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Carbon emissions from the service sector: an input-output application to Beijing, China

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ABSTRACT: Beijing is a large city and a major consumer of energy and producer of carbon emissions. According to Beijing's 12th Five-Year Plan, the local government will continue to both promote the service sector and seek reductions in carbon emissions. We developed an input-output subsystem assessment to study carbon emissions associated with the service sector. Based on the subsystem of service productive activity, the analysis decomposes carbon emissions into 5 components (demand volume component, own component, feedback component, spillover component, and intra-sector spillover component) to construct a detailed direct and indirect emissions path. We found that the transportation, storage, mail and telecommunications subsector accounts for a high level of direct emissions, as shown by the demand volume component and the own component. In this subsector, financial support and policies focus on the promotion of new-energy vehicles (e.g. electric vehicles) and renewable energy for transportation (e.g. fuel ethanol) to reduce emissions. Furthermore, the scientific studies and technical services subsector, the hotels and restaurants subsector, and the health care, social security and social welfare subsector contribute greatly to indirect emissions. However, these service activities are widely seen as low-carbon emitters and are neglected by regulations aimed at reducing emissions. With respect to these subsectors, financial support should be provided and guidelines established to improve energy efficiency and prevent carbon emissions from spilling over from the service to the non-service sector.

KEY WORDS: Carbon emission component · Direct and indirect emission · Input-output model · Subsystem

1. INTRODUCTION

As a result of soaring coal-dominated energy consumption and the low efficiency of energy use, China's rapid economic development has occasioned an increase in carbon emissions by 150% from 2002 to 2011 (Olivier et al. 2012). In 2007, China replaced the US as the world's largest emitter of carbon (Zhou et al. 2011). Although the Chinese government has made efforts to shut down energy-inefficient, highly polluting thermal power plants and industrial projects such as steel factories over the last 5 yr, China's CO_2 emissions jumped 9% to 9.7 billion t in 2011 (Olivier et al. 2012). At the Copenhagen Summit (2009 UN climate change Conference), the government promised that China would cut its CO_2 emission by 40–45% per unit of gross domestic product (GDP) by 2020 compared with its level in 2005. However, this promise lacks concrete measures by which to achieve the stated emission intensity reduction target at the local level.

Cities are the backbone of global efforts to address climate change (IEA 2008, Zhang et al. 2011), and they account for more than two-thirds of the world's energy consumption and contribute more than 70% of global CO_2 emissions (C40 Cities Climate Leadership Group 2011). As the capital of China, Beijing is densely populated and is a major consumer of energy

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and emitter of carbon. The population of Beijing now exceeds 20.18 million, which increases pressure to reduce carbon emissions because of the contribution of population growth to increases in indirect carbon emissions (Liu et al. 2011b). Heavy consumption of coal, oil, and natural gas also contributes to the rapid increase in emissions. Total energy use reached 69.54 million t of coal equivalent in 2010, of which coal, crude oil, and natural gas accounted for 26.35 million t, 11.16 million t and 7.5 billion m^3, respectively (Energy Statistics of NBS 2011). Accordingly, Beijing's energy-related carbon emissions increased by 9.03 million t between 1995 and 2009, an average annual growth rate of 3.14% (Zhang et al. 2013). In response to national energy-saving and carbon emission reduction policies, the Beijing government is forcing certain industrial sectors, such as chemicals and non-ferrous metals, to control their carbon emissions. In contrast, the service sector, which is widely viewed as a low-carbon sector, is expected to develop rapidly and will account for more than 78% of the regional GDP by 2015, according to Beijing's 12th Five-Year Plan[1].

However, the view that the service sector is an environmentally friendly sector requires further investigation (Alcántara & Padilla 2009, Fourcroy et al. 2012). Carbon emissions directly associated with activities in the service sector are considered minimal, but emissions from its forward and backward sectors cannot be ignored. At present, Beijing shows some characteristics of a post-industrial society, for example, with information and knowledge as directive forces in development. The service sector, especially transportation, has become one of the principal consumers of energy and is a key element in the rise in carbon emissions (Nansai et al. 2009). The Beijing government should therefore consider carbon emission control measures that pertain to the service sector, in addition to those that pertain to industrial sectors.

Several studies have used an input-output methodology to analyze the structure of carbon emissions, as input-output analysis can capture both direct and indirect emissions based on the forward and backward linkages between industries and the effects of final changes in demand (Gay & Proops 1993, Lenzen 1998, Machado et al. 2001, Lenzen et al. 2004, Nassen et al. 2007, Chen & Zhang 2010, Su & Ang 2011, Zhu et al. 2012). Several authors have analyzed carbon emissions of the service sector using an input-output framework and have found that service sector development is associated with a significant increase in carbon emissions (Krackeler et al. 1998, Suh 2006, Tarancon & del Rio 2007, Alcántara & Padilla 2009). As the manufacturing industry still dominates the industrial structure of China, most studies focus only on carbon emissions from all sectors or from the manufacturing sector and are less concerned with emissions from the service sector (Wang et al. 2005, Zhang et al. 2009, Chen & Zhang 2010). In a regional study of Beijing, Guo et al. (2012) employed an input-output analysis to investigate embodied CO_2 emissions induced by fossil fuel combustion in the Beijing economy in 2007, and showed that the secondary industries are the predominant carbon emitters, with high intensities. Other studies of carbon emissions in Beijing have focused on coordinated development between the economy, energy, and the environment from a macro perspective (Liu et al. 2011a, Zhang et al. 2011) and the impact of the patterns of urban development on motorized travel (Zhao & Lu 2011) and of civilian vehicle growth (Zhao et al. 2012) on carbon emissions. Although the service industry contributed 1.2 trillion China Yuan (CNY; ~US$185.8), accounting for 75.5% of Beijing's total GDP in 2011 (BMBS 2012a), the above studies do not identify any role for the service sector in carbon emission mitigation actions.

