Carbon dioxide emission drivers for a typical metropolis using input–output structural decomposition analysis

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HIGHLIGHTS

- Changes in production structure and population are drivers of CO2 increment.
- Changes in CO2 intensity and per capita GDP are forces to offset CO2 increment.
- Final demand structure change has limited effect on Beijing's CO2 emission change.
- Beijing's key final demand categories and economic sectors are identified.
- Policy implications of Beijing's results are analyzed.

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ABSTRACT

As the capital of China, Beijing is regarded as a major metropolis in the world. Study of the variation in temporal CO2 emissions generated by the driving forces in Beijing can provide guidance for policy decisions on CO2 emissions mitigation in global metropolises. Based on input–output structural decomposition analysis (IO-SDA), we analysed the driving forces for the increment in CO2 emissions in Beijing from both production and final demand perspectives during 1997–2010. According to our results, the CO2 emission growth in Beijing is driven mainly by production structure change and population growth, partly offset by CO2 emission intensity reduction as well as the decline in per capita final demand volume during the study period. Final demand structure change has a limited effect on the change in the CO2 emissions in Beijing. From the final demand perspective, urban trades, urban residential consumption, government consumption and fixed capital formation are mainly responsible for the booming emissions. This study showed how the “top-down” IO-SDA methodology was implemented on a city scale. Policy implications from this study would be helpful for addressing CO2 emissions mitigation in global capital cities and metropolises.

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1. Introduction

Cities are centres of anthropogenic activities, making them major contributors to global CO2 emissions (Satterthwaite, 2008). Cities thus play a crucial role in human actions for curbing global climate change (Hillman and Ramaswami, 2010; Kennedy et al., 2010; Koehn, 2008). The impact of cities on energy use and associated emissions is more severe in developing countries that are in a state of rapid urbanisation and industrialisation. China, the world largest developing country, has already become the top primary energy consumer as well as the top CO2 emitter in the world (Boden et al., 2012; Gregg et al., 2008). About half of the Chinese population now lives in cities, especially in metropolises such as Beijing and Shanghai (NBSC, 2011). Energy usage in Chinese cities consumes the major share (84%) of the national total (Dhakal, 2009). The expected increase in urban households and the improvement of quality of life imply an even higher emission scenario over the next decades. Understanding the emission status of Chinese cities is therefore critical for global mitigation.

Based on current knowledge of emission status, uncovering the driving forces of the increment in emissions is the cornerstone for presenting a comprehensive analysis and projecting future emission
scenarios (Guan et al., 2008; Liang et al., in press; Wang and Liang, in press). The relative contributions of socio-economic factors, such as population, economic growth, production, and final demand structures, and CO2 intensity to the change in the CO2 emissions in China have been examined (Guan et al., 2008, 2009; Liang and Zhang, 2011d; Minx et al., 2011; Peters et al., 2007; Xu et al., 2011; Zhang, 2009). Index decomposing analysis (IDA) and structure decomposing analysis (SDA) models are two major methods for presenting the analysis of the driving forces. The IDA model inherited from the IPAT framework uses the index number concept for decomposition analysis. The IDA model requires less data and thus has an advantage in spatial and time series analysis. Several types of IDA models are available, including the most famous Kaya identity as well as the most generally used Laspeyres index decomposition analysis and Divisia index decomposition analysis (Ang, 2005; Liu et al., 2012a). Many researchers have used IDA methods to reveal the driving forces for the variation in the national and regional CO2 emissions in China, including several case studies conducted in cities (Chong et al., 2012; Liu et al., 2012c). However, sectors are highly aggregated when using IDA models, and this aggregation limits policy decisions to the sectoral or product scale. Final demands (such as residential consumption, capital investment, and export) that drive production activities are often neglected when using IDA models due to the limits of the model framework and data sources. These technological gaps can be filled by using the SDA method. The SDA model can present decompositions on the sectoral scale and has advantages for analysing the driving forces for emissions from high-resolution sectors. Input–output structure decomposing analysis (IO-SDA) using economic input–output tables can shape socio-economic drivers from both production and final demand perspectives. The IO-SDA model has been applied successfully on the national scale and has resulted in concrete achievements and policy implications. However, the IO-SDA model is rarely applied on the city scale because applying the IO-SDA model requires time series input–output tables and sectoral energy use data that are usually challenging on a city scale.

