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RESEARCH ARTICLE

Multi-regional input–output analysis for China's regional CH_4 emissions

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Abstract China is the largest CH_4 emitter in the world. Given the importance of CH_4 in greenhouse gas emission inventories, the characteristics of China's CH_4 emissions at different scales deserve to be fully understood. Presented in this paper is an interprovincial input–output embodiment analysis of China's regional CH_4 emissions in 2007, based on the most recently available multi-regional input–output table, and relevant CH_4 emissions data. The results show that the eastern, central and western areas contribute to 48.2%, 28.6%, and 23.3% of the national total embodied emissions, respectively. Guangdong has the highest level of embodied CH_4 emissions among all of the 30 regions. The *Agriculture* sector produces the most embodied CH_4 emissions in final demand, followed by the *Construction*, *Food Production and Tobacco Processing*, and *Other Service Activities* sectors. Significant net transfers of embodied CH_4 emission flows are identified from the central and western areas to the eastern area via interregional trade. Shanxi is the largest interregional exporter of embodied CH_4 emissions. In contrast, Guangdong is the largest interregional importer. Energy activities, agricultural activities, and waste management comprise 65.6%, 30.7%, and 3.7% of the total embodied CH_4 emissions in interregional trade, respectively. By using consumption-based accounting principles, the emission magnitudes, per capita emissions, and emission intensities of most eastern regions increase remarkably, while those of some central and western regions decrease largely. To achieve regional CH_4 emission mitigation, comprehensive mitigation measures should be designed under consideration of regional transfer of emission responsibility.

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1 Introduction

In addition to the direct greenhouse gas (GHG) emission mitigation for prominent industries, there is an urgent need to make consumption-side mitigation polices by identifying embodied emissions induced by final demand (Munksgaard and Pedersen, 2001; Bastianoni et al., 2004; Lenzen et al., 2007; Peters, 2008; Zhang et al., 2011). Input-output embodiment analysis facilitates a deeper appreciation of sector-specific total emission requirements in terms of both direct/visible, and indirect/hidden emission costs (Leontief, 1970; Miller and Blair, 2009). This type of analysis has been popular as a main frontier method for benchmarking GHG emissions embodied in final consumption and international trade (Wiedmann et al., 2007; Liu and Wang, 2009; Minx et al., 2009; Wiedmann, 2009). Relevant input–output models, which have been rigorously extended and widely used in the embodiment analysis of GHG emissions at different scales (Chen et al., 2011; Wiedmann et al., 2011), can be roughly divided into two types: a) single-regional input–output models, and b) multi-regional input–output models. Many studies have contributed to GHG emission embodiment analysis by applying different input–output models for several individual countries (e.g., Lenzen, 1998; Machado et al., 2001; Labandeira and Labeaga, 2002; Sánchez-Chóliz and Duarte, 2004; Mongelli et al., 2006; Peters and Hertwich, 2006; Ipec Tunç et al., 2007; Limmeechokchai and Suksuntornsiri, 2007; Mäenpää and Siikavirta, 2007; Roca and Serrano, 2007; Weber and Matthews, 2007; Andrew and Forgie, 2008; Chung et al., 2009), as well as for multiple countries and regions (e.g., Blair and Miller, 1983; Miller and Shao, 1990; Lenzen et al., 2004; McGregor et al., 2008; Peters and Hertwich, 2008; Andrew et al., 2009; Hertwich and Peters, 2009; Davis and Caldeira, 2010; Wiedmann et al., 2010; Chen and Chen, 2011a,b; Peters et al., 2011) .

China's GHG emissions have become a focal point for policy makers, researchers, and other groups around the world (Zhang, 2010). Many studies have contributed to the estimation of CO_2 emissions and related assessments for mitigation potential in China. Regional or sector-specific emission performances, in particular, have been extensively evaluated (e.g., Liu et al., 2010b; Clarke-Sather et al., 2011; Geng et al., 2011; Meng et al., 2011; Feng et al., 2012; Guan et al., 2012; Liu et al., 2012b; Zhao et al., 2012). Much of the existing research has also applied input–output models to perform embodiment analyses of China's CO_2 emissions (e.g., Peters et al., 2007; Wang and Watson, 2007; Guan et al., 2008, 2009; Li and Hewitt, 2008; Pan et al., 2008; Weber et al., 2008; Xu et al., 2009; Chen and Chen, 2010; Dong et al., 2010; Guo et al., 2010; Lin and Sun, 2010; Liu et al., 2010c; Yan and Yang, 2010; Zhang, 2010; Du et al., 2011; Xu et al., 2011; Zhang et al., 2011). To reflect the regional diversity in China, some studies have focused on the embodied CO_2 emissions at the regional level (e.g., Liang et al., 2007; Liu et al., 2010a; Guo et al., 2012b; Tong and Ma, 2012), specifically using multi-regional input–output models to calculate the regional emissions embodied in interprovincial trade (Chen, 2011a; Guo et al., 2012a).

Methane (CH_4) is considered to be the second most important GHG after CO_2; and China is the largest CH_4 emitter in the world (Zhang, 2011). The official GHG emissions inventory from the Initial National Communication on Climate Change of China (INCCCC, 2004) reported that China's CH_4 emissions in 1994 totaled 34,287 Gg, accounting for 23.43% of total GHG emissions by the CO_2-eq value. Zhang and Chen (2010) reported that total CH_4 emissions by the Chinese economy in 2007 were 989.8 Mt CO_2-eq, a magnitude of about one sixth of China's CO_2 emissions from fuel combustion, and greater than the nationwide CO_2 emissions from fuel combustion of many developed countries such as the UK, Canada, and Germany. It follows that the mere consideration of CO_2 emissions does not reflect the real situation and the complete picture of China's GHG emissions (Chen and Zhang, 2010; Zhang et al., 2011). Although direct anthropogenic CH_4 emissions at the national and subnational levels have been explored by many authors (e.g., Du, 2006; EPA, 2006; Fu and Yu, 2010; Zhang and Chen, 2010; Cheng et al., 2011; Zhang, 2011), more efforts have to be made to understand China's CH_4 emissions and related emission mitigation from different perspectives.

Embodied (direct plus indirect) CH_4 emissions in China, by statistically defined industrial sectors and final use categories, have been extensively measured by Chen and his fellows in their multi-scale ecological input–output analyses of environmental emissions and resource use. In his doctoral dissertation, Zhou (2008) presented two databases for embodied CH_4 emission intensity, one for the Chinese economy 1992 under the Material Product System (MPS) for planning economies of the socialist Soviet style, and another for the Chinese economy 2002 under the System of National Accounts (SNA) for marketing economies. Chen et al. (2010) provided the embodiment intensities of CH_4 emissions by the Chinese economy in 2005. Zhang and Chen (2010) accounted for embodied CH_4 emissions by the Chinese economy in 2007. Zhou et al. (2010) provided CH_4 embodiment intensities in the regional urban economy of Beijing in 2002. Nevertheless, there has been little research on the embodiment analysis of China's regional CH_4 emissions from a consumption-based perspective, especially considering the large scale of interregional trade.

To fill this gap, an interprovincial input–output embodiment analysis for China's regional CH_4 emissions was conducted and is reported in this paper. We investigated the regional CH_4 emissions embodied in final demand and interregional trade in 2007, based on the most recently available multi-regional input–output table and relevant CH_4 emission data, with the emphasis on the transfer of embodied CH_4 emissions among regions. Furthermore, regional CH_4 emissions, in terms of emission magnitude, per capita emission, and emission intensity, under both production-based and consumption-based accounting principles, are systematically revealed. The results of this investigation will help policy makers to allocate regional responsibility for China's CH_4 emissions, and to design comprehensive measures for CH_4 emissions reduction among regions, based on different accounting principles.