Given the importance of the service sector in economic development and in carbon emissions in the present and future, our analysis identified the subsectors within the service sector most relevant to emissions controls and their emissions paths to gain an understanding of both direct and indirect carbon emissions in the service sector. In this analysis, an input-output model developed by Alcántara & Padilla (2009) is employed, as this model enables us to examine the roles played by the branches of the service sector and their relationships with other economic sectors.

2. METHODS

An input-output model measures changes in sector output or total output caused by changes in final demand. In addition, it enables measurement of changes in direct and indirect carbon emissions through energy use and sector linkages (Lenzen 1998). Alcántara & Padilla (2009) developed an input-output subsystem to study CO_2 emissions associated with individual branches of the service sector

[1]Available at www.bjpc.gov.cn/fzgh_1/guihua/12_5/Picture_12_F_Y_P/201208/P020120809377417514420.pdf

in the Spanish economy, based on previous studies of input-output decomposition (Heimler 1991) and subsystem construction (Sraffa 1960, Harcourt & Massaro 1964). In our work, the approach described by Alcántara & Padilla (2009) was adopted to investigate the role of the service sector in Beijing's carbon emissions.

The definitions of symbols used in this model are given in Table 1.

From these definitions, the production and final demand vectors are obtained as follows:

$$x = \begin{pmatrix} x^M \\ x^S \end{pmatrix} \quad \text{and} \quad y = \begin{pmatrix} y^M \\ y^S \end{pmatrix} \tag{1}$$

The matrices B and A can be expressed as

$$B = \begin{pmatrix} B_{MM} & B_{MS} \\ B_{SM} & B_{SS} \end{pmatrix} \quad \text{and} \quad A = \begin{pmatrix} A_{MM} & A_{MS} \\ A_{SM} & A_{SS} \end{pmatrix} \tag{2}$$

where the subscripts *MM*, *MS*, *SM*, and *SS* represent the submatrices of matrix ($n \times n$). Specifically, only the service subsectors and non-service subsectors are included in the column and the row of submatrices *MM* and *SS*. *MS* is the submatrix in which the column includes the service activities and the row contains the non-service activities, while in submatrix *SM*, the column covers the non-service subsectors and the row includes the service subsectors.

From the Leontief model, a balance equation can be obtained as follows:

$$\begin{pmatrix} A_{MM} & A_{MS} \\ A_{SM} & A_{SS} \end{pmatrix} \begin{pmatrix} x^M \\ x^S \end{pmatrix} + \begin{pmatrix} y^M \\ y^S \end{pmatrix} = \begin{pmatrix} x^M \\ x^S \end{pmatrix} \tag{3}$$

Solving for total output:

$$\left[\begin{pmatrix} I & 0 \\ 0 & I \end{pmatrix} - \begin{pmatrix} A_{MM} & A_{MS} \\ A_{SM} & A_{SS} \end{pmatrix}\right]^{-1} \begin{pmatrix} y^M \\ y^S \end{pmatrix} = \begin{pmatrix} B_{MM} & B_{MS} \\ B_{SM} & B_{SS} \end{pmatrix} \begin{pmatrix} y^M \\ y^S \end{pmatrix} = \begin{pmatrix} x^M \\ x^S \end{pmatrix} \tag{4}$$

Substituting Eq. (4) in Eq. (3), we obtain:

$$\begin{pmatrix} A_{MM} & A_{MS} \\ A_{SM} & A_{SS} \end{pmatrix} \begin{pmatrix} B_{MM} & B_{MS} \\ B_{SM} & B_{SS} \end{pmatrix} \begin{pmatrix} y^M \\ y^S \end{pmatrix} + \begin{pmatrix} y^M \\ y^S \end{pmatrix} = \begin{pmatrix} x^M \\ x^S \end{pmatrix} \tag{5}$$

In Eq. (3), the production of the entire economic system is divided into production for final demand and the inputs needed to produce total output.

If $y^M = 0$, Eq. (5) can be expressed by:

$$\begin{pmatrix} A_{MM} & A_{MS} \\ A_{SM} & A_{SS} \end{pmatrix} \begin{pmatrix} B_{MM} & B_{MS} \\ B_{SM} & B_{SS} \end{pmatrix} \begin{pmatrix} 0 \\ y^S \end{pmatrix} + \begin{pmatrix} 0 \\ y^S \end{pmatrix} = \begin{pmatrix} x_S^M \\ x_S^S \end{pmatrix} \tag{6}$$

where x_S^M indicates non-service sector output that meets final demand in the service sector, y^S, and x_S^S indicates service sector output that meets final demand in the service sector itself. As noted above, Eq. (6) shows the total production in the service sector and non-service sector that meets the final demand of the service sector. An in-depth analysis is required to decompose the input and output processes, thereby enabling an understanding of the carbon emission paths entailed by the final demand of the service sector. The technical coefficient matrix A is decomposed into A^D and A^0, so that $A = A^D + A^0$. A^D is defined as the diagonal matrix ($n \times n$), whose main diagonal elements come from matrix A and whose remaining elements are 0. A^0 is a matrix ($n \times n$) whose main diagonal elements are 0 and whose remaining elements come from matrix A. Therefore, Eq. (6) is rewritten as:

$$\left[\begin{pmatrix} A_{MM}^D & 0 \\ 0 & A_{SS}^D \end{pmatrix} + \begin{pmatrix} A_{MM}^0 & A_{MS}^0 \\ A_{SM}^0 & A_{SS}^0 \end{pmatrix}\right] \begin{pmatrix} B_{MM} & B_{MS} \\ B_{SM} & B_{SS} \end{pmatrix} \begin{pmatrix} 0 \\ y^S \end{pmatrix} + \begin{pmatrix} 0 \\ y^S \end{pmatrix} = \begin{pmatrix} x_S^M \\ x_S^S \end{pmatrix} \tag{7}$$

We can solve Eq. (7) to obtain Eqs. (8) and (9) as follows:

$$A_{MM}^D B_{MS} y^S + A_{MM}^0 B_{MS} y^S + A_{MS}^0 B_{SS} y^S + y^S + 0 = x_S^M \tag{8}$$

Table 1. Definitions of symbols used in the input-output model to investigate the role of the service sector in Beijing's carbon emissions

Symbol	Definition
A	Technical coefficient matrix ($n \times n$) of the input-output table
N	(1, 2, …, n) where sectors 1, 2, …, m are the subsectors not belonging to the service sector and sector $m + 1$, …, n are the subsectors of the service sector
I	Identity matrix ($n \times n$)
B	Leontief inverse matrix ($n \times n$) which means $(I - A)^{-1}$
x^M	Production of sectors 1, 2, …, m which are the subsectors not belonging to the service sector
x^S	Production of sectors $m + 1$, …, n which are the subsectors of the service sector
y^M	Final demand of sectors 1, 2, …, m which are the subsectors not belonging to the service sector
y^S	Final demand of sectors $m + 1$, …, n which are the subsectors of the service sector
(^)	Diagonalization of a vector
(')	Transposition of a vector or matrix

$$A_{SS}^{D} B_{SS} y^{S} + A_{SM}^{0} B_{MS} y^{S} + A_{SS}^{0} B_{SS} y^{S} + y^{S} = x_{S}^{S} \quad (9)$$

Eq. (8) represents the spillover component (SOC) of final demand of the service sector. We refer to this output of the non-service sector as the SOC.

The vector on the right side of Eq. (9) shows the production processes of the service sector that meet the final demand of the service sector itself. In addition, the 4 vectors on the left side of Eq. (9) decompose the production process into 4 parts. The first component, $A_{SS}^{D} B_{SS} y^{S}$, denotes inputs into the service subsectors needed to meet their own final demand, namely, their own component (OC). The vector y^S denotes the final demand of the service sector and represents the direct effect of final demand. We call this component the demand volume component (DVC). Additionally, the second component, $A_{SM}^{0} B_{MS} y^{S}$, indicates inputs produced in the service sector for the non-service sector to meet final demand of the service sector. This is the feedback component (FBC) from the service sector to the other sectors of the economy. Lastly, the third component, $A_{SS}^{0} B_{SS} y^{S}$, denotes the mutual demand among the service branches themselves and is referred to as the intra-sector spillover component (ISC).

Subsequently, the direct and indirect carbon emissions of the service sector demand are obtained based on the above input-output subsystem. Let c^M be an ($m \times 1$) vector of carbon emissions per unit of output in the non-service sector. Let c^S be an ($s \times 1$) vector indicating carbon emissions per unit of output of the subsectors of the service sector.

According to Eqs. (8) and (9), the carbon emissions of the service sector can be divided into 5 components, using c^M and c^S.

The DVC of carbon emissions of the service sector as a whole can be expressed as

$$\text{DVC} = c^{S'} y^{S} \quad (10)$$

For the individual subsectors indicated by e', we obtain the following expression:

$$e'\text{DVC} = c^{S'} \widehat{y^{S}} \quad (11)$$

The OC of carbon emissions of the service sector is given by

$$\text{OC} = c^{S'} A_{SS}^{0} B_{SS} y^{S} \quad (12)$$

Then, for the individual branches of the service sector, the OC can be represented by the expression

$$e'\text{OC} = c^{S'} A_{SS}^{0} B_{SS} \widehat{y^{S}} \quad (13)$$

The FBC of carbon emissions of the service sector can be written as

$$\text{FBC} = c^{S'} A_{SM}^{0} B_{MS} y^{S} \quad (14)$$

For the individual subsectors, it can be expressed as

$$e'\text{FBC} = c^{S'} A_{SM}^{0} B_{MS} \widehat{y^{S}} \quad (15)$$

The SOC of carbon emissions in the service sector as a whole is

$$\text{SOC} = c^{M'} (A_{MM}^{D} B_{MS} + A_{MM}^{0} B_{MS} + A_{MS}^{0} B_{SS}) y^{S} \quad (16)$$

For the individual subsectors, it is

$$e'\text{SOC} = c^{M'} (A_{MM}^{D} B_{MS} + A_{MM}^{0} B_{MS} + A_{MS}^{0} B_{SS}) \widehat{y^{S}} \quad (17)$$