We present a case study applying the IO-SDA model on the city scale. Beijing, the capital of China and one of the world’s largest metropolises, is chosen as the case due to its unique features and availability of data. Beijing has experienced intensive industrialisation and urbanisation in past decades. Along with rapid urbanisation, Beijing is also optimising its economic structure. Service sectors have been highly promoted in Beijing, and the proportions of agriculture, industry and construction have gradually decreased. These changes indicate the shift in Beijing’s economic structure from industry-oriented to service-oriented. Promoted by the government’s interest in constructing a modern global metropolis, Beijing is being transformed by the development of intensive service and commercial industries. Accompanying this trend, the CO2 emissions trajectory in Beijing has recently decreased slightly. This feature has distinguished Beijing from other Chinese cities, most of which are rapidly increasing their CO2 emissions. Analysing the driving forces of the CO2 emission trends in Beijing could direct policy decisions on global industrial restructuring and greenhouse gas (GHG) mitigation, especially for metropolises.

This study contributes mainly to the analysis of the driving forces of the change in CO2 emissions in Beijing during the period 1997–2010 using the IO-SDA model. We covered high-resolution industrial sectors and updated time series in this study. The relative contributions of socio-economic factors were investigated from both production and final demand perspectives.

2. Methodology and data

Structural decomposition analysis based on the environmental input–output (IO-SDA) model is used widely to analyse the relative contributions of influencing factors to changes in economic and environmental flows (Dietzenbacher and Los, 1998; Guan et al., 2008, 2009; Haan, 2001; Hoekstra and Bergh, 2002; Liang et al., in press; Liang and Zhang, 2011d; Minx et al., 2011; Peters et al., 2007; Rørmose and Olsen, 2005; Weinzettel and Kovanda, 2011; Wood, 2009; Xu et al., 2011; Zhang, 2009). The use of environmental input–output tables within the IO-SDA model can describe driving forces such as material intensity, production structure, final demand structure, and economic growth on the sectoral scale (Miller and Blair, 2009; Xu et al., 2008). The selection of driving forces, however, is flexible from various perspectives. We disaggregated driving forces from both production and final demand perspectives in this study. From the production perspective, five socio-economic factors were considered, namely, CO2 intensity, production structure, final demand structure, per capita final demand volume (final demand volume equals gross domestic product (GDP)), and population. From the final demand perspective, nine driving forces are considered: rural residential consumption, urban residential consumption, government consumption, fixed capital formation, stock increments, intranational exports, international exports, intranational imports, and international imports.

For the decomposing process, there is a technical problem with the IO-SDA model: the non-uniqueness of decomposing results (Guan et al., 2008; Liang et al., in press; Liang and Zhang, 2011d; Peters et al., 2007). If the number of decomposed factors is n, the number of possible decomposition forms is n!/n (Dietzenbacher and Los, 1998). We calculated the average of all possible first-order decomposition forms in this study to address this problem (Dietzenbacher and Los, 1998; Haan, 2001; Hoekstra and Bergh, 2002; Liang et al., in press; Rørmose and Olsen, 2005). Details of the IO-SDA model can be found in Electronic Annex 1 in the online version of this article.

Cities have close interactions with the surrounding regions. Most of the materials consumed by cities are produced in the surrounding regions. The analysis of the drivers of the change in CO2 emissions embodied in urban imports is important. We also used the IO-SDA model to analyse the relative contributions of four socio-economic factors (including CO2 intensity, production structure, import structure, and import volume) to the change in CO2 emissions embodied in imports to Beijing.

To run the IO-SDA model for Beijing, three categories of data are required: monetary input–output tables (MIOTs), population, and energy consumption. The MIOTs for Beijing in 1997, 2000, 2002, 2005, 2007, and 2010 were obtained from the website of the Municipal Bureau of Statistics of Beijing (http://www.bjstats.gov.cn/2007trcc/zxzw/lssj). To make the classification of economic sectors in the MIOTs for Beijing consistent with its energy statistics, these MIOTs were all changed into the 28-sector format. These MIOTs were all converted into 2000 constant prices by price indices. Producer price indices for detailed economic sectors in Beijing are unavailable. The indexes for Beijing’s GDP were therefore used (MBSB, 1998–2012). The population of Beijing in 1997, 2000, 2002, 2005, 2007, and 2010 was obtained from Beijing Statistical Yearbooks (MBSB, 1998–2012).

