Cities: the core of climate change mitigation

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Abstract: Cities, the core of the global climate change mitigation and strategic low-carbon development, are shelters to more than half of the world population and responsible for three quarters of global energy consumption and greenhouse gas (GHG). This special volume (SV) provides a platform that promotes multi- and inter-disciplinary analyses and discussions on the climate change mitigation for cities. All papers are divided into several themes, including GHG emission inventory and accounting, climate change and urban sectors, climate change and sustainable development, and strategies and mitigation action plans. First, this SV provides methods for constructing emission inventory from both production and consumption perspectives. These methods are useful to improve the comprehensiveness and accuracy of carbon accounting for international cities. Second, the climate change affects urban sectors from various aspects; simultaneously, GHG emissions caused by activities in urban sectors affect the climate system. This SV focuses on mitigation policies and assessment in energy, transport, construction, and service sectors. Third, climate change mitigation of cities is closely connected to urban sustainable development. This SV explores the relationships between climate change mitigation

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with urbanization, ecosystems, air pollution, and extreme events. Fourth, climate change mitigation policies can be divided into two categories: quantity-based mechanism (e.g., carbon emission trading) and price-based mechanism (e.g., carbon tax). This SV provides experiences of local climate change mitigation all over the world and proposes the city-to-city cooperation on climate change mitigation.

Keywords: Climate change, mitigation, city, emission inventory, sustainable development

1. Introduction

Cities are central to global climate change mitigation and the implementation of low-carbon development strategies. Cities are home to more than half of the world population and are responsible for three quarters of global energy consumption and greenhouse gas (GHG) emissions (Gouldson et al., 2016). As centers of wealth and innovation, cities also have resources and tools that are needed to address climate change challenges (Rosenzweig et al., 2010). Meanwhile, cities, traditionally built in coastal locations or on riverbanks, are highly exposed and vulnerable to climate change impacts (Vermeer and Rahmstorf, 2009), which brings huge risks to urban infrastructure, the life of urban residents, and the entire urban system.

Cities are increasingly at the forefront of efforts to address climate change mitigation with many signing up to frameworks for reducing GHG emissions. For example, C40 Cities Climate Leadership Group (C40) connects more than 80 of the world's megacities, representing more than 600 million people and 25% of the global economy, to address climate change and drive urban actions which reduce GHG emissions and climate risks. The Local Governments for Sustainability (ICLEI) establishes a global network of more than 1500 cities in 86 countries committed to build a sustainable and low-carbon future, which impacts over 20% of the world urban population.

These urban climate actions place urgent demands on the scientific community to provide timely and useful information and knowledge. Cities need an integrated approach of mitigating climate change which considers urban development, energy use, environments, human health, and ecosystem. However, crucial knowledge gaps remain in this field: 1) lack of consistent and comparable GHG emissions data at the city level; 2) lack of scientific understanding of the roles of urban sectors in mitigating climate change; 3) lack of scientific understanding of dynamics between sustainable development and climate change mitigation in cities; 4) lack of scientific understanding of how cities choose climate change mitigation strategies and local actions. Therefore, this special volume (SV) provides a platform that promotes multi- and inter- disciplinary analyses and discussions on the climate change mitigation and adaption for cities. This special volume aims to fill these four knowledge gaps, so all papers are divided into four themes:

Theme one: emission inventory and accounting at the city level;

Theme two: climate change and urban sectors;

Theme three: climate change and sustainable development of cities;

Theme four: strategies and mitigation action plans at the city level.

We would like to highlight several papers for each theme in the introduction, and all papers included in the special volume are demonstrated in section 2. Firstly, several feasible methods were developed for constructing CO_2 emissions inventories for cities. From the production-based perspective, a set of methods based on energy balance table to construct production-based CO_2 emissions inventories for Chinese cities were developed (Shan et al., 2017), and a high spatial resolution dataset of CO_2 emissions (CHRED) for 286 Chinese cities was generated (Cai et al., 2018). From consumption-based perspective, carbon footprint of of urban zone by six different kinds within the Helsinki Metropolitan Area (HMA) was mapped (Ottelin et al., 2018). In addition, substantial differences between production-based and consumption-based CO_2 emissions account were demonstrated in Sudmant et al. (2018) and Meng et al. (2017).

