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Research article

Source data supported high resolution carbon emissions inventory for urban areas of the Beijing-Tianjin-Hebei region: Spatial patterns, decomposition and policy implications

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A B S T R A C T

This paper developed internationally compatible methods for delineating boundaries of urban areas in China. By integrating emission source data with existing official statistics as well as using rescaling methodology of data mapping for 1 km grid, the authors constructed high resolution emission gridded data in Beijing-Tianjin-Hebei (Jing-Jin-Ji) region in China for 2012. Comparisons between urban and non-urban areas of carbon emissions from industry, agriculture, household and transport exhibited regional disparities as well as sectoral differences. Except for the Hebei province, per capita total direct carbon emissions from urban extents in Beijing and Tianjin were both lower than provincial averages, indicating the climate benefit of urbanization, comparable to results from developed countries. Urban extents in the Hebei province were mainly industrial centers while those in Beijing and Tianjin were more service oriented. Further decomposition analysis revealed population to be a common major driver for increased carbon emissions but climate implications of urban design, economic productivity of land use, and carbon intensity of GDP were both cluster- and sector-specific. This study disapproves the one-size-fits-all solution for carbon mitigation but calls for down-scaled analysis of carbon emissions and formulation of localized carbon reduction strategies in the Jing-Jin-Ji as well as other regions in China.

1. Introduction

Cities account for 71–76 per cent of carbon emissions from energy activities in the world and thus are target for carbon reduction efforts (IPCC, 2014). The United Nations population estimate predicts global population growth between 2012 and 2050 to mainly occur in cities (United Nations. Department of Economic and Social Affairs. Population Division., 2015). World CO_2 emissions, as well as its spatial distribution, would be significantly altered if anticipated rapid urbanization would occur and the per capita urban energy consumption would increase in Africa, non-OECD (Organization for Economic Co-operation and Development) countries and Asia (IEA, 2014).

In the context of rapid industrialization and urbanization in China, the activities related to energy were even more important than other parts of the world. From 1973 to 2013, China's total primary energy supply, electricity generation, fuel consumption, and CO_2 emissions from combustion had been increasing by 14.5, 71, 10.2, and 20.7 per cent annually, respectively. This is about 5, 10.7, 4.3, and 8 times that of the world average, respectively (Table 1) (IEA, 2015). Consequently, the Chinese government has taken several measures for upgrading energy mix and increasing energy efficiency for achieving low carbon development (State Council, 2011).

Most recently, changing urban design for the Beijing-Tianjin-Hebei (Jing-Jin-Ji) capital region has been initiated by the State Council of China. It is aimed to differentiate sectoral focus by locality and to enhance regional collaboration for environmental protection, carbon reduction, industrial development and provision of public services (Xinhua Net, 2015). Carbon emissions inventory

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Table 1
Energy supply and consumption and energy-related CO_2 emissions, comparing China with the world, 1973–2013.

	World			China's share		
	1973	2013	Average annual rate of increase	1973	2013	Average annual rate of increase
Total primary energy supply (TPES) (Mtoe)	6100	13,541	2.90%	7.0%	22.3%	14.46%
Electricity generation (TWh)	6131	23,322	6.68%	2.9%	23.5%	71.01%
Fuel consumption (Mtoe)	4667	9301	2.36%	7.9%	21.0%	10.23%
CO_2 emissions from combustion (Mts)	15,515	32,190	2.56%	6.0%	28.0%	20.67%

Note: Authors' compilation based on *Key World Energy Statistics* published by the International Energy Agency in 2015.

as well as its spatial distribution form a basis for building evidence-based development and carbon mitigation strategies that can potentially lead to regionally aligned green growth in the Jing-Jin-Ji capital region.

In the past, several attempts have been made to construct carbon emissions inventories for Chinese cities. However, a Chinese 'city' refers to an administrative region, usually comprising urban areas as well as a large proportion of non-built-up areas such as agricultural and forest land. Consequently, carbon emissions calculated for Chinese cities based on officially defined city boundaries do not capture similar human settlements as in literature studying urban carbon emissions in other countries, and pose challenge for international comparison. Furthermore, those results can hardly inform the Chinese government in urban planning or formulating space-based mitigation strategies. As a remedy, Montgomery (2008) suggested to follow boundaries of central business districts of Beijing and Dhakal (2009) suggested to only include urban districts but to leave out counties. Although the above modifications for calculating carbon emissions of Chinese cities can improve precision of analysis, those boundaries are still administratively defined and do not accurately capture features of urban forms and human settlements.