The volume of energy sources consumed by energy conversion (primary energy used for power generation), agriculture, industry, construction, services, and residents in Beijing is obtained directly from Beijing’s Energy Balance Table in China Energy Statistical Yearbooks (NBSC, 1998–2011). Energy consumption for detailed industrial sectors of Beijing was obtained from Beijing Statistical Yearbooks (MBSB, 1998–2012). We re-allocated energy sources used for generating electric and heat power into the sector Production and supply of electric and heat power, based on data from Beijing’s Energy Balance Table (NBSC, 1998–2011). Electric and heat power consumed by each sector was then removed to
avoid double-counting. Finally, we calculated CO₂ emissions covering fossil fuel combustion and cement production in Beijing. Specific CO₂ emission factors (including carbon content, net calorific value, and carbon oxidation factors) for China were used instead of the default values of the Intergovernmental Panel on Climate Change, as coal usage in China is usually inefficient (Guan et al., 2012). The specific CO₂ emission factors for China are shown in the study by Guan et al. (Guan et al., 2012; Liu et al., 2012a).

3. Results and discussion

3.1. Analysis from the production perspective

Based on the CO₂ emission inventory for Beijing during 1997–2010, we shaped Beijing’s emission trajectory (Fig. 1). Fig. 1 shows that CO₂ emissions in Beijing presented an unstable trend. The CO₂ emissions in Beijing decreased sharply during 2000–2002 but rebounded during 2002–2007. Then there was a slight decline during 2007–2010. The fluctuation of the CO₂ emission trajectory in Beijing emphasizes the importance of analyzing the hidden drivers. We will analyse the contribution of the driving forces for the change in the CO₂ emissions in Beijing during 1997–2010 below (Figs. 2 and 3).

From the production perspective, production structure change is the biggest driver for the CO₂ emission increment in Beijing during 1997–2010 (Fig. 2). Production structure change in this period comprises two aspects: (1) Proportions of heavy manufacturing sectors in the industrial sectors of Beijing increased rapidly from 1997 to 2010 (MBSB, 1998–2012). Those heavy manufacturing sectors are usually energy-intensive and CO₂-emission-intensive. (2) Many small and medium scale enterprises emerged in Beijing in the last decade. These enterprises are usually inefficient in energy usage. Subsequently, the production structure change during 1997–2010 contributed 309.4% (62.6 million tonnes) of the increment in CO₂ emissions in Beijing. This increment implies a higher proportion of CO₂ intensive sectors in Beijing’s economy.

Population growth is the second largest driver of Beijing’s CO₂ emission increment during 1997–2010 (Fig. 2). Beijing’s permanent population (19.6 million) and permanent floating population (7.0 million) in 2010 increased by 58.2% and 356.1%, respectively, over the 1997 level (MBSB, 1998–2012). Rapid population growth contributed to 158.5% (32.2 million tonnes) of the CO₂ emission increment in this period.

Final demand structure change had limited effect on the change in CO₂ emissions in Beijing, contributing only 36.4% (7.4 million tonnes) of CO₂ increment during 1997–2010 (Fig. 2).

Changes in CO₂ emission intensity and per capita final demand volume are two factors offsetting the increment in CO₂ in Beijing from 1997 to 2010 (Fig. 2). Beijing has taken efficient measures for energy conservation and reduction of air pollutants in the 10th (2001–2005) and 11th (2006–2010) Five-year Social and Economic Development Plans due to mandatory requirements imposed by the Central Government. These measures resulted in the decline in CO₂ emissions, which has significantly offset the total CO₂ emissions boom during the study period. Beijing also took major measures to ensure energy conservation and air quality control during the 2008 Olympic Games, such as banning approximately half of the private vehicles and temporarily stopping production activities of high-pollution enterprises. These measures also contributed to the reduction of domestic CO₂ emissions intensity in Beijing. The decline in CO₂ intensity offset Beijing’s CO₂ emissions by 41.2 million tonnes (−203.8%). Per capita final demand volume (also named per capita GDP) is another force offsetting total CO₂ emissions. According to data from Beijing’s MIOTs in constant prices, Beijing’s per capita GDP in 2010 decreased by 6.5% over the 1997 level. This decline is caused mainly by an increase in the number of Beijing’s permanent floating population who are usually of lower income. Finally, the decline in Beijing’s per capita GDP resulted in a reduction in CO₂ emissions by 40.7 million tonnes (−201.0%).