Secondly, climate change affects urban sectors from various aspects; simultaneously, GHG emissions caused by activities in urban sectors affect the climate system. The theme two emphasized on the roles of key sectors in mitigating climate change, including energy, transport, and construction. Plenty of actions were took for decarbonization in energy system, such as developing renewable energy (Rocha et al., 2017; Waheed et al., 2018) and improving energy efficiency (Waheed et al., 2018). The city is the hub of modern human life and the urban transport sector is developing fast, and electric vehicles will play a critical role in reducing emissions in transport sector (Álvarez Fernández, 2018; Magueta et al., 2018). From life cycle analysis perspective, there are considerable indirect emissions of CO2 as a result of activities in construction sector (Seo et al., 2018).

Thirdly, there are interactive relationships between climate change and urban sustainable development. Urbanization has large impacts on climate and environment all over the world (Yang et al., 2017), and the possible effects of future urbanization on climate change were estimated (Vasenev et al., 2018). Climate change is expected to increase the intensity and frequency of extreme events. These extreme events (e.g., floods and sea level rising) will have great impacts on urban sustainability. The concept of flood footprint was developed to measure the total economic impact directly or indirectly on the production system caused by the flooding losses (Mendoza-Tinoco et al., 2017), and a multiregional general equilibrium model was used to estimate the economic impacts of sea level rise in coastal cities in China (Cui et al., 2018).

Fourthly, many cities have taken actions to mitigate climate change. These actions can be divided into two categories, including quantity- and price-based mechanisms. The most widely used quantity-based mitigation policy in carbon emission trading (Hu et al., 2017; Zhou et al., 2018), which works by first giving participants a limit on emission permits, and then allowing them to buy or sell permits in the market. The most widely used price-based mechanism is carbon or energy consumption tax requiring a fixed every ton of CO2 emission fee (Li and Su, 2017).

2. Overview of papers included in the special volume

Theme one: GHG emission inventory and accounting at the city level

As one of the foundations for both climate change research and climate policy making, GHG emission inventory has attracted attention among the public and academic in recent years. Most of existing inventories are discussed at the national level or global level, while research on emission inventories for cities is limited.

It remains an open challenge to appropriately account for local-scale GHG emissions and identify GHG-reduced actions in many contexts (Martire et al., 2018). At the city level, it is still thought-provoking to complete a proper and consistent systematic boundary and computable processes for the calculation of carbon emissions. Boundaries of emission accounting vary from city to city, which depends on the purpose and definitions of the analysis. Three different scopes of regional carbon emissions are commonly accepted, involving territorial emissions, emissions embodied in electricity produced and imported or purchased from outside the boundary, and emissions refer to emissions embodied in imported products and services. Additionally, there are intensive interactions across system boundaries in cities, namely cross-boundary activities including domestic and international transportation, inter-regional electricity transmission and flows of other goods and services and purchased power supply generated outside the boundary, which have significant influence on the calculations of carbon emissions depending on the level of boundary chosen.

At the city level, substantial differences between production-based and consumption-based CO_2 emissions account for carbon emissions. More specifically, production-based CO_2 emissions, caused by domestic production together with exports, accounts for emissions at the point of production, excluding the consideration of final-used destinations or ultimately-used customers of goods. Shan et al. (2017) proposed a set of methods based on energy balance table to construct production-based CO_2 emissions inventories for Chinese cities. The new-constructed emission inventory, in terms of the definition provided by the IPCC territorial emission accounting, is composed covering 47 socioeconomic sectors, 17 fossil fuels and 9 primary industry products. Liu et al. (2018b) developed an improved allocating model to trace the CO_2 emissions of mainland China in 2000, 2005, 2010, and 2013 at the city level according to an enhanced vegetation index (EVI) adjusted nighttime light index (EANTLI) and LandScan population data. Li et al. (2017b) proposed a location-based emission inventory approach by using sampling surveys, enterprise GHG reports and the geo-referenced data to estimate the emissions and the spatial distributions. Zhu et al. (2017) calculated the industrial CO_2 emissions related to energy among 17 cities in China's Yangtze River Delta region between 2005 and 2014. Chen et al. (2018a) estimated industrial CO_2 emissions in 187 prefecture-level cities in China from 2005 to 2013 by mainly-used fossil energies in industrial sectors. (Du et al., 2018) developed an integrated system dynamic model with eight sub-models (socio-economic; primary, secondary, and tertiary industry; residential; transportation; waste disposal; and electricity models) to evaluate carbon emissions in Shanghai during 1991-2015. Cai et al. (2018) improved carbon accounting method on the comprehensiveness and accuracy by generating a high spatial resolution dataset of CO_2 emissions (CHRED) for 286 Chinese cities.