The ISC of carbon emissions of the service sector is given by the expression

$$\text{ISC} = c^{S'} A_{SS}^{0} B_{SS} y^{S} \quad (18)$$

For the individual branches, it is

$$e'\text{ISC} = c^{S'} A_{SS}^{0} B_{SS} \widehat{y^{S}} \quad (19)$$

Total carbon emissions (TE), including direct and indirect emissions, caused by the final demand of the service sector, are given by:

$$\text{TE} = \text{DVC} + \text{OC} + \text{FBC} + \text{SOC} + \text{ISC} \quad (20)$$

3. RESULTS AND APPLICATION

3.1. Data management

The input-output data for Beijing used in this study are from the input-output extension table of Beijing for 2010 (BMBS 2012b). Carbon emissions per unit of output are estimated based on energy consumption and a carbon emission factor (determined by fuel type) and is given by the following expression:

$$C_n = \frac{\sum E_i f_i}{X_n} \quad (21)$$

where C_n is carbon emissions per unit of output in the nth sector, E_i is energy consumption of the ith fuel type in the nth sector, f_i is the carbon emission factor of the ith fuel type, and X_n is output of the nth sector.

The carbon emission factor, f_i, can be calculated based on 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006). The data on energy consumption are from the Beijing Statistical Yearbook 2011 (BMBS 2011). Based on the availability of data from the above 2 sources, the fuel used in production can be decomposed into 8 detailed types (Table 2).

As energy data are in physical units, calorific values per unit of fuel and CO_2 emission factors pro-

Table 2. Calorific value and carbon emissions per unit of fuel (in kg, except for natural gas: in m^3) in China

	Calorific value (kJ)[a]	Carbon emission (kg C)
Coal	20908	0.5589
Coke	28435	0.8313
Gasoline	43070	0.8236
Kerosene	43070	0.8452
Diesel oil	42552	0.8626
Fuel oil	41816	0.8834
Liquefied petroleum gases	50179	0.8641
Natural gas	38931	0.5964

[a]Source: Energy Statistics of NBS (2011)

vided by the IPCC were used to obtain f_i for each fuel type (Table 2).

For Eq. (21), carbon emissions per unit of output in the production sectors can be obtained as shown in Table 3. Here, since we have mentioned carbon emissions generated by service sector demand, it is necessary to explain the difference between carbon emissions related to production and carbon emissions generated by demand. The former indicates the carbon emissions caused by the total output of the sector itself, while the latter means the carbon emissions caused by the production of intermediate goods in order to meet the final demand of the sector.

As seen in Table 3, the 2 subsectors with the highest levels of emissions per unit of output are the mining and processing of metal ores and the production and distribution of electric power and heat power, with 0.4995 t per 10000 CNY (~US$1477 in 2010) and 0.3153 t per 10000 CNY, respectively. Moreover, Table 3 also clearly shows that the manufacture of non-metallic mineral products and their transportation have high carbon emission intensity, producing 0.1458 and 0.1203 t per 10000 CNY, respectively. In terms of total direct emissions, the production and distribution of electric power and heat power, transportation, and the mining and processing of metal ores are the largest carbon emitters, as shown in Tables 4 and 5. Of much less relative importance are

Table 3. Carbon emissions per unit of output of the production sectors (2010) (t per 10000 CNY; ~US$1477 in 2010)

Sector	Emission	Sector	Emission
Farming, forestry, animal husbandry and fishery	0.0443	Manufacture of artwork and other manufacturing	0.0057
Mining and washing of coal	0.0011	Recycling and disposal of waste	0.0302
Extraction of petroleum and natural gas	0.0062	Production and distribution of electric power and heat power	0.3153
Mining and processing of metal ores	0.4995	Production and distribution of gas	0.0119
Mining and processing of nonmetal ores and other ores	0.0112	Production and distribution of water	0.0104
Manufacture of foods and tobacco	0.0265	Construction	0.0123
Manufacture of textiles	0.0163	Transportation, storage, mail and telecommunications	0.1203
Manufacture of apparel, footware, caps, leather, furs and related products	0.0148	Information transmission, computer services and software	0.0013
Manufacture of wood and furniture	0.0104	Wholesale trade and retail trade	0.0059
Manufacture of paper, printing, and manufacture of articles for culture, education and sports activities	0.0169	Hotel and restaurants	0.0246
Processing of petroleum, coking and nuclear fuel	0.0343	Finance	0.0009
Chemical industry	0.0291	Real estate trade	0.0342
Manufacture of non-metallic mineral products	0.1458	Tenancy and commercial services	0.0061
Smelting and pressing of metals	0.0019	Scientific studies and technical services	0.0035
Manufacture of metal products	0.0104	Water, environment and municipal engineering conservancy	0.0268
Manufacture of general and special-purpose machinery	0.0106	Resident services and other services	0.0424
Manufacture of transport equipment	0.0055	Education	0.0211
Manufacture of electrical machinery and equipment	0.0038	Health care, social security and social welfare	0.0059
Manufacture of communication equipment, computers and other electronic equipment	0.0003	Culture, art, sports and recreation	0.0044
Manufacture of measuring instruments and machinery for cultural activities and office work	0.0023	Public management and social organization	0.0127

Table 4. Direct carbon emissions generated by the service sector production and total (direct and indirect) carbon emissions caused by the service sector demand (2010)