3.2. Analysis from the final demand perspective

3.2.1. Underlying drivers from final demand perspective

Analysing the CO₂ emission inventory from the final demand perspective could uncover underlying drivers throughout whole supply chains (Liang et al., 2012b, 2013a, in press, 2013c; Liu et al.,...
CO2 emission increment in Beijing caused by international export activities, and services are mainly responsible for the increment in CO2 emissions (Table 1). Similarly, increasing international exports of petroleum, natural gas, metal ores, and services are the main drivers for the avoidance of CO2 emissions in Beijing due to international import changes (95.9 million tonnes) (Table 1).

Urban trades are mainly responsible for the CO2 emission changes in Beijing during 1997–2010 (Fig. 3). Changes in net intranational exports caused an increase of 17.0 million tonnes in embodied CO2 emissions in Beijing, accounting for 84.0% of the total CO2 emission change. Changes in net international imports avoided 52.9 million tonnes of CO2 emissions, assuming that urban imports to Beijing are reproduced with the application of Beijing urban fixed capital formation (25.8 million tonnes) (Table 1).

Intrational export changes caused a 162.9 million tonne increase in CO2 emissions (Fig. 3) due mainly to increasing intranational exports of petroleum, natural gas, metal ores, transport equipment, construction activities, and other services (Table 1). Similarly, increasing international exports of petroleum products, coke, metals, electronics and communication equipment, construction activities, and services are mainly responsible for the CO2 emission increment in Beijing caused by international export changes (42.9 million tonnes) (Table 1). Increasing international imports of petroleum, natural gas, metal ores, and services are the main drivers for the avoidance of CO2 emissions in Beijing due to international import changes (95.9 million tonnes) (Table 1).

Urban residential consumption, government consumption and fixed capital formation are three main drivers of the CO2 emission increment in Beijing (Fig. 3). The increase in urban residential consumption caused an increase of 14.9 million tonnes in CO2 emissions in Beijing, due mainly to increasing demands of agricultural products and other services (Table 1). The increment in CO2 emissions in Beijing caused by growth in government consumption (17.7 million tonnes) resulted mainly from increasing demands of agricultural products and other services (Table 1). Increasing fixed capital formation from construction activities and services is mainly responsible for the increment in CO2 emissions caused by fixed capital formation (25.8 million tonnes) (Table 1).