The remainder of this paper is organized as follows. In Section 2, the multi-regional input–output analysis method, the algorithms for input–output analyses and the data sources are introduced. China's regional CH_4 emissions embodied in final demand and interregional trade from both regional and sector-specific perspectives are presented in Section 3. The characteristics of China's regional CH_4 emissions under different accounting principles and the corresponding emission responsibility among regions are also discussed in this section. Some concluding remarks are made in Section 4.

2 Methodology and data sources

2.1 Input–output analysis and emissions embodiment

Multi-regional input–output (MRIO) analysis can not only reveal the relationship between different sectors, but also identify the economic links between regions (Wiedmann et al., 2011; Guo et al., 2012a). The Chinese MRIO table for the year of 2007 compiled by Liu et al. (2012a), as the most recently available, was adopted for this study. It provides complete data on China's 30-region trade for 30 sectors. In order to focus on the interregional connection, the imports item, which was separated in the original MRIO table, has been further removed in this study. The format of the revised MRIO table is shown in Table 1. Detailed sector-specific and regional information is shown in Tables A1 and A2 in the Appendix.

For the revised MRIO table in 2007, the basic row balance can be expressed as

$$\begin{aligned} x_i^f &= \sum_{s=1}^{30}\sum_{j=1}^{30} z_{ij}^{fs} + \sum_{s=1}^{30}\sum_{t=1}^{2} d_{it}^{fs} + e_i^f + o_i^f \\ &= \sum_{s=1}^{30}\sum_{j=1}^{30} z_{ij}^{fs} + p_i^f, \end{aligned} \tag{1}$$

where x_i^f represents the total output of sector i in region f; z_{ij}^{fs} represents the intermediate use of sector j in region s supplied by sector i in region f; d_{it}^{fs} represents final use, including consumption (rural household, urban household and government consumption) ($t=1$),and investment (fixed capital formation and stock increase) ($t=2$), of region s supplied by sector i in region f; e_i^f represents exports from sector i in region f; o_i^f is the other balance items of sector i in region f; p_i^f is the total final use supplied by sector i in region f. There are 30 regions, with 30 sectors in each region in the MRIO model.

Each sector in a given regional economy links with the environment and the economy via direct emissions, imported embodied emissions associated with purchasing commodities, and exported embodied emissions associated with selling commodities. With Eq. (1), the MRIO model for the total emission balance of sector i in region f can be formulated as (Zhou, 2008; Chen et al., 2010; Chen, 2011b; Chen and Chen, 2013a, b)

$$\begin{aligned} c_i^f + \sum_{s=1}^{30}\sum_{j=1}^{30} \varepsilon_j^s \times z_{ji}^{fs} &= \sum_{s=1}^{30}\sum_{j=1}^{30} \varepsilon_i^f \times z_{ij}^{fs} \\ &\quad + \sum_{s=1}^{30}\sum_{t=1}^{2} \varepsilon_i^f \times d_{it}^{fs} \\ &\quad + \varepsilon_i^f \times e_i^f + \varepsilon_i^f \times o_i^f \\ &= \sum_{s=1}^{30}\sum_{j=1}^{30} \varepsilon_i^f \times z_{ij}^{fs} + \varepsilon_i^f \times p_i^f, \end{aligned} \tag{2}$$

where c_i^f is direct CH_4 emissions of sector i in region f; ε_j^s is the embodied (direct plus indirect) emission intensity of output from sector j in region s; z_{ji}^{fs} denotes the intermediate input from sector j in region s; and ε_i^f denotes the embodied (direct plus indirect) emission intensity of output from sector i in region f.

For the whole system in terms of all regional economies with 900 entries, we have

$$\begin{cases} c_1^1 + \sum_{s=1}^{30}\sum_{j=1}^{30} \varepsilon_j^s \times z_{j1}^{1s} = \sum_{s=1}^{30}\sum_{j=1}^{30} \varepsilon_1^1 \times z_{1j}^{1s} + \varepsilon_1^1 \times p_1^1 \\ c_2^1 + \sum_{s=1}^{30}\sum_{j=1}^{30} \varepsilon_j^s \times z_{j2}^{1s} = \sum_{s=1}^{30}\sum_{j=1}^{30} \varepsilon_2^1 \times z_{2j}^{1s} + \varepsilon_2^1 \times p_2^1 \\ \qquad\vdots \\ c_{30}^{30} + \sum_{s=1}^{30}\sum_{j=1}^{30} \varepsilon_j^s \times z_{j30}^{30s} = \sum_{s=1}^{30}\sum_{j=1}^{30} \varepsilon_{30}^{30} \times z_{30j}^{30s} + \varepsilon_{30}^{30} \times p_{30}^{30} \end{cases} . \tag{3}$$

If we introduce the following denotations,

Table 1 The format of revised multi–regional input–output table in 2007

Input		Intermediate use							Final use							Total output
		R1			…	R30			R1		…	R30		Export	Others	
		S1	…	S30	…	S1	…	S30	Consumption	Investment	…	Consumption	Invest-ment			
R1	S1															
	⋮															
	S30															
⋮	⋮				z_{ij}^{fs}						d_{it}^{fs}			e_i^f	o_i^f	x_i^f
R30	S1															
	⋮															
	S30															
Direct CH_4 emissions					c_i^f											

$$\boldsymbol{E}^{*}=\begin{bmatrix}\begin{pmatrix}\varepsilon_1^1\\ \vdots\\ \varepsilon_{30}^1\end{pmatrix}\\ \vdots\\ \begin{pmatrix}\varepsilon_1^{30}\\ \vdots\\ \varepsilon_{30}^1\end{pmatrix}\end{bmatrix},C^{*}=\begin{bmatrix}\begin{pmatrix}c_1^1\\ \vdots\\ c_{30}^1\end{pmatrix}\\ \vdots\\ \begin{pmatrix}c_1^{30}\\ \vdots\\ c_{30}^{30}\end{pmatrix}\end{bmatrix},\qquad \boldsymbol{Z}^{*}=\begin{bmatrix}\begin{pmatrix}z_{11}^{11} & \cdots & z_{301}^{11}\\ \vdots & \ddots & \vdots\\ z_{130}^{11} & \cdots & z_{3030}^{11}\end{pmatrix} & \cdots & \begin{pmatrix}z_{11}^{301} & \cdots & z_{301}^{301}\\ \vdots & \ddots & \vdots\\ z_{130}^{301} & \cdots & z_{3030}^{301}\end{pmatrix}\\ \vdots & \ddots & \vdots\\ \begin{pmatrix}z_{11}^{130} & \cdots & z_{301}^{130}\\ \vdots & \ddots & \vdots\\ z_{130}^{130} & \cdots & z_{3030}^{130}\end{pmatrix} & \cdots & \begin{pmatrix}z_{11}^{3030} & \cdots & z_{301}^{3030}\\ \vdots & \ddots & \vdots\\ z_{130}^{3030} & \cdots & z_{3030}^{3030}\end{pmatrix}\end{bmatrix},$$

and

$$\boldsymbol{X}=\begin{bmatrix}\begin{pmatrix}\sum_{s=1}^{30}\sum_{j=1}^{30}z_{1j}^{1s}+p_1^1 & & \\ & \ddots & \\ & & \sum_{s=1}^{30}\sum_{j=1}^{30}z_{30j}^{1s}+p_{30}^1\end{pmatrix} & & \\ & \ddots & \\ & & \begin{pmatrix}\sum_{s=1}^{30}\sum_{j=1}^{30}z_{1j}^{30s}+p_1^{30} & & \\ & \ddots & \\ & & \sum_{s=1}^{30}\sum_{j=1}^{30}z_{30j}^{30s}+p_{30}^{30}\end{pmatrix}\end{bmatrix},$$

then the above simultaneous equations can be expressed in a compressed matrix form of

$$\boldsymbol{C}^{*}+\boldsymbol{Z}^{*}\times\boldsymbol{E}^{*}=\boldsymbol{X}\times\boldsymbol{E}^{*},\tag{4}$$

where $\boldsymbol{X}$ is the total output, in terms of a diagonal matrix.