On the contrary, all emissions occurring in the production and distribution sectors are allocated to the final product consumers in the calculation based on consumption. According to this method, emissions from imported product areas are allocated to their production. Ottelin et al. (2018) mapped carbon footprints of urban zone by six different kinds within the Helsinki Metropolitan Area (HMA), including the central pedestrian zone, the fringe of the central pedestrian zone, intensive public transport zone, public transport zone, car zone and the pedestrian zones of subcentres. Long et al. (2017) explored the indirect household carbon emissions by source and its relationship with potentially affecting attributes through a case study on 49 Japanese prefecture capital-level cities. Liao et al. (2017) used the semi-enclosed input-output model and improved hypothesis extraction method to measure the economic contribution of sectors and households made to CO_2 emissions in Beijing. Isman et al. (2018) focused on the carbon footprint subcomponent of the Ecological Footprint, and further translated and disaggregated the carbon footprint into detailed classification of individual consumption. Fry et al. (2018) believed that urban carbon footprint analysis needs to include input-output databases and related calculations to avoid serious errors caused by unacceptable range limitations resulted from the cutoff of footprint assessment boundary. Thus, according to different data availability levels, the carbon footprints of Beijing, Shanghai, Chongqing and Tianjin in four cities in China were determined.

The two emission accounting approaches are compared in certain studies. Sudmant et al. (2018) analyzed and compared production- and consumption-based emissions accounts for cities in China, the UK and the US. Meng et al. (2017) calculated the production- and consumption-based emissions in 2012 in four Chinese megacities: Beijing, Shanghai, Tianjin and Chongqing. Andrade et al. (2018) analyzed the challenges faced by Madrid's production-based GHG emission inventory to estimate the emissions caused by the supply chain and final consumers by London's GHG emission inventory experience.

Theme two: Climate change and urban sectors

Climate change affects urban sectors from various aspects; simultaneously, GHG emissions caused by activities in urban sectors affect the climate system. Urban energy systems which provide the “life blood” to cities contribute largely to global CO_2 emissions. CO_2 emissions from energy use in cities account for a dominant part of global emissions. Emissions in energy sectors are determined by many factors, such as energy use levels, energy mix, and technology. Conversely, climate change may affect urban energy systems in many different ways. While the contributions of energy consumption to global climate change have been extensively researched, studies on climate changing impacts on energy systems are still limited. However, it is clear that urban energy sector can be influenced by the changing climate at all parts of the processes including supply, demand, operations, and assets. Wei et al. (2017) calculated the carbon emissions of urban power grid in one of the most populous and economically dynamic regions in China, namely Jing-Jin-Ji region. Wang et al. (2018a) undertook the IPCC bottom-up inventory indicator to estimate the GHG emissions from biomass combustion in China and used GIS to reveal the temporal and spatial characteristics of biomass combustion emissions. To and Lee (2017) used a life cycle approach and fuel mix data from power companies' sustainability reports to analyze GHG emissions from electricity consumption in Hong Kong. Rocha et al. (2017) analysed the influence on the circulation of goods and services by tax exemptions together with the returns and risks of photovoltaic (PV) micro-generation projects in four cities in different regions of Brazil. Dou et al. (2018) evaluated land use influence on indicators of economy and environment by establishing a comprehensive model for the feasibility evaluation of heat exchange networks between city-scale incineration facilities and industries. Waheed et al. (2018) investigated the effects of renewable energy consumption on carbon emission in Pakistan. Gupta and Gregg (2018) presented a localised Geographical Information System (GIS) based approach that utilized publicly-available national and local datasets on housing and energy to provide targeted low carbon measures across UK cities. Roelich et al. (2018) conducted a longitudinal analysis from 2013 to 2017 including five British cities which try to form new institutional arrangements for the participation of the national energy system and contribution to the climate change mitigation. Ramadan (2017) developed an optimization model to assess the wind energy farm sizing for an optimal energy yield in Sinai Peninsula, Egypt.

