders. This needs to be guided by robust science and understanding.

As for now, my take-home message when I gave the plenary lecture at the 9th ICUC conference in Toulouse is still valid: The giants of our discipline, Professor Tim Oke, Professor Robert Bornstein, and the like, and our predecessors have inspired us much on what we need to “know”, now it is our turn to pay respect by making “real” what we know.

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