If $\boldsymbol{C}$, $\boldsymbol{Z}$, and $\boldsymbol{E}$ are introduced as the transpositions of $\boldsymbol{C}^{*}$, $\boldsymbol{Z}^{*}$, and $\boldsymbol{E}^{*}$, then Eq. (4) can be transformed into

$$\boldsymbol{E}=\boldsymbol{C}(\boldsymbol{X}-\boldsymbol{Z})^{-1}.\tag{5}$$

To get the value of $\boldsymbol{E}$, the elements of $\boldsymbol{C}$, i.e., c_i^f, can be extracted from the direct CH_4 emissions of sector i in region f; the elements of $\boldsymbol{Z}$, i.e., z_{ij}^{fs}, can be extracted from the whole economic intermediate input–output table, which describes the intermediate trade relationship between all regional economies included in the MRIO table; and the elements of $\boldsymbol{X}$, i.e., $\sum_{s=1}^{30}\sum_{j=1}^{30}z_{ij}^{fs}+p_i^f$, can be calculated based on the data extracted from the economic intermediate and final demand input–output tables, shown in Table 1.

Thus the embodied emissions $\boldsymbol{C}_{EMBODIMENT}$ of any given set of commodities $\boldsymbol{B}^{*}=[b_1, b_2, \ldots, b_{900}]$ (b_i indicates the output of Entry i contained in the commodities set, and $\boldsymbol{B}$ is the transposition of $\boldsymbol{B}^{*}$) can be obtained as

$$\boldsymbol{C}_{EMBODIMENT}=\boldsymbol{E}\times\boldsymbol{B}.\tag{6}$$

Thereafter, concrete analyses can be accomplished in terms of embodied emission flows related to specific economic activity. For instance, the embodied emissions induced by each category of final demand, such as consumption and investment, can be calculated by multiplying the embodied emission intensity matrix $\boldsymbol{E}$ by the corresponding final-use vector. Therefore, we are able to calculate the embodied emissions induced by the final demand of all of the 30 regions (or 30 sectors) directly.

For the calculation of CH_4 emissions embodied in interregional trade, the embodied emissions of interregional imports (*EEII*) can be expressed as

$$EEII^{f}=\sum_{s}EEIT^{sf},\tag{7}$$

where $EEII^f$ is embodied CH_4 emissions from interregional imports of region f; and $EEIT^{sf}$ is the transfer of embodied CH_4 emissions between region s and region f ($s\neq f$), resulting from the intermediate use and final use by region f supplied by region s.

The embodied CH_4 emissions of interregional exports (*EEIE*) also can be expressed as

$$EEIE^{f}=\sum_{s}EEIT^{fs},\tag{8}$$

where $EEIE^f$ is embodied CH_4 emissions from interregional exports of region f ; and $EEIT^{fs}$ is the transfer of embodied CH_4 emissions between region f and region s ($f \neq s$), resulting from the intermediate use and final use by region s supplied by region f. Similarly, the sector-specific embodied emissions of interregional imports (*EEII*) and interregional exports (*EEIE*) can be calculated according to interregional transfers of sector-specific embodied CH_4 emission flows.

Hence, we have the net embodied emissions of interregional trade balance (*EEIB*) expressed as

$$EEIB^f = EEIE^f - EEII^f, \tag{9}$$

where $EEIB^f$ is embodied CH_4 emissions of interregional trade balance in region f .

More detailed procedures illustrating systems multi-region input–output modeling can be examined in the work by Chen and his colleagues (e.g., Chen, 2011b; Chen and Chen, 2011a, b; Chen and Chen, 2013a, b).

2.2 Data sources and emission data preparation

With regard to the administrative division, the Mainland of China consists of 31 regions at the provincial level, including 22 provinces, 5 autonomous regions (Inner Mongolia, Guangxi, Xinjiang, Ningxia, and Tibet) and 4 municipalities (Beijing, Shanghai, Tianjin, and Chongqing, directly under the Central Government), and excludes the Hong Kong Special Administrative Region, the Macau Special Administrative Region, and the Taiwan Province. Conventionally, Mainland China has been divided into three areas, the eastern, central, and western areas. In this study, referring to the regional divisions published by Wang et al. (2012) and Guo et al. (2012a), the geographical distribution of the three areas associated with corresponding regional information is listed in Appendix Table A2. The eastern area consists of 12 coastal regions with the regional codes R1 to R12. The central area consists of 9 regions, coded R13 to R21. The western area consists of 10 regions coded R22 to R30 (Tibet is not included due to lack of data). Population and GDP data are available from the China Statistical Yearbook (CSY, 2008).

In this study, the CH_4 emissions data for all of the 30 regions were adopted from Zhang (2011). The major emission sources of CH_4 by regional economy considered include agricultural activities (i.e., enteric fermentation, manure management, rice cultivation, and field burning of crop residues), energy activities (i.e., coal mining, oil system leakage, and natural gas system leakage), and waste management (i.e., municipal solid waste landfill, industrial wastewater management, and domestic sewage management). For the estimation of regional CH_4 emissions by economic sector, the construction and service sectors are assumed to contribute to 1/3 of the total amount of domestic sewage and municipal solid waste respectively (Okadera et al., 2006; Zhang and Chen, 2010). Thus, regional CH_4 emissions from the construction and service sectors can be taken as one third of the total CH_4 emissions from municipal solid waste landfill and domestic sewage management. For the input–output analysis, the CH_4 emissions from the waste management by sector can be estimated based on total emissions and corresponding sector-specific economic output. Detailed results of CH_4 emissions by regional economy in 2007 are listed in Table 2.

3 Results and discussion

3.1 Emissions embodied in final demand

3.1.1 Regional analysis

The CH_4 emissions embodied in final demand of the 30 regions in 2007 are shown in Fig. 1. There are remarkable regional disparities in embodied CH_4 emissions among the eastern, central and western regions. The eastern area contributes the largest percentage, 48.2%, to national total embodied emissions, (15,925.4 Gg), followed by the central area at 28.6%, and the western area at 23.3%. At the sub-area level, eastern regions generally have higher embodied emissions compared to central and western regions. Guangdong (R10), as the largest region of economic scale and urban population in China, holds the top emissions volume of 3,502.4 Gg, followed by Jiangsu (R6) at 2,023.6 Gg, Sichuan (R27) at 1,962.3 Gg, Shandong (R5) at 1,826.1 Gg, Henan (R17) at 1,664.9 Gg, and Zhejiang (R8) at 1,641.6 Gg. As to the composition of emissions, energy-related CH_4 emissions are the leading emission type in 14 regions, contributing about 50%–60% of the embodied emissions in these regions. This is particularly evident in Shanxi (R16), where energy-related emissions are 73.6%, and in Chongqing (R28) where they are 71.8%. Emission compositions are different in the other 16 regions, where agricultural activities are the leading source of embodied CH_4 emissions. For instance, agricultural CH_4 emissions account for 85.2% of the embodied emissions in Hainan (R12), and 83.6% in Qinghai (R26), respectively.