Transport sector accounts for a large proportion of energy demand and carbon emissions and is growing rapidly. The city is the hub of modern human life and the urban transport sector is developing fast. Specifically, in the Internet era, the development of public transport has brought new challenges and opportunities to urban passenger transport. Thus, research on the carbon emissions of the urban transport sector is significant and timely. Yu et al. (2017) investigated total factor carbon-sensitive productivity growth in the regional transport sector in China and decomposed its dynamic changes over time taking account of the regional heterogeneity of different provinces. Magueta et al. (2018) explored average CO_2 emissions and sales evolution, in terms of descriptive statistics, by using the sales database of new cars sold in Portugal from 2002 to 2016, where different types of new car sales (gasoline, diesel and electricity) are taken into account. Fan et al. (2017) took Beijing's public transport as an example and applied the Long-range Energy Alternatives Planning (LEAP) model to analyze the energy demand and the main GHG emissions under different scenarios during the period 2016–2030. Beheshtian et al. (2018) introduced an infrastructure of alternative fuel as a synergistic approach to climate-adaptation and -mitigation, and advanced a quantitative method to simulate the dependency of travel behavior on fuel availability when the infrastructure of transportation energy is stressed or under attack. Becherif et al. (2018) presented three novel methods for an efficient and rapid estimation of the Electrochemical Impedance Spectrum (EIS) of the Fuel Cell. Cong et al. (2017) examined the whole chain of biogas utilisation (biomass supply, biogas production and distribution, and fuel substitution) from both environmental and economic perspectives in the Danish transport sector. Yin et al. (2018) developed an integrated land-use transport model to estimate the climate change impacts of ride-sharing in the Paris. Álvarez Fernández (2018) analyzed the impacts of the use of electric vehicles on GHG emissions. Liu and He (2017) estimated the demand for road passenger transport in China, which is considered to be one of the most important sources of air pollution in city. Hofer et al. (2018) estimated CO_2 emissions caused by urban car traffic for the city of Graz, a typical European inland city. Guo et al. (2018) used input-output model to analyze energy consumption and CO_2 emissions from the key sectors in China. Their results demonstrated that China's road transportation contributed a dominant part to carbon emissions of the whole transportation sector. Yang et al. (2018) estimated the carbon emission and mitigation potential in the domain of daily travel in Beijing.

Construction sector can cause carbon emissions from direct and indirect approaches. There are many direct CO_2 use in construction sector, such as compressed gases for pneumatic systems in portable pressure tools. From life cycle analysis perspective, there are considerable indirect emissions of CO_2 as a result of activities in construction sector. Tam et al. (2018) reviewed the research about the biologically inspired algorithms in different fields of sustainable building designs together with the module modelling development till 2016. Ziogou et al. (2017) studied not only energy conservation also its sustainability related to two alternative green roof solutions for a typical urban office building in the areas representing the climate of Cyprus in the Eastern Mediterranean. Seo et al. (2018) analyzed the embodied impacts of different dwelling stock retrofit programs using a combination of a top-down and a bottom-up approach, in the Greater Melbourne Area (GMA), the fastest growing capital city in Australia. Heidarinejad et al. (2018) analyzed the influence of Personalized Conditioning (PC) systems for potential savings of energy, cost, and CO_2 emissions from commercial buildings in different U.S. cities. Bertone et al. (2018) adopted a mixed methods approach including scenario modelling and stakeholder workshops and interviews to identify the key challenges and potential coping strategies for retrofitting public buildings. Fastenrath and Braun (2018) analyzed the co-evolution and interplay of building practices, policy making and involved actors in Brisbane in Australia to exam the place-specific contextualization of green building transitions. Palermo et al. (2018) found that building retrofit can largely reduce energy use and emissions at the neighborhood scale. Zhang et al. (2018) discussed the co-benefits of urban concrete recycling on the mitigation of greenhouse gas emissions. Ribeiro et al. (2018) assessed the water and energy efficiency programs in buildings in developing cities.

Service sector is always considered as cleaner than industrial sectors. Both energy and carbon intensities are lower. Lin and Zhang (2017) applied a meta-frontier slack-based efficiency measure (MSBM) approach to estimate the energy efficiency of Chinese service sector. Chaplin-Kramer et al. (2017) applied a meta-frontier slack-based efficiency measure (MSBM) approach to estimate the energy efficiency of service sector in China by panel data at province level between 1995 and 2013. Wang and Lin (2017) applied VAR and STIRPAT models to investigate the major influencing factors of CO_2 emissions in China's commercial sector over the period 1980–2014.