	Direct emissions		Total emissions	
	(kt)	(% total emission)	(kt)	(% total emission)
Transportation, storage, mail and telecommunications	4905.96	21.61	1370.43	6.04
Information transmission, computer services and software	40.69	0.18	871.42	3.84
Wholesale trade and retail trade	299.49	1.32	718.66	3.17
Hotel and restaurants	329.86	1.45	617.36	2.72
Finance	31.11	0.14	1033.2	4.55
Real estate trade	618.63	2.72	1556.93	6.86
Tenancy and commercial services	278.93	1.23	961.06	4.23
Scientific studies and technical services	141.39	0.62	1554.14	6.84
Water, environment and municipal engineering conservancy	72.4	0.32	169.24	0.75
Resident services and other services	96.31	0.42	79.02	0.35
Education	258.2	1.14	693.36	3.05
Health care, social security and social welfare	75.78	0.33	633.07	2.79
Culture, art, sports and recreation	41.54	0.18	302.42	1.33
Public management and social organization	183.18	0.81	993.7	4.38
Total		32.47		50.89

Table 5. Direct carbon emissions generated by the non-service sector production and total carbon emissions generated by the non-service sector to satisfy final demand in the service sector (2010)

	Direct emissions (kt)	Total emissions (kt)
Farming, forestry, animal husbandry and fishery	352.26	58.65
Mining and washing of coal	7.75	2.31
Extraction of petroleum and natural gas	141.88	4.96
Mining and processing of metal ores	3521.11	251.05
Mining and processing of nonmetal ores and other ores	27.04	5.07
Manufacture of foods and tobacco	381.71	72.87
Manufacture of textiles	50.93	5.63
Manufacture of apparel, footware, caps, leather, furs and related products	66.99	7.71
Manufacture of wood and furniture	20.29	3.75
Manufacture of paper, printing, and manufacture of articles for culture, education and sports activities	100.04	71.80
Processing of petroleum, coking and nuclear fuel	513.40	141.24
Chemical industry	686.01	258.51
Manufacture of non-metallic mineral products	1161.02	222.23
Smelting and pressing of metals	30.76	4.86
Manufacture of metal products	54.12	26.12
Manufacture of general and special-purpose machinery	149.49	32.66
Manufacture of transport equipment	183.18	17.14
Manufacture of electrical machinery and equipment	50.10	18.09
Manufacture of communication equipment, computers and other electronic equipment	11.76	5.07
Manufacture of measuring instruments and machinery for cultural activities and office work	7.85	4.15
Manufacture of artwork and other manufacturing	21.65	2.75
Recycling and disposal of waste	10.84	1.89
Production and distribution of electric power and heat power	7220.70	4437.83
Production and distribution of gas	25.74	14.47
Production and distribution of water	5.16	2.15
Construction	530.43	66.06
Total	15332.22	5739.03

service subsectors, such as finance and information transmission, computer services and software, and some manufacturing subsectors, such as the manufacture of communication equipment, computers and other electronic equipment, as these sectors consume less fossil energy. Based on the above analysis, we questioned whether one can ignore carbon emissions of the service sector and some high-tech sectors, given current levels of technology and energy efficiency. The following analysis, which focuses on services, provides insights on this issue.

3.2. General view of carbon emissions from the service sector

Given the methodology presented in Section 2 and the data provided by the BMBS (2012b), TE by the production sectors in the year 2010 was 22705.68 kt. To gain an intuitive understanding of emissions in the service subsectors, we have constructed Table 4, which shows direct emissions resulting from the production of services and total emissions related to service sector final demand.

TE generated by all production sectors to meet final demand in the service sector accounted for half (50.89%) of total emissions in the whole Beijing economy in 2010. Comparatively speaking, direct emissions comprise a smaller portion, accounting for 32.47% of total emission generated by all production sectors combined. However, the pull effects of the service sector on emissions are also important. In particular, carbon emissions generated by non-service sector production of intermediate goods for the service sector would be neglected if we only examine the direct emissions of the service sector. Thus, the role of the service sector in carbon emissions would be underestimated, and this may result in failure of emission reduction policies. However, the service subsectors play differing roles in direct and in total emissions, which is also shown in Table 4.

With respect to direct emissions generated by production in the service subsectors, the transportation, storage, mail and telecommunications subsector is the dominant contributor to carbon emissions, with 4905.96 kt of emissions, accounting for 21.61% of total carbon emissions. Real estate trade is the second largest carbon-emitting subsector, accounting for 2.72% of total carbon emissions. Among service subsectors, the information transmission, computer services and software subsector and the culture, arts, sports and recreation subsector have the lowest levels of direct emissions, both accounting for 0.18% of total emissions. On the basis of these results, if only direct emissions are considered, policy makers should regulate the transportation, storage, mail and telecommunications subsector and real estate trade while promoting the information transmission, computer services and software subsector and the culture, arts, sports and recreation subsector. However, we must also consider that the emissions that some service subsectors pull from other sectors often exceed the direct emissions they generate themselves. Hence, total emissions generated by the final demand of the service subsectors should be taken into consideration as well.