Figure 2 presents embodied CH_4 emissions by final demand category in terms of consumption, investment, exports, and others for all of the regions. In 2007, the total amount of CH_4 emissions embodied in consumption, investment, exports, and others are 15,935.5, 10,402.5, 6,008.0, and 718.5 Gg, respectively. CH_4 emissions embodied in consumption are the leading final demand category in most regions, accounting for 40%–60% of total embodied emissions, and notably, reaching 72.6% in Hebei

Table 2 Direct anthropogenic CH_4 emissions by region in 2007 (Gg)

Region code	Agricultural activities	Energy activities	Waste management	Total
Eastern area	**4,720.7**	**1,483.2**	**1,420.0**	**7,623.9**
R1	28.0	12.4	57.5	97.9
R2	28.9	25.7	23.2	77.8
R3	504.1	415.4	111.9	1,031.4
R4	373.3	539.2	102.3	1,014.8
R5	636.0	294.5	231.9	1,162.4
R6	587.8	73.3	183.9	845.0
R7	28.8	1.9	70.8	101.5
R8	258.9	0.1	164.7	423.7
R9	269.6	57.8	145.0	472.4
R10	866.8	30.1	224.8	1,121.7
R11	970.4	32.8	91.0	1,094.2
R12	168.1	0.0	13.0	181.1
Central area	**6,781.8**	**8,404.5**	**704.8**	**15,891.1**
R13	611.0	748.8	102.1	1,461.9
R14	430.4	159.1	68.9	658.4
R15	712.0	452.0	62.9	1,226.9
R16	136.1	4,284.7	46.5	4,467.3
R17	1,022.8	1,189.4	156.0	2,368.2
R18	664.1	703.6	69.4	1,437.1
R19	804.6	103.1	81.4	989.1
R20	1,313.7	486.2	82.1	1,882.0
R21	1,087.1	277.6	35.5	1,400.2
Western area	**3,847.5**	**5,368.3**	**333.7**	**9,549.5**
R22	487.4	269.4	39.3	796.1
R23	356.1	138.2	24.2	518.5
R24	89.6	223.9	22.1	335.6
R25	195.0	526.9	48.6	770.5
R26	332.2	26.4	6.8	365.4
R27	1,091.4	1,065.3	100.2	2,256.9
R28	179.8	719.5	30.4	929.7
R29	458.7	1,871.4	17.6	2,347.7
R30	657.3	527.3	44.5	1,229.1
Total	**15,350.0**	**15,256.0**	**2,458.5**	**33,064.5**

(R3), and 66.9% in Hainan (R12). This is most likely because agricultural products and foodstuff are mainly consumed by rural and urban households.

CH_4 emissions embodied in investment contribute about 20%–50% to embodied CH_4 emissions for most regions. In China, capital investments, such as in infrastructure, are an important motor for economic growth (Peters et al., 2007). Moreover, most of the investment in the industry sector flows into infrastructure construction and heavy industrial processes, such as energy-intensive industrial production for iron and steel, cement, and aluminum electrolysis (CSY, 2008), resulting in increased embodied GHG emissions (Chen and Zhang, 2010).

Shares of CH_4 emissions embodied in exports are especially high in some eastern coastal regions due to their location advantages and great economic openness. For instance, 39.3%, 33.9%, and 36.9% of the total embodied emissions, respectively in the Jiangsu, Zhejiang, and

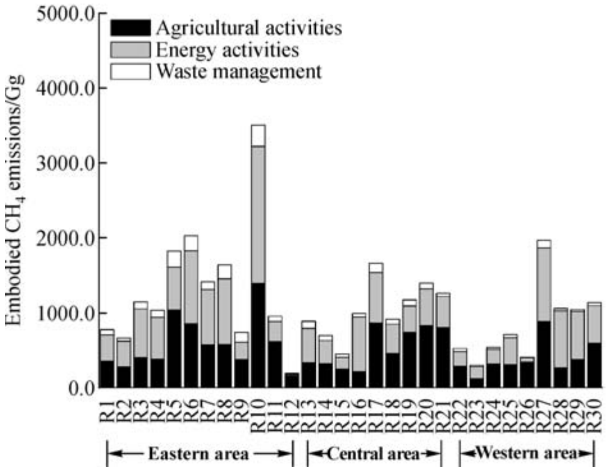

Fig. 1 CH_4 emissions embodied in final demand by source and by region.

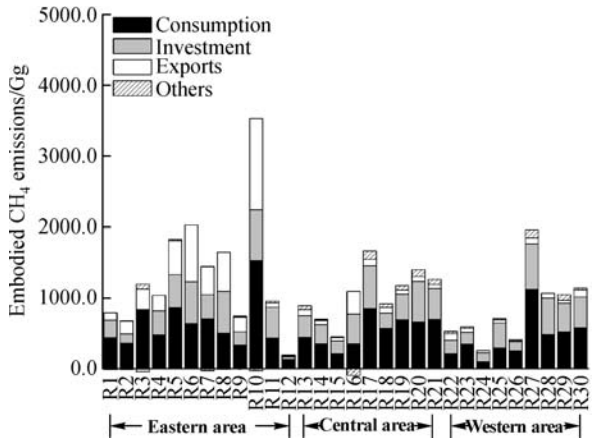

Fig. 2 CH_4 emissions embodied in final demand by final demand category and by region.

Guangdong regions, are attributed to CH_4 emissions embodied in exports.

3.1.2 Sector-specific analysis

The embodied CH_4 emissions of each specific sector are obtained by summing the emissions of the same sector across all of the 30 regions. Figure 3 presents the distribution of CH_4 emissions embodied in final demand by sector. *Agriculture* (S1) ranks first in CH_4 emissions embodied in final demand, amounting to 7,898.8 Gg, and accounting for 23.9% of national total embodied emissions. *Construction* (S24), *Food Production, Food Processing and Tobacco Processing* (S6), and *Other Service Activities* (S30) are the next three sectors in rank, contributing 15.8%, 14.0%, and 8.6% to the national total, respectively. In contrast, direct CH_4 emissions are

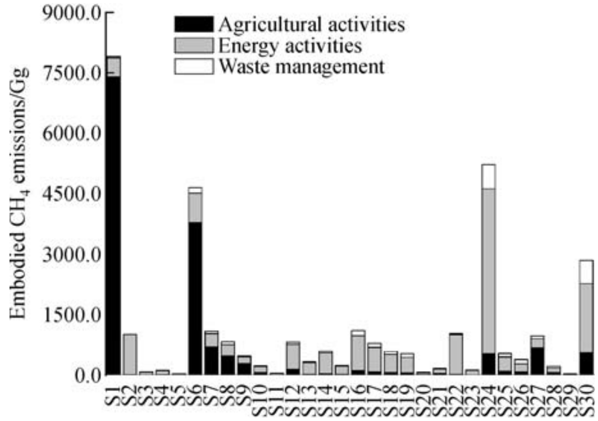

Fig. 3 CH_4 emissions embodied in final demand by source and by sector.

mainly concentrated in the two sectors of *Agriculture*, and *Coal Mining and Dressing* (S2), which account for 46.4% and 44.8% of the national total, respectively.