Theme three: Climate change and sustainable development of cities

There are interactive relationships between climate change and urban sustainable development (SD) (Jin et al., 2015; Vergragt et al., 2015). On the one hand, priorities of society on urban sustainable development have impacts on the GHG emissions which are the main reason for climate change. Policies and institutions on urban sustainable development may constrain or facilitate climate change mitigation and adaptation. Many studies have integrated climate change mitigation and adaptation perspectives into sustainable development policies, because tackling climate change will make urban development more sustainable. In the *Transforming Our World: the 2030 Agenda for Sustainable Development* adopted by United Nations, for example, the adopting and implementing policies to mitigate and adapt climate change are an important goal for sustainable cities. On the other hand, climate change has impacts on human living conditions which are the basis for urban socio-economic development. The ability of cities to achieve sustainable development goals will be affected by climate change and climate policy responses. So urban sustainable development can be considered as an issue which is indirectly influenced by climate change policies.

Urbanization has large impacts on climate and environment all over the world. The effects of urbanization and climate change are converging in many ways. Zhang and

Wu (2018) presented observational evidence for the impacts of human migration on urban relative humidity in Beijing, China. Yang et al. (2017) investigated the impact of urbanization on energy consumption using data from China's 266 prefecture-level cities over the 2000–2010 period and examined the heterogeneity of this impact across income and urbanization groups. Vasenev et al. (2018) explored the possible net effects of future urbanization, based on the model of soil survey and land conversion, on soil organic carbon stocks in the Moscow Region. Pardo Martínez et al. (2018) analysed the opinion on climate change from the urban population by a survey based on the next-year vulnerable effect by this phenomenon on cities. Han et al. (2018) used the theory of agglomeration economies to explore the mechanism when urban agglomeration economies affecting carbon emission. Fujii et al. (2017) identified factors determining changes in urban carbon emissions according to the city type by a dataset from metropolitans. Shen et al. (2018) used logarithmic mean Divisia index (LMDI) to decompose emission factors into energy structure, energy intensity, industrial structure, economic output and population scale. Chen et al. (2018b) explored the global warming impact of suburbanization in the city of Sydney.

Urban ecosystems have great impacts on biogeochemical cycles of elements and influence climate through gaseous emissions. Mauerhofer and Essl (2018) provided a new framework to analyze how to solve conflicting interests between climate change and biodiversity conservation laws on Vienna in Austria as an example. Wang et al. (2018d) used emergy analysis involving urban ecosystem health assessment and Difference-in-Difference approach to analyze precipitation extreme and urban ecosystem health in Beijing and Tianjin. Hou et al. (2018) quantitatively assess the climate change mitigation potential of contaminated land redevelopment for the city of San Francisco in the US. Bonn et al. (2018) explored potential urban management strategies by the survey of increasing urban vegetation effect, taking tree species on atmospheric chemistry counteracting high levels of local pollutants including ozone, OH and PM_{10} as an example. Zölch et al. (2018) investigated the implementation of ecosystem-based approach into municipal climate adaptation strategies. Wu et al.

(2018) collected the Air Quality Index (AQI) from key control cities above prefecture level in China as well as the stock yield data of these cities' heavy pollution enterprises from 2014 to 2016 and through multi-discontinuities regression model, tested the effect of air pollution on the stock yield of heavy pollution enterprise. Hao et al. (2018) used city-level panel data to estimate the influence of PM2.5 concentrations on economic development. Alavipanah et al. (2018) derived the surface temperature and two-dimensional (2D) and three-dimensional (3D) information at the city level by a range of multispectral and spatial vector data. Wang et al. (2018e) investigated urban resilience in Beijing from a social-economic-ecological system perspective.