In terms of total emissions, most service subsectors show similar levels of emissions, ranging from 4 to 6% of total emissions. Real estate trade, scientific studies and technical services, and transportation, storage, mail and telecommunications have higher emissions, accounting for 6.86, 6.84, and 6.04% of total emissions, respectively. Of much less relative importance are the water, environment and municipal engineering conservancy subsector and the residential services subsector, with 0.75 and 0.35% of total emissions, respectively. Of particular interest is the lower relative importance of the transportation, storage, mail and telecommunications subsector, which accounts for 21.61% of direct emission but only 6.04% of total emissions, that is, its ranking falls from first to third in emission contributions. This implies that, while the transportation, storage, mail and telecommunications subsector accounts for minimal demand from other productive activities, it frequently serves other productive sectors. Hence, the transportation, storage, mail and telecommunications subsector emits substantial amounts of carbon in meeting the final demand of other productive activities. Similarly, while direct emissions generated by the residential services subsector represent 0.42% of total emissions, it accounts for only 0.35% of total emissions when indirect emissions are factored in.

Table 4 also shows another trend, namely, lower direct emissions than total emissions caused by the service sector demand as a share of total emissions generated by the whole Beijing economy. In the case of real estate trade, a major emitter, its direct emissions account for 2.72% of total emissions, while its direct and indirect emissions combined account for 6.86% of total emissions. The same is true for other service subsectors, although not transportation, storage, mail and telecommunications, or residential and other services. This upward trend shows that the productive activities of these subsectors are minimally dependent on fossil fuels and therefore have small direct emissions while requiring many intermediate inputs from other sectors, giving rise to larger indirect emissions.

It is clear from the above analysis that indirect carbon emissions in the service sector are considerable, especially in the scientific studies and technical services subsector, the real estate trade subsector, and the finance subsector, which are generally considered to be low-carbon subsectors. The results also establish that indirect carbon emissions are generally of great importance (Lenzen 1998). Furthermore, in view of this macro-level emissions analysis, it is clearly essential to examine emission paths, including causes and impacts, to determine the policy implications for low-carbon development of the service sector.

3.3. Analysis of different emission components of the service sector

To investigate the emission paths of each subsector, based on Eqs. (10)–(19), total emissions are decomposed into 5 components, 4 of which reflect indirect effects arising from interactions among sectors. The concrete results and emission shares of the service subsectors are shown in Table 6.

The first column in Table 6 shows the DVC caused by final demand and direct emissions in the service sector, which account for 10.6% of total emissions of all sectors combined. This relatively low percentage indicates that direct emissions generated by own final demand in the service sector are less than indirect emissions. With regard to the OC, as shown in the second column, depending on the service subsector's own production to meet its final demand, this component accounts for 4.35% of total emissions. In the same way, a low share of total emissions (1.54%) is also found in the FBC, which depends on the importance of the service and other production sectors as suppliers and indicates forward linkages. As for the ISC, which depends on the input requirements of service subsectors from other service subsectors in satisfying their own final demand, it accounts for 9.11% of total emissions. The final but most important component is the SOC, which pertains to carbon emissions generated in other sectors to meet the final demand of the service sector, in other words, the backward linkage or pull effects of the service sector. The SOC accounts for 5739.03 kt, which comprises 25.28% of total emissions of all production sectors. Furthermore, the role of the SOC of the service sector in the direct emissions of the non-service sector can be examined in Table 3. As the non-service sector directly emitted 15332.22 kt of carbon in 2010 (Table 5), we find that 37.43% of direct emissions was generated by the non-service sector to satisfy final demand in the service sector.

Table 6. Decomposition of service sector carbon emissions into the emissions generated by the demand volume component (DVC), own component (OC), feedback component (FBC), spillover component (SOC), and intra-sector spillover component (ISC) (kt)

Subsectors of the service sector	DVC	OC	FBC	SOC	ISC	Total direct and indirect emission	% of service sector emission
Transportation, storage, mail and telecommunications	860.4	298.2	13.0	176.5	22.4	1370.4	11.9
Information transmission, computer services and software	34.5	74.9	50.8	483.4	227.9	871.4	7.5
Wholesale trade and retail trade	105.0	74.2	17.1	278.8	243.6	718.7	6.2
Hotel and restaurants	151.2	16.1	17.6	387.4	45.1	617.4	5.3
Finance	21.6	84.3	29.4	589.2	308.7	1033.2	8.9
Real estate trade	514.7	52.6	27.6	832.2	129.9	1556.9	13.5
Tenancy and commercial services	102.9	104.2	30.2	425.7	298.1	961.1	8.3
Scientific studies and technical services	86.9	135.0	79.0	894.7	358.6	1554.1	13.5
Water, environment and municipal engineering conservancy	51.1	6.4	6.3	89.9	15.5	169.2	1.5
Resident services and other services	36.7	3.0	2.0	28.7	8.6	79.0	0.7
Education	215.4	35.4	13.2	349.5	79.8	693.4	6.0
Health care, social security and social welfare	75.2	21.6	32.9	456.3	47.1	633.1	5.5
Culture, art, sports and recreation	24.6	21.6	9.2	178.3	68.7	302.4	2.6
Public management and social organization	127.8	60.8	21.6	568.4	215.1	993.7	8.6
Total service sector	2407.9	988.2	349.8	5739.0	2069.1	11554.0	100.0
% of total carbon emission generated by the whole economy of Beijing	10.6	4.4	1.5	25.3	9.1	50.9	

Therefore, similar correlation effects between sectors should be considered in formulating emission reduction policies.

In practical terms, each service subsector plays a different role in the above 5 emission components because the relationships between each subsector and the other economic sectors differ. The specific roles of the service subsectors are shown in Table 6.