CH_4 emissions from agricultural activities are the leading emission type in the 6 sectors numbered 1, 6–9, and 27, which are either directly involved in food production and processing, or are manufacturing industries that depend on the raw materials from the *Agriculture* sector. In contrast, emission compositions are different in the other 24 sectors, with CH_4 emissions from energy activities as the leading emission type. Prominently, the *Construction* sector holds the top embodied energy-related CH_4 emissions, as shown in Fig. 3. The energy consumption in China's building sector is responsible for about one quarter of the total energy use, which includes direct energy used in maintaining thermal comfort and normal operation, and indirect embedded energy use associated with the construction of buildings, including material manufacture and transportation of those materials to the site (Jiang and Keith Tovey, 2009, Chang et al., 2011). Other sectors, such as *Ordinary Machinery, and Equipment for Special Purposes* (S16), *Electric Power, Steam and Hot Water Production and Supply* (S22), and *Other Service Activities,* also contribute massive embodied energy-related CH_4 emissions to the final demand.

Figure 4 presents the components of embodied CH_4 emissions by final demand category. Consumption is found to be the leading final demand category for sectors such as S1, S6, and several service sectors, which are the main food providers and major consumers of agricultural products. Investment is the dominating final demand category in four extraction sectors (S2–S5), two manufacturing sectors (S16 and S17), and the *Construction* sector. Prominently, investment accounts for 96.6% of the sector-specific embodied emissions associated with *Construction*. Export also contributes a large proportion of embodied CH_4 emissions for most manufacturing sectors,

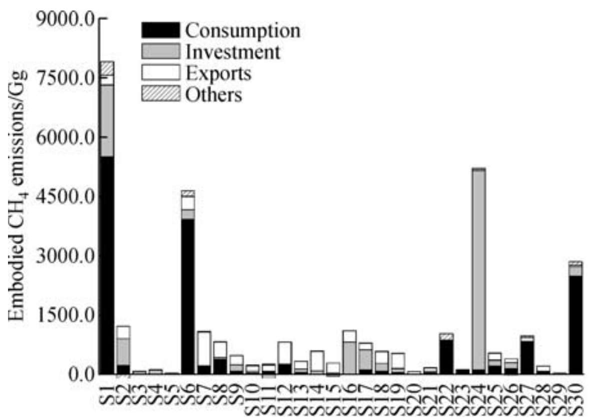

Fig. 4 CH_4 emissions embodied in final demand by final demand category and by sector.

such as S7–S15, and S18–S21, owing to China's textile products, industrial raw materials, and primary machinery and equipment products export.

3.2 Emissions embodied in interregional trade

3.2.1 Regional analysis

In 2007, China's CH_4 emissions embodied in interregional trade were 24,073.4 Gg in magnitude, up to 72.8% of national total direct emissions. The geographic distributions of the embodied CH_4 emissions associated with interregional trade have significant regional differences. Table 3 shows the distribution of embodied CH_4 emissions from interregional exports (*EEIE*) and imports (*EEII*) by region. Shanxi is the largest interregional CH_4-export region, accounting for 15.5% of the total *EEIE*, followed by Hebei (11.3%), Henan (6.7%), Guizhou (R29, 6.4%), and Anhui (R18, 4.6%). Guangdong and Hebei are the leading interregional CH_4-import regions, with 14.1% and 11.8% of the total *EEII*, respectively, followed by Jiangsu (8.4%), Zhejiang (7.1%), Shanghai (6.8%), and Shandong (4.9%). The aforementioned six regions, all located in the eastern coastal area, contribute to 53.1% of the total *EEII*. On the whole, the central area contributes the largest share, 46.0%, to the total *EEIE*, followed by the eastern area (33.4%), and the western area (20.6%), while the eastern area accounts for 67.9% of the total *EEII*.

According to the distribution of the net embodied emissions for interregional trade balance (*EEIB*) by region, listed in Table 3, all of the 30 regions can be categorized into two groups, net exporters with positive emissions, and net importers with negative emissions of embodied CH_4 in interregional trade. In the first group, Shanxi is the largest net exporter of embodied CH_4 emissions, amounting to 3,474.8 Gg, followed by Guizhou (1,301.3 Gg), Inner Mongolia (R15, 775.6 Gg), and Henan (703.3 Gg). In the second group, Guangdong is the leading region among all of the net importers of embodied CH_4 emissions, with a net embodied emission amount of 2,380.6 Gg. Shanghai, Zhejiang, and Jiangsu are the next three biggest net importers of embodied CH_4 emissions. The eastern area, as the net interregional importer, has a total *EEIB* of 8,300.9 Gg. The western and central inland areas, as the net interregional exporters, show totals of 6,443.2 and 1,857.7 Gg, respectively. The major interregional embodied emission fluxes in the amount of emission flows larger than 200 Gg are shown in Fig. 5, according to which, net transfers of embodied CH_4 emission flows from the central and western areas to the eastern area are explicit.

Figure 6 further shows the distribution of the regional *EEIB* by emission type. As to the composition of emissions, embodied CH_4 emissions from agricultural activities are the leading emission type in the 11 regions numbered 5, 11, 15, 20–24, 27, 28, and 30. Emission compositions are different in the other 19 regions, where embodied CH_4 emissions from energy activities are the leading emission category. As the largest net embodied interregional CH_4-exporter, Shanxi's *EEIB* is wholly dominated by embodied energy-related CH_4 emissions. In most emission-prominent regions such as Guangdong, Guizhou, and Zhejiang, energy-related CH_4 emissions also comprise dominant shares of their *EEIB*s. Shanxi and Guizhou are the top two net interregional exporters for embodied energy-related CH_4 emissions, accounting for 54.1% and 18.7% of the total net interregional export, respectively. Meanwhile, Guangdong, Jiangsu, Zhejiang, and Shanghai are the top four net interregional importers for embodied energy-related CH_4 emissions, accounting for 27.3%, 13.7%, 13.4%, and 11.2% of the total net interregional import, respectively. For embodied CH_4 emissions from agricultural activities, the top five net interregional exporters are the Hunan, Inner Mongolia, Guangxi, Jiangxi (R21), and Heilongjiang (R13) regions. The top five net interregional importers are Shanghai, Guangdong, Shandong, Beijing, and Zhejiang.

3.2.2 Sector-specific analysis

Displayed in Fig. 7 is the distribution of CH_4 emissions embodied in interregional trade by sector. It is noteworthy that the total sector-specific emissions embodied in interregional import are equal to those of interregional export. The *Coal Mining and Dressing* sector contributes the largest share of 27.9% to total CH_4 emissions embodied in interregional trade, followed by *Agriculture* (18.1%), *Food Production, Food Processing and Tobacco Processing* (9.2%), *Smelting and Pressing of Ferrous and Nonferrous Metals* (S14, 7.4%), *Electric Power, Steam and Hot Water Production and Supply* (5.7%), *Chemical Industry* (S12, 4.5%), and *Petroleum Processing, Coking, and Nuclear Fuel Processing* (S11, 4.3%). The 7 sectors mentioned above, out of all of the 30 sectors, are

Table 3 Distribution of embodied CH_4 emissions associated with interregional trade by region