Climate change is expected to increase the intensity and frequency of extreme events. These extreme events (e.g., floods and sea level rising) will have great impacts on urban sustainability. Mendoza-Tinoco et al. (2017) introduced the concept of flood footprint as a novel accounting framework to measure the total economic impact directly or indirectly on the production system caused by the flooding losses for the production factors, infrastructure and housing capital. Abebe et al. (2018) proposed a coupled Geographic Information System and Bayesian Belief Network based flood vulnerability assessment model to quantify uncertainty and capture the casual nexus between pluvial flood influencing factors. Chan et al. (2018) reviewed the mitigation strategies policies to reduce the flooding damages in Hong Kong and Singapore. Wang et al. (2018c) studied the effective urban storm water infrastructure under different scenarios for potential future changes. Rodríguez-Sinobas et al. (2018) improved water management in the new urban development of Valdebebas in Madrid by the Low Impact Development measures. Cui et al. (2018) used a multiregional general equilibrium model to estimate the economic impacts of sea level rise in coastal cities in China. Abadie (2018) proposed a model which assigned probabilities to IPCC scenarios with Local Sea Level Rise information, and obtained expected damage and risk measures for the world's 120 major coastal mega-cities at specific moments in time. Salas and Yepes (2018) selected urban vulnerability assessment models which are more evolved with many objectives.

Theme four: Strategies and mitigation action plans at the city level

Many cities have taken actions to mitigate climate change. For example, C40 Cities Climate Leadership Group (C40) and Local Governments for Sustainability (ICLEI) are two global networks where many cities cooperate to address climate change. Cities need more the scientific community to provide useful information to support their climate actions.

There are many policy options for one city to address climate change, such as improving energy efficiency, reducing fossil energy use, advocating low-carbon life, and establishing carbon trading markets. Cities need to find appropriate low-carbon development pathways for their sustainable development. Many criteria need to be considered for evaluating and choosing urban climate policies, including environmental effectiveness, cost-effectiveness, intergenerational equity, interregional equity, institutional feasibility, technical feasibility, and ethics.

Many researchers divided climate change mitigation policies into two categories, including quantity- and price-based mechanism. The most widely used quantity-based mitigation policy in carbon emission trading, which works by first giving participants a limit on emission permits, and then allowing them to buy or sell permits in the market. Its advantage is that it can directly control the level of emission reduction in case of carbon price uncertainty. One of the key elements of the cap-and-trade system is that participants can purchase and sell permits to obtain the lowest cost for the city with the lowest cost for themselves. Particularly, participants who can reduce emissions more cheaply will sell extra permits. On the contrary, lower-cost participants will avoid buying permits. Hu et al. (2017) assessed the operational performance and maturity of the carbon trading pilot program in Beijing. The allocation of carbon emission quotas is the basic and essential milestone to establish a national carbon emissions trading market. Qin et al. (2017) proposed a decision analysis model with multi criteria to allocate carbon emission quota in east coastal areas in China. Zhou et al. (2018) developed a multi-abated factor DEA approach to allocate CO_2 emission quotas for cities in China.

The most widely used price-based mechanism is carbon or energy consumption tax requiring a fixed every ton of CO_2 emission fee. By determining reduction level indirectly, the carbon price can be controlled directly. The price-based mechanism is cost-effective because of the choices made by the emitters who can reduce emissions at a cost below the tax or fixed fee. Li and Su (2017) developed a city-level Computable General Equilibrium (CGE) model to simulate potential impacts of carbon pricing on the city, including paying border-carbon-adjustment (BCA) on exports or introducing a domestic carbon tax. Zhao et al. (2018) investigated the rationality of the way adjusting the consumption tax and its impacts on carbon emissions. Zhang and Lin (2018) investigated the effectiveness of the tiered-electricity pricing system, which intended to motivate electricity saving behavior and address cross-subsidization issue.

Some studies proposed to used branding tools to promote emission reduction of cities. Many countries and organizations are trying to identify branding methods for guiding low-carbon consumption by residents in order to actively respond to global climate change. As a method for identifying the greenhouse gas emissions produced during the full life cycle of a product, the effects of carbon labels on low-carbon consumption behavior by different types of consumers is worthy of investigation. Li et al. (2017a) surveyed the willingness when consumers purchasing low-carbon products with carbon labels. de Jong et al. (2018) compared the city branding practices to respond to the challenge of ecological modernization in three Chinese megacities, including Hong Kong, Shanghai and Beijing. Illankoon et al. (2018) analyzed the life cycle costs of concrete using supplementary cementitious materials in obtaining concrete credits according to Green Star rating system in Australia. Axon et al. (2018) investigated factors and barriers to behavior change initiatives, which were classified into six categories including community-based interventions, information and awareness based interventions, eco-districts, show-case events, energy switching and smart-technology focused interventions.