With respect to the DVC, especially noteworthy are the roles of the transportation, storage, mail and telecommunications subsector, the real estate trade subsector, and the education subsector, which emit 860.4, 514.7, and 215.4 kt of carbon, respectively, and rank first, second, and third in terms of this component. In contrast, among these 3 subsectors, only transportation, storage mail and telecommunications plays a significant role in the OC, while the other 2 subsectors, real estate trade and education, show relatively low emissions, accounting for 5.32% (52.6 kt) and 3.58% (35.4 kt) of the total OC, respectively. On the other hand, the scientific studies and technical services subsector and the tenancy and commercial services subsector show higher OC rankings, accounting for 13.66% (135.0 kt) and 10.55% (104.2 kt) of the total OC, respectively. With respect to the FBC, we especially note the scientific studies and technical services subsector, which accounts for 22.6% (79.0 kt) of the total component. However, the OC and the FBC play smaller roles in total emissions compared with the other components. As with the FBC, we should also consider the roles of the scientific studies and technical services subsector in the ISC, as it accounts for 17.33% (358.6 kt) of this component. In addition, carbon emissions generated by other service subsectors induced by transportation, storage, mail and telecommunications is small, accounting for only 1.08% (22.4 kt) of the total ISC.

The SOC, representing emissions produced by the non-service sector to meet the final demand of the service sector, is the greatest contributor to total emissions and therefore should be analyzed in detail. Again, the scientific studies and technical services subsector and the real estate trade subsector are notable because of their larger emissions compared with other subsectors, accounting for 15.59% (894.7 kt) and 14.5% (832.2 kt) of this component, respectively. In addition to these 2 subsectors, the finance subsector (589.2 kt) and the public management and social organization subsector (568.4 kt), which are generally seen as low carbon emitters, play a notable role in the SOC. This is because finance and public sector development require intermediate inputs from the manufacturing sectors, as shown in the input-output extension table for Beijing for 2010. We should also note the pull effect of the information transmission, computer services and software subsector, the health care, social security and social welfare subsector, and the tenancy and commercial services subsector. Precisely because the SOC is greatly neglected, emission reduction policies rarely incorporate the above service subsectors into the scope of regulation.

Moreover, in terms of the SOC, the transportation, storage, mail and telecommunications subsector shows a weak pull effect on other sectors, accounting for only 3.08% (176.5 kt) of the total component. This reflects the weak demand of the transportation, storage, mail and telecommunications subsector for intermediate goods produced in other sectors. However, the direct emissions of this subsector are huge, as shown in Table 4. This arises from the fact that services produced in the transportation, storage, mail and telecommunications subsector are strongly pulled by the final demand of other productive activities. Therefore, policy makers should examine the emission sources of the transportation, storage, mail and telecommunications subsector to effectively control carbon emissions without harming industrial interests.

3.4. Specific analysis of the SOC of the service sector

In view of the above analysis, the SOC of the service sector accounts for the largest share of total carbon emissions, which are mainly caused by demand of the service sector for products produced by the non-service sector. In this section, we examine the SOC in detail, especially the carbon emissions of the non-service subsectors that produce most heavily for the service sector. Table 7 indicates the pull effects of the service subsectors on the largest non-service subsectors, which are shown by diagonalizing $c^{M'}$ in Eq. (17).

As shown in Table 7, the largest SOC of the service sector, accounting for 77.33% of the total SOC, arises from carbon emissions associated with the production and distribution of power for electricity and heat. Of this percentage, real estate trade accounts for 13.14%, the scientific studies and technical services subsector accounts for 9.93%, the public management and social organization subsector accounts for 8.53%, and finance accounts for 8.47%. All of these subsectors require offices and venues, such as laboratories, government buildings, and bank buildings, and thus require power for electricity and heat. Energy efficiency is relatively low in China compared

Table 7. Percentage distribution of the spill-over component (SOC)

Subsectors of the service sector	Farming, forestry, animal husbandry and fishery	Mining and processing of metal ores	Processing of petroleum, coking and nuclear fuel	Chemical industry	Manufacture of non-metallic mineral products	Production and distribution of electric power and heat power	Construction	Other sectors	Total service sector
Transportation, storage, mail and telecommunications	0.01	0.10	0.40	0.03	0.07	2.31	0.01	0.14	3.08
Information transmission, computer services and software	0.05	0.45	0.16	0.33	0.36	6.60	0.06	0.41	8.42
Wholesale trade and retail trade	0.05	0.22	0.16	0.18	0.16	3.77	0.07	0.25	4.86
Hotel and restaurants	0.22	0.09	0.05	0.08	0.10	5.50	0.03	0.70	6.75
Finance	0.07	0.28	0.33	0.20	0.21	8.47	0.10	0.59	10.27
Real estate trade	0.06	0.25	0.19	0.15	0.24	13.14	0.12	0.36	14.50
Tenancy and commercial services	0.17	0.47	0.31	0.28	0.23	5.38	0.06	0.53	7.42
Scientific studies and technical services	0.16	1.52	0.36	0.75	1.17	9.93	0.44	1.27	15.59
Water, environment and municipal engineering conservancy	0.05	0.11	0.05	0.03	0.16	1.01	0.10	0.06	1.57
Resident services and other services	0.01	0.03	0.01	0.02	0.02	0.37	0.01	0.03	0.50
Education	0.05	0.14	0.11	0.07	0.41	5.10	0.05	0.17	6.09
Health care, social security and social welfare	0.04	0.43	0.12	2.19	0.23	4.79	0.02	0.14	7.95
Culture, art, sports and recreation	0.03	0.10	0.06	0.09	0.12	2.43	0.02	0.26	3.11
Public management and social organization	0.06	0.21	0.18	0.12	0.38	8.53	0.06	0.37	9.90
Total service sector	1.02	4.37	2.46	4.50	3.87	77.33	1.15	5.29	100.00