Region code	*EEIE*/Gg	Fraction	*EEII*/Gg	Fraction	*EEIB*/Gg
Eastern area	**8,048.3**	**33.4%**	**16,349.2**	**67.9%**	**−8,300.9**
R1	175.2	0.7%	853.5	3.5%	−678.3
R2	342.6	1.4%	929.7	3.9%	−587.1
R3	2,715.3	11.3%	2,832.9	11.8%	−117.6
R4	657.2	2.7%	676.5	2.8%	−19.3
R5	506.5	2.1%	1,170.1	4.9%	−663.6
R6	853.7	3.5%	2,032.4	8.4%	−1,178.7
R7	331.2	1.4%	1,645.7	6.8%	−1,314.5
R8	499.5	2.1%	1,717.4	7.1%	−1,217.9
R9	201.7	0.8%	470.8	2.0%	−269.1
R10	1,024.0	4.3%	3,404.6	14.1%	−2,380.6
R11	712.0	3.0%	573.7	2.4%	138.3
R12	29.4	0.1%	41.9	0.2%	−12.5
Central area	**11,071.8**	**46.0%**	**4,628.6**	**19.2%**	**6,443.2**
R13	978.0	4.1%	404.7	1.7%	573.3
R14	791.7	3.3%	832.9	3.5%	−41.2
R15	1,032.9	4.3%	257.3	1.1%	775.6
R16	3,722.7	15.5%	247.9	1.0%	3,474.8
R17	1,625.1	6.7%	921.8	3.8%	703.3
R18	1,107.8	4.6%	585.8	2.4%	522
R19	406.2	1.7%	591.0	2.5%	−184.8
R20	903.9	3.7%	421.2	1.7%	482.7
R21	503.5	2.1%	366.0	1.5%	137.5
Western area	**4,953.3**	**20.6%**	**3,095.6**	**12.9%**	**1,857.7**
R22	481.6	2.0%	210.9	0.9%	270.7
R23	202.0	0.8%	273.6	1.1%	−71.6
R24	168.7	0.7%	84.0	0.3%	84.7
R25	651.6	2.7%	591.2	2.5%	60.4
R26	45.0	0.2%	89.3	0.4%	−44.3
R27	837.1	3.5%	542.5	2.3%	294.6
R28	470.9	2.0%	599.8	2.5%	−128.9
R29	1,544.5	6.4%	243.2	1.0%	1,301.3
R30	551.9	2.3%	461.1	1.9%	90.8
Total	**24,073.4**	**100.0%**	**24,073.4**	**100.0%**	**0**

responsible for 77.2% of total emissions embodied in interregional trade.

As to the composition of emissions, the emissions from agricultural activities, energy activities, and waste management account for 30.7%, 65.6%, and 3.7% of the total embodied CH_4 emissions in interregional trade, respectively. From a sector-specific perspective, embodied CH_4 emissions from agricultural activities are concentrated in Sectors 1, 6–9, and 27, where agricultural products are the dominant commodities in interregional trade. The remaining sectors, especially Sectors 2, 14, 22, 11, and 12, are the main contributors to embodied CH_4 emissions from energy activities in interregional trade.

CH_4 emissions embodied in interregional trade by sector, in terms of the eastern, central and western areas, are shown in Fig. 8. Here, the net transfer of embodied CH_4 emissions from the eastern area to the central and western areas can be identified from the sector-specific perspective. As illustrated in Fig. 8(a), most sectors of the eastern area are net importers of CH_4 emissions embodied in

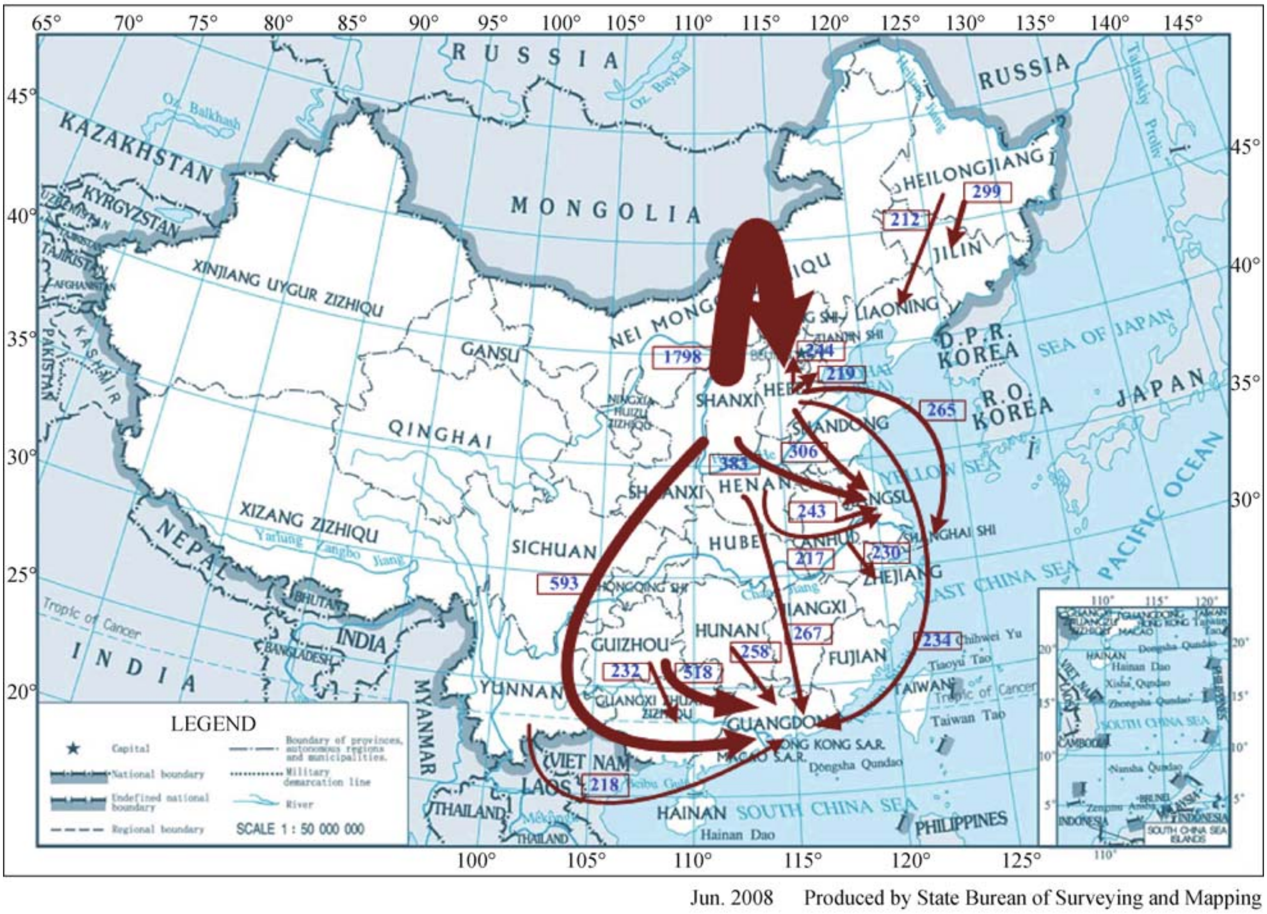

Fig. 5 Major embodied emission fluxes of interregional trade.