<table>
<thead>
<tr>
<th>Items</th>
<th>Rural resident (%)</th>
<th>Urban resident (%)</th>
<th>Government (%)</th>
<th>Fixed capital formation (%)</th>
<th>Stock increments (%)</th>
<th>Intrational exports (%)</th>
<th>International exports (%)</th>
<th>Intrational imports (%)</th>
<th>International imports (%)</th>
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<tr>
<td>Agriculture</td>
<td>7.58</td>
<td>16.85</td>
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<td>1.36</td>
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<td>Mining and washing of coal</td>
<td>-10.13</td>
<td>-0.04</td>
<td>0.00</td>
<td>0.00</td>
<td>5.34</td>
<td>0.43</td>
<td>1.31</td>
<td>0.59</td>
<td>0.00</td>
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<td>-3.20</td>
<td>0.15</td>
<td>0.00</td>
<td>0.00</td>
<td>-24.38</td>
<td>12.02</td>
<td>0.43</td>
<td>1.08</td>
<td>20.69</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>83.62</td>
<td>18.02</td>
<td>0.92</td>
<td>0.42</td>
<td>26.23</td>
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<tr>
<td>Mining and processing of nonmetal ores</td>
<td>4.68</td>
<td>-0.11</td>
<td>0.00</td>
<td>-0.08</td>
<td>-29.98</td>
<td>-0.01</td>
<td>0.53</td>
<td>5.58</td>
<td>-0.04</td>
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<td>Processing and manufacture of foods</td>
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<td>2.96</td>
<td>0.00</td>
<td>0.00</td>
<td>-37.42</td>
<td>2.43</td>
<td>0.20</td>
<td>2.50</td>
<td>0.99</td>
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<td>0.00</td>
<td>-2.29</td>
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<td>-3.25</td>
<td>0.74</td>
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<td>Manufacture of clothes, leather and related products</td>
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<td>0.00</td>
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<td>0.19</td>
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<td>1.27</td>
<td>0.08</td>
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<td>0.00</td>
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<td>-0.01</td>
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<td>Papemaking, printing and articles manufacture</td>
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<td>0.00</td>
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<td>2.68</td>
<td>9.45</td>
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<td>Chemistry</td>
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<td>Smelting and pressing of metals</td>
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<td>5.97</td>
<td>12.19</td>
<td>27.16</td>
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<td>-10.57</td>
<td>2.10</td>
<td>-0.51</td>
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<tr>
<td>Manufacture of measuring instruments and machinery for cultural activity and office work</td>
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<td>0.65</td>
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<td>0.00</td>
<td>0.00</td>
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<tr>
<td>Production and supply of water</td>
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<td>Construction</td>
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<td>Transport, storage and post</td>
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<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
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Beijing’s import is the underlying driver for CO2 emissions for regions providing goods for Beijing. Optimising Beijing’s import structure and promoting Beijing’s green consumption to reduce its import volume can contribute effectively to global CO2 mitigation. Urban imports to Beijing are internal to the intermediate delivery matrix of MIOTs for Beijing. The intermediate delivery matrix for Beijing’s domestic production is merged with the matrix for Beijing’s urban imports. Urban imports and urban exports are expressed by two columns in the final demands of the MIOTs for Beijing. The IO-SDA of Beijing’s CO2 emissions is thus based on the assumption that imports to Beijing are produced using Beijing’s domestic technologies.

We used the IO-SDA model to investigate the drivers for CO2 emission change caused by urban imports (Fig. 4). Beijing has been in a rapid urbanisation stage over the period 1997–2010. Increasing urban population and improved quality of life produced larger demands for resources and products, further resulting in rapid growth of urban import volume. Subsequently, growth of urban import volume is the biggest driver of the increment in Beijing’s CO2 emissions embodied in urban imports. The volume growth of Beijing’s intranational and international imports increased embodied CO2 emissions by 115.6 million tonnes (79.3%) and 72.3 million tonnes (75.4%), respectively.

Production structure change is the second driver for the increment in CO2 emissions in Beijing embodied in urban imports. Increasing proportions of heavy manufacturing sectors and many newly emerged inefficient small scale enterprises in Chinese sub-regions produced production structure changes. Production structure changes subsequently increased Beijing’s CO2 emissions embodied in intranational and international imports by 8.40 million tonnes (57.6%) and 31.8 million tonnes (33.2%), respectively, during 1997–2010.

CO2 intensity change is the main driver to offset the growth of CO2 emissions embodied in urban imports. China established compulsory targets for energy conservation and air pollutant reduction in the 10th and 11th Five-year Plans. China also established a CO2 mitigation target of reducing CO2 emission intensity per unit GDP by 40–45% in 2020 above the 2005 level. China’s sub-regions (such as provinces and cities) have taken various measures to achieve these targets, such as promoting cleaner production, adjusting economic structure, and encouraging renewable energy usage. Some cities even use power rationing measures to limit energy usage. These measures have significantly reduced the CO2 emission intensity of goods imported to Beijing. CO2 intensity change during 1997–2010 reduced CO2 emissions in Beijing embodied in intranational and international imports by 50.5 million tonnes (−34.6%) and 7.7 million tonnes (−8.0%), respectively.

Urban import structure change has a limited effect on the change in CO2 emissions in Beijing embodied in intranational and international imports, causing a decline of embodied CO2 emissions by only 3.3 million tonnes (−2.2%) and 0.6 million tonnes (−0.6%), respectively.