City-to-city (C2C) cooperation, in which cities collectively face the climate change by its transnational networks, is significant for climate change mitigation. It is an opportunity for policymakers to learn from other cities who conduct climate mitigation and adaptation measures through the interaction and collaboration. While many studies have introduced the climate change mitigation actions in single city, such as Cologne in Germany (Holtz et al., 2018), Vienna in Austria (Essl and Mauerhofer, 2018), Copenhagen, Denmark (Damsø et al., 2017), Bangkok, Thailand (Ali et al., 2017), Shenzhen, China (Zhan and de Jong, 2018), Shanghai, China (den Hartog et al., 2018; Peng and Bai, 2018), Nanchang, China (Jia et al., 2018), and Suzhou, China (Liu et al., 2018a), some studies have introduced the C2C climate networks. Lee and Jung (2018) identified and categorized C2C networks for climate change action, and to link the functions with levels of activity. The European Commission started the Covenant of Mayors to encourage the sustainable energy plans by local authorities contributing to greenhouse gases emissions mitigation, which aims to achieve the goals for climate change and energy efficiency in the European Strategy, known as the 20-20-20 package. Pablo-Romero et al. (2018) used the database from the Covenant of Mayors organization to study the main benchmark actions of nearly 1300 cities. Coelho et al. (2018) examined the Sustainable Energy Action Plan (SEAP) submitted by 124 Portuguese municipalities. Nagorny-Koring and Nochta (2018) analyzed two EU-funded projects for eight cities from diverse European countries in a case study to estimate the urban transitions theoretically and practically. Reckien et al. (2018) collected the climate mitigation and adaptation plans across 885 urban areas of the EU, and divided these plans into three types.

Many performance evaluation methods are used to to evaluate the performance of strategies or actions of climate change mitigation at the city level. The most widely used approach is Data Envelopment Analysis (DEA). Zhou et al. (2018) evaluated CO_2 emission performance and allocated emission quotas for cities in China by a DEA approach with multi-abated factors. Sun et al. (2018) proposed an improved DEA model for measuring emission-reduction and energy-conservation efficiency of 211 Chinese cities. Gonzalez-Garcia et al. (2018) used a DEA model with multi criteria, which takes an indicators' offset from the three pillars of sustainability into consideration, to identify the non-sustainable cities. Pu and Fu (2018) estimated the contribution to the political career of a Chinese mayor made by the economic performance and environmental quality. Wang et al. (2018b) developed an urban green development evaluation index to analyze the green development level of nine cities in the Pearl River Delta, China. Wu et al. (2017) used a model of distance function with non-radial direction to examines CO_2 emission efficiency and productivity in 286 Chinese cities.

3. Conclusions

Cities play a key role in the low-carbon transition, with an increasing number of cities engaging in carbon mitigation actions. This SV discusses emission accounting, sustainability, strategies and mitigation action plans at the city level. This SV provides methods for constructing emission inventories from both production and consumption perspectives. These methods are useful to improve the comprehensiveness and accuracy of carbon accounting for international cities. Climate change mitigation of cities is closely connected to urban sustainable development. This SV discusses the relationships between climate change mitigation with urbanization, ecosystems, air pollution, and extreme events. In addition, this SV provides experiences of local climate change mitigation all over the world and proposes the city-to-city cooperation on climate change mitigation. The Covenant of Mayors launched by the European

Commission is examined in this SV. All in all, city-level study will be the trend for climate change mitigation.

However, some knowledge gaps still remain in this field. First, efforts are needed to reduce uncertainties in emission inventories for cities. Emission data are foundations of climate change mitigation research and actions. Although this SV provides methods to improve the comprehensiveness and accuracy of carbon accounting for international cities, there are still uncertainties in these inventories. Second, there are gaps between researchers and policy makers on city-level climate change mitigation. Some studies did quantitative or qualitative analysis on climate change mitigation in cities, without providing any practicable policy implications. Third, the interdependencies of climate adaptation and mitigation measures are critical in cities. This SV focuses on climate change mitigation in cities. More efforts are needed to research the balance and interdependencies between climate adaptation and mitigation in cities.

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