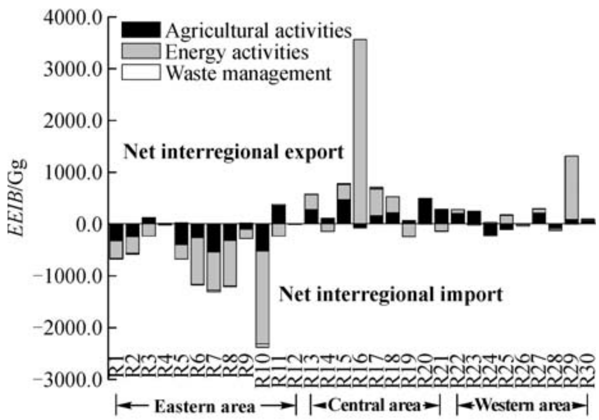

Fig. 6 Distribution of *EEIB* by region.

interregional trade. *Agriculture* and *Coal Mining and Dressing* are the top two sectors for the import of embodied emissions. *Food Production, Food Processing and Tobacco Processing*, *Smelting and Pressing of Ferrous and Nonferrous Metals,* and *Electric Power, Steam and Hot Water Production and Supply* are also major importers of embodied emissions.

The aforementioned five sectors, among all of the 30 sectors, contribute 71.8% of the total *EEII* in the eastern area. This is in contrast to the sector-specific order of the emissions embodied in interregional trade in the central and western areas, as shown in Figs. 8(b) and 8(c). *Agriculture* and *Coal Mining and Dressing* are the leading sectors for the export of embodied emissions, contributing 63.9% of the total *EEIE* in the central area. The six sectors of *Coal Mining and Dressing*, *Agriculture*, *Smelting and Pressing of Ferrous and Nonferrous Metals*, *Food Production, Food Processing and Tobacco Processing*, *Electric Power, Steam and Hot Water Production and Supply* and *Petroleum Processing, Coking, and Nuclear Fuel Processing* were the main contributors, accounting for 69.0% of the total *EEIE* in the western area, 76.3% of the total *EEIE* in the central area, and 58.4% of the western area flow into the eastern area. It is noted that some manufacturing industries, such as *Ordinary Machinery, and Equipment for Special Purposes* (S16), in the central and western areas, are net emission importers, due to the interregional imports of industrial products from the eastern area.

3.3 Regional emissions under different principles

It is well known that there are two GHG emission

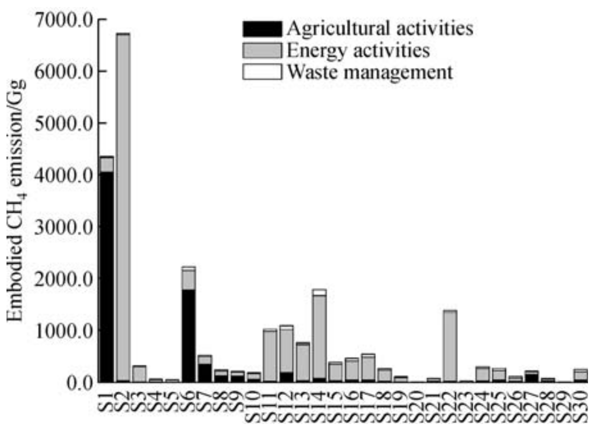

Fig. 7 CH_4 emissions embodied in interregional trade by sector.

accounting principles, production-based, and consumption-based (Peters, 2008). In view of the large scale of interregional trade in China, accounting results for regional GHG emissions may differ depending upon which accounting principles are applied. Fig. 9 shows CH_4 emissions by region, in 2007, under the two different accounting principles.

According to regional production-based accounting principles for CH_4 emissions, most emission-prominent regions belong to the central and western areas. Emission shares are much lower for the coastal eastern regions. The eastern, central and western areas are responsible for 23.1%, 48.1%, and 28.9% of total direct CH_4 emissions, respectively. Shanxi is the largest emitter with an emission amount of 4,467.4 Gg, 13.5% of the national total CH_4 emissions, mainly due to the massive fugitive emissions coming from coal mining (Zhang, 2011). The four regions of Henan, Guizhou, Sichuan, and Hunan also generate very large amounts of CH_4 emissions, respectively from 1,882.0 Gg to 2,368.2 Gg, accounting for more than 5.0% of the total. On the contrary, the least emissions occur in Tianjin, Beijing, Shanghai, and Hainan, ranging from 77.8 Gg to 181.1 Gg, all less than 1.0% of the total.

The picture of regional consumption-based CH_4 emissions, as reflected by the MRIO modeling, is quite different from that of regional production-based CH_4 emissions. The eastern, central, and western areas contribute 48.2%, 28.6%, and 23.3% to the national total of embodied emissions, respectively. Values obtained for CH_4 emissions in most eastern regions increase remarkably when the accounting principle is changed from production-based to consumption-based. For instance, using the consumption-based method, values obtained for embodied CH_4 emissions in Shanghai, Tianjin and Beijing, respectively, are 13.9, 8.5, and 7.9 times larger than those obtained using production-based accounting principles. Zhejiang, Guangdong, and Jiangsu also have prominent consumption-based emissions, which are, respectively, 3.9, 3.1, and 2.4 times the value of the production-based emissions. However, the

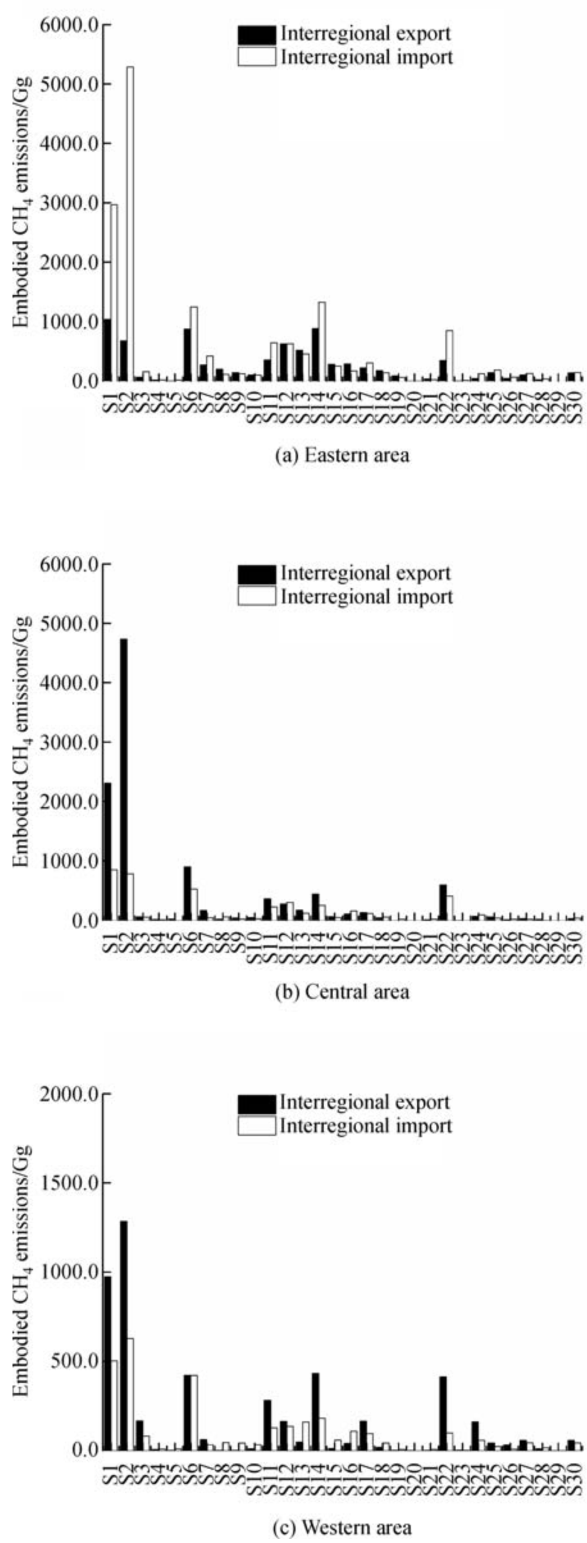

Fig. 8 CH_4 emissions embodied in interregional trade among three areas by sector.