Thus, scholars are faced with the following two challenges in advancing analysis on carbon emissions from Chinese cities: (1) defining boundaries of analysis taking into consideration levels of human activities; and (2) obtaining disaggregated data on human activities for constructing high resolution carbon emissions inventories for the above specified urban areas within administratively defined 'Chinese cities'. However, only modest efforts have been made to advance alternative methods for documenting carbon emissions for Chinese cities. For example, Cai and Zhang (2014) experimented with four different methods for defining boundaries of urban extents: administrative boundary, district boundary, built-up area, and urban proper and derived CO_2 emissions of the Tianjin municipality by adopting those four methods which reported as large as 654% of difference in results. They concluded urban extent is appropriate for understanding spatial patterns of CO_2 emissions in China and for making international comparisons. Explorations have also been made on spatial analysis of CO_2 emissions in Japan (Makido et al., 2012), Asia (Marcotullio et al., 2012) and the U.S. (Gurney et al., 2009; Parshall et al., 2010; Zhou and Gurney, 2011). Furthermore, although researchers have invented statistical methods for disaggregating carbon emissions to small geographical areas (Seya et al., 2016), high resolution carbon inventories constructed from emission source data are scarce due to challenges in data availability and computation.

China is expected to reach an urbanization rate of 70–75 per cent by 2050 (Institute for Scientific Research on Chinese Cities, 2009). In the meantime, the Chinese government is aiming for CO_2 emissions to peak around 2030 (The White House and Office of the Press Secretary, 2014). Thus, it is important to gain a good understanding of the complex socio-ecological system and to instrument sectoral and space-based strategies for carbon mitigation (Duit et al., 2010). This paper makes a contribution to both Chinese policymaking and the academic literature by (1) developing internationally compatible method for delineating boundaries of urban extents based on population density in the Jing-Jin-Ji region, (2) constructing 1 km gridded high resolution carbon emissions inventory by data rescaling and mapping of emission source data and official statistics, (3) comparing urban with non-urban extents and adopting cluster analysis for identifying spatial patterns of CO_2 emission across the Jing-Jin-Ji region, and (4) decomposing CO_2 emissions by the following four driving forces, using Kaya equation: population, urban design (land area per capita), economic productivity of land use (GDP generated per unit land area), and carbon intensity (CO_2 emissions per unit GDP). The study is a forerunner in bridging science and policy by the construction of the high resolution carbon emissions inventory to a human scale for the identified 213 urban extents, identification of spatial and sectoral patterns, and decomposition of driving forces of CO_2 emissions. Those results will inform carbon mitigation and regionally aligned development strategies in the Jing-Jin-Ji region. Furthermore, methodology adopted in this study for integrating emission source data and official statistics as well as data rescaling and mapping can be replicated for other localities and can inform formulation of locally appropriate carbon reduction strategies.

2. Methodology and data

2.1. Basic information about Jing-Jin-Ji region

Jing-Jin-Ji region, the national capital region, with two centrally directly-controlled municipalities (Beijing and Tianjin, CDCM) and Hebei province, is the biggest urbanized region in Northern China. The region covers 216,760 km^2 of land, inhabited by a total population of 107.7 million in 2012 (National Bureau of Statistics, 2013). Fig. 1 illustrates 13 administratively defined cities altogether in the Jing-Jin-Ji region, namely, Beijing, Tianjin, and 11 prefectural level cities[1] in the Hebei province.

2.2. Data

Data used in the analysis is all from the year of 2012. Following Cai and Zhang (2014), for building 1 km gridded carbon emissions inventory for sources in Scope 1 and Scope 2[2] for the Jing-Jin-Ji

[1] All territories in China are classified into the following four administrative levels, from the highest to the lowest: province/autonomous region/centrally directly controlled municipality, prefectural level city, county/county-level city/district, and township/village.

[2] Scope 1 includes all direct emissions that occur within the territorial boundary of the city. Scope 2 includes indirect emissions that occur outside the city boundary as a result of activities that occur within the city, which are limited to electricity consumption, district heating, steam and cooling. Scope 3 includes other indirect emissions and embodied emissions that occur outside the city boundary as a result of activities of the city, including electrical transmission and distribution losses, embodied emissions in fuels and imported goods, etc. (Cai and Zhang, 2014).