with other countries. China's building sector consumes 25% of the total energy in China, and with an estimated total area of over 50 billion m^2, energy use was approximately 5500 TWh in 2007 (NBS 2008, Jiang 2011). Moreover, in addition to the widespread use of air-conditioning in the summer, Beijing (which is located in a cold region) has a long heating season, lasting almost 4 to 5 mo (Kong et al. 2012). Because offices and venues in Beijing consume large amounts of power for electricity and heat, causing substantial carbon emissions, improving building energy efficiency should be an aspect of emissions mitigation policies. Other major non-service subsectors, including 'other sectors', the chemical industry, and the mining and processing of metal ore are just behind the production and distribution of power for electricity and heat in terms of the pull effect from the service sector, accounting for 5.29, 4.50, and 4.37% of the total SOC, respectively.

According to Table 7, among the service subsectors, the scientific studies and technical services subsector accounts for the largest share of the SOC, inducing carbon emissions from the mining and processing of metal ores subsector (1.52% of total carbon emissions), the manufacture of non-metallic mineral products (1.17%), construction (0.44%), and the 'other sectors' (1.27%). This is mainly because scientific studies and technical services require many research facilities and thus depend on related sectors such as metal ores, non-metallic mineral products, and construction. Similarly, owing to their demand for raw materials, the hotel and restaurant subsector, the transportation, storage, mail and telecommunications subsector, and the health care, social security and social welfare subsector account for substantial portions of the SOC through their demand for outputs from the farming, forestry, animal husbandry and fisheries subsector

(0.22%), the petroleum processing, coking and nuclear fuel processing subsector (0.40%), and the chemical industry (2.19%).

Because the Beijing government continues to promote an increase in the share of the service sector in the Beijing economy in its '12th Five-Year' period and aims to reduce carbon emissions by 18% compared to 2010, emission control policies should focus on the indirect effects of the service sector on emissions generated by other sectors in addition to the direct emissions caused by the production of such services as transportation.

4. CONCLUSIONS AND POLICY IMPLICATIONS

In this study, an input-output subsystem is employed to conduct a systematic analysis of carbon emissions of the service sector. The analysis divides carbon emissions into 5 components (DVC, OC, FBC, SOC, ISC), enabling an understanding of the economic ties between carbon emissions generated by the service sector and the economy of Beijing as a whole. In particular, the application of an input-output subsystem reveals the roles played by different service subsectors and their relationship with non-service subsectors. At present, this study may be seen as a contribution to the general discussion of carbon emissions caused by the service sector, as Beijing continues to vigorously advance the service industry while aiming to reduce carbon emissions.

From the analysis of this study, we drew the following important conclusions. (1) Total carbon emissions produced by Beijing's economy as a whole to satisfy the final demand of the service sector amount to half of total carbon emissions produced by all production sectors combined, i.e. significantly greater than the direct emissions generated by the service production.

(2) With respect to the decomposition of emissions, we should highlight the importance of the SOC. The major share of the SOC is related to the production and distribution of power for electricity and heat. The service sector strongly pulls energy consumption and carbon emissions, and likely plays a greater role in total emissions than is generally assumed.

(3) In terms of the different roles played by the service subsectors, the transportation, storage, mail and telecommunications subsector is the main direct emitter of carbon in the service sector. However, in addition to direct emissions, indirect emissions should also be addressed. In this respect, the scientific studies and technical services subsector, the hotel and restaurant subsector, and the health care, social security and social welfare subsector all show the strong pull effects of the service sector on the other productive activities of the economy.

Given the above conclusions, we conclude that Beijing should promote the service sector carefully, in view of its large indirect use of fossil fuels. Moreover, some policy implications follow.

With respect to the subsectors that have small direct emissions but large indirect emissions — such as real estate trade, the scientific studies and technical services subsector, and finance — financial support, and guidelines for technical innovation in reducing consumption of electricity, heat and raw materials and improving energy efficiency should be increased to mitigate carbon emission spillover from the service to the non-service sector. More specifically, policy makers should consider and implement energy taxes combined with policies concerning technology and relative prices to improve energy efficiency. Based on the practices of European Union members such as Finland, Sweden and Norway, an appropriate policy consideration is reducing taxes on employment by revenue recycling while levying energy taxes in order to have environmental gain without adverse effects on economic activity (Birol & Keppler 2000, Hanley et al. 2009).

With respect to the subsectors that have large direct, but small indirect, emission effects — such as the transportation, storage, mail and telecommunications subsector — financial support and polices regarding renewable energy (e.g. ethanol as fuel for vehicles) development and large-scale production and use should be continuously updated. For instance, policies promoting new-energy vehicles (e.g. hybrid cars and electric vehicles) and fuel ethanol can be effective in energy conservation and reducing emissions, but they require better and more detailed terms to be effectively implemented.

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