3.3. Policy implications

In summary, as a famous global metropolis, Beijing illustrates how driving forces compete with one another and then result in a fluctuation in the CO2 emission trajectory. The features of the CO2 emission trend in Beijing are summarised below.

First, carbonised production structure. According to Fig. 2, production structure change contributed significantly to the increment in CO2 emissions, especially in the period of 2002–2005 and 2007–2010.

Second, dramatic change of per capita final demand volume. The effect of per capita final demand volume change on CO2 mitigation was positive during 1997–2002, negative during 2002–2005, and then positive again during 2005–2010 (Fig. 2). The recent decline of per capita final demand volume is actually caused by rapid population growth.

Third, effective CO2 emission intensity reduction. CO2 emission intensity reduction, achieved mainly by technology improvement, has considerably offset the total CO2 emission increment. The CO2 emission intensity increase is the largest contributor to the increment in CO2 emissions in Beijing during 1997–2000 (Fig. 2). The total CO2 emissions in Beijing also increased dramatically from 58.0 million tonnes of CO2 in 1997 to 79.3 million tonnes of CO2 in 2000 (Fig. 1). These results indicate that CO2 intensity reduction seems to be the inevitable factor for curbing total increment in CO2 emissions.

Finally, importing energy-intensive products rather than producing them domestically can also significantly decrease domestic CO2 emissions due to the transition of Beijing’s economic structure to a service orientation, further resulting in rapid development of domestic services and the increase in imports. However, this transition will push CO2 emissions into regions that provide goods for Beijing. Reducing the product demand in Beijing to decrease its imports is preferred to achieve global CO2 mitigation.

Several policy implications follow.

3.3.1. Policy implications for reducing Beijing’s domestic CO2 emissions

Beijing is featured as a centre for China’s modern service industries. More and more people tend to work and live in Beijing due to its better social resources. Beijing’s permanent floating population will most likely continue to grow in the near future. The declining trend of Beijing’s per capita GDP, however, will
gradually be weakened, as the Chinese government is paying special attention to people’s livelihoods. In general, Beijing’s GDP will continue to grow, indicating that the effects of permanent population growth on the increment in CO2 emissions will exceed the effects of per capita GDP decline on mitigation of CO2 emissions. Mitigation of CO2 emissions in Beijing in the future would rely mainly on CO2 emission intensity reduction and structural optimisation of production and final demand activities.

In addition to conventional measures proposed by national governments (such as sectoral cleaner production and renewable energy utilisation), two points should be specifically considered to reduce Beijing’s CO2 emission intensity effectively: energy conservation for transportation and buildings and carbon capture and storage. Energy consumption in Beijing is dominated by service activities that are mainly transportation and buildings (MBSB, 1998–2012). This situation differs from the national level and that in many other Chinese cities. Beijing’s manufacturing enterprises are gradually being moved away, which gradually reduces CO2 emissions from industry. Energy-efficient buildings and public transportation should be especially encouraged in Beijing to reduce Beijing’s domestic CO2 emissions effectively. In addition to source control of CO2 emissions, end-of-pipe treatment should also be promoted. Beijing should also develop technologies for carbon capture and storage to reduce CO2 emissions released to the atmosphere. Technological innovation is challenging. However, Beijing has abundant research resources such as China’s most famous universities and institutes. As one of China’s most developed areas (NBSC, 2011), Beijing also has the economic capability to support technology innovation for carbon capture and storage.

According to the results shown in Section 3.1, Beijing’s production structure change is influenced mainly by the change in the proportion of heavy manufacturing sectors and the appearance of many small and medium scale enterprises utilising inefficient technologies. Beijing is gradually moving its heavy manufacturing enterprises away. To improve production structure further, Beijing should take action to limit the number of small scale enterprises with inefficient technologies. Beijing’s production structure change during 1997–2010 shows the largest negative contribution to its mitigation of CO2 emissions. Improving production structure can therefore produce a large potential for mitigation of CO2 emissions in Beijing.

According to the results shown in Section 3.1, the change in the final demand structure in Beijing during 1997–2010 shows a negative contribution to mitigation of CO2 emissions in Beijing. Beijing should therefore also optimise its final demand structure. Green consumption, such as controlling luxury consumption, should be encouraged, resulting in the use of fewer energy-intensive products and using mass transit for transportation.

3.3.2. Policy implications for reducing CO2 emissions embodied in imports

Beijing is a world-famous metropolis. Goods consumed by Beijing’s production and consumption activities depend mainly on urban imports, indicating that Beijing is the underlying driver for CO2 emissions in trading partners. Mitigating the CO2 emissions embodied in urban imports for Beijing relies not only on CO2 emission intensity reduction and production structure optimisation of trading partners but also on import structure optimisation and import volume reduction for Beijing.

China’s sub-regions will take various measures to reduce their CO2 emission intensity and improve their production structure due to mandatory requirements imposed by China’s central government. From the supply chain perspective, reducing the demand of the downstream economy can effectively mitigate CO2 emissions throughout whole supply chains. Thus, optimising Beijing’s import structure and reducing Beijing’s import volume are more significant for reducing national and global CO2 emissions. Beijing should take measures to encourage the import of goods that are less carbon-intensive. Moreover, Beijing should promote sectoral cleaner production and a green lifestyle to reduce its import volume.

In the near future, China will continue to improve life quality for its citizens. Rapid economic growth and urbanisation will still continue for some time. Beijing’s economic structure is approaching relative maturity. The success of Beijing’s CO2 emission mitigation actions will provide a potential pathway for low-carbon development for global metropolises.

3.3.3. Policy implications for administrative measures

Beijing apparently reduced its CO2 emissions during 2007–2010, unique among Chinese cities. In addition to technology improvement and industrial restructuring, Beijing’s administrative measures actually play an inevitable role in this dramatic change. To promote the “Green Olympic Games” in Beijing in 2008 (Wu and Zhang, 2008), the Beijing government mandated moving many energy-intensive manufacturing enterprises into other regions. The Beijing government also closed enormous inefficient power plants and manufacturing enterprises. These administrative measures had strong effects on both the decline in domestic energy intensity and the increment in imports. Compared with mandated government-led measures, market mechanisms such as domestic cap-and-trade systems and carbon taxation should be encouraged to promote further decreases in CO2 emissions.

4. Conclusion

Using the IO-SDA model, we analysed drivers for the change in CO2 emissions in Beijing during 1997–2010 from both production and final demand perspectives. Production structure change and population growth were two main drivers for an increment in CO2 emissions during 1997–2010, while CO2 emission intensity reduction and per capita final demand volume decline were two main forces to offset this increment. Final demand structure change, however, had a small effect on the change in CO2 emissions in Beijing. From the final demand perspective, urban trades, urban residential consumption, government consumption, and fixed capital formation are the main factors responsible for the change in CO2 emissions in Beijing. Mitigation of domestic CO2 emissions in Beijing will rely on CO2 emission intensity reduction and structural optimisation of production and final demand activities. Optimising Beijing’s import structure and reducing Beijing’s import volume are more significant for reduction of national and global CO2 emissions.

In future work, the drivers of CO2 emissions in more representative cities should be investigated using the IO-SDA model to provide more guidance for policy decisions for low-carbon city construction. However, developing this guidance requires the construction of urban MIOTs because many cities do not compile MIOTs. Liang and Zhang have proposed methods to construct physical input–output tables (PIOTs) in Chinese cities (Liang et al., 2010; Liang and Zhang, 2011a) and industrial clusters (Liang et al., 2011). These investigators also applied those methods in a typical Chinese city for urban energy system management (Liang et al., 2010; Liang and Zhang, 2011c), urban solid waste recycling (Liang and Zhang, 2012), and urban air pollutant mitigation (Liang et al., 2012b). The PIOT is the basis for the MIOT, as they interact with each other through sectoral prices (Liang and Zhang, in press; Weisz and Duchin, 2006). The PIOT and MIOT can also be combined to construct hybrid input–output tables (HIOTs) (Liang and Zhang, in press), which can be used for life cycle assessment (Hawkins et al., 2007; Liang et al., 2012a, 2013b, 2012c) and the

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investigation of policy interactions (Liang and Zhang, 2011b). In future work, methods for the construction of urban PIOTs should be improved to reduce uncertainty.

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Appendix A. Supporting information

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References