consumption-based emissions for some central and western regions decrease accordingly. Shanxi, Inner Mongolia, Guizhou, Heilongjiang, Anhui, and Xinjiang

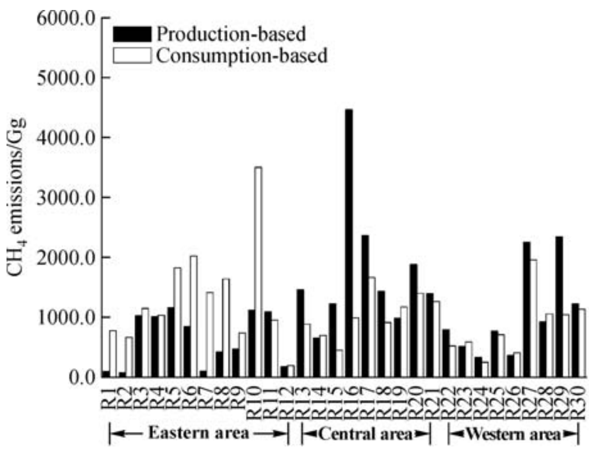

Fig. 9 CH_4 emissions under different principles by region in 2007.

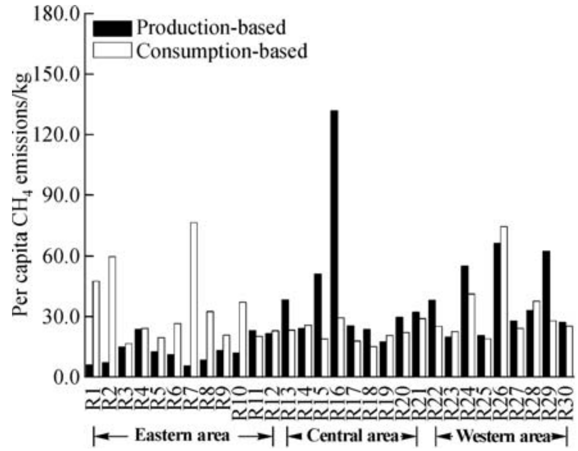

Fig. 10 Per capita CH_4 emissions by region under different principles in 2007.

contribute 22.2%, 36.8%, 44.6%, 60.8%, 63.7%, and 66.0% of production-based emissions, respectively. This implies that interregional trade affects regional emission inventories significantly, due to the emissions transfer from the eastern area to the central and western areas.

Interregional CH_4 emission transfer caused by interregional trade also influences the calculation results for regional emission indicators. Fig. 10 further displays per capita CH_4 emissions by region under the two different principles in 2007. From the production-based perspective, Shanxi has the highest per capita emissions of all, as much as 131.7 kg, followed by Qinghai (66.2 kg), Guizhou (62.4 kg), Ningxia (55.0 kg), and Inner Mongolia (51.0 kg). The distribution of regional per capita emissions based on the ‘producer responsibility’ principle, is hugely different from the distribution of per capita CH_4 emissions among the three areas using consumption-based accounting principles. Shanghai (76.2 kg), Tianjin (59.6 kg), and Beijing (47.5 kg) in the eastern area, and Qinghai (74.2 kg) and Ningxia (41.1 kg) in the western area, have significantly higher per capita CH_4 emissions when consumption based accounting principles are applied. Fig. 10 clearly demonstrates that the use of different accounting principles will have distinctive effects on values obtained for per capita CH_4 emissions among regions.

Presented in Fig. 11 are values for CH_4 emission intensity by region, in terms of emissions per CNY of regional GDP under the two different principles in 2007. From a geographical perspective, there also exist great regional differences in CH_4 emission intensity. The western and central areas generally have higher emission intensities under both production and consumption principles than the eastern area, the most developed area in China. As to production-based emission intensity, Guizhou and Shanxi have the highest emission intensities of 8.6 g/CNY and 7.8 g/CNY, respectively. Qinghai (4.7 g/CNY), Ningxia (3.8 g/CNY), and Yunnan (2.6 g/CNY) also have high emission intensities. The differences

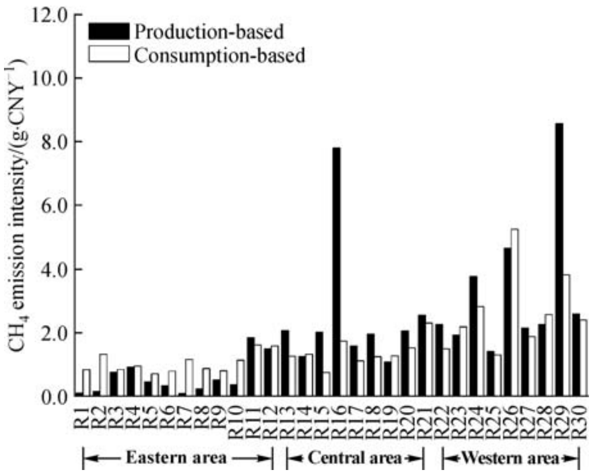

Fig. 11 CH_4 emission intensities by region under different principles in 2007.

of regional emission intensity among different regions are diminished under the ‘consumer responsibility’ principle; and the spatial distribution of the consumption-based CH_4 emission intensity is relatively balanced. The emission intensities of most eastern regions increase slightly, and the emission intensities of some central and western regions, such as Shanxi, Guizhou and Ningxia, decrease remarkably. The regions with higher consumption-based CH_4 emission intensities are mainly concentrated in the western area, including Qinghai (5.2 g/CNY), Guizhou (3.82 g/CNY), Ningxia (2.8 g/CNY), Chongqing (2.6 g/CNY), and Yunnan (2.4 g/CNY).

From the eastern area to the western area, the imbalances in economic development and urbanization level among different areas become more remarkable (Guo et al., 2012a). In 2007, the total GDP of the eastern area was about 2.4 and 4.8 times those of the central and western areas, respectively (CSY, 2008). The huge differences among regions in energy consumption level, industrial structure, and human lifestyle determine the diverse characteristics of China's interregional trade.

The eastern area has China's three economic circles, the Circum-Bohai Sea Economic Circle, the Yangtze River Delta, and the Pearl River Delta; and resource outputs of eastern regions are always unable to satisfy regional production demands. A major part of the resource supply for the eastern area belongs to interregional imports. As China's energy bases, the central and western areas provide coal and other energy resources to support the economic development of the eastern area (Guo et al., 2012a). Meanwhile, a large amount of agricultural products are also transported from the central and western regions to the eastern area through interregional trade, used for direct household consumption, or as industrial raw materials in manufacturing industries such as textiles and paper making. Correspondingly, the net transfers of embodied CH_4 emissions are from the central and western areas to the eastern area in interregional trade. Meng et al. (2011) also reported that the inverse distribution of energy production and consumption, and regional unfairness caused by institutional factors (e.g., energy price, government efficiency, and tax system) in China resulted in interregional energy-related CO_2 emissions transfer embodied in interregional trade. In view of the fact that large amounts of goods are moved from the central and western areas to the eastern area, the eastern area avoids massive direct CH_4 emissions by consuming the goods of the central and western areas. Certainly, eastern regions, such as Guangdong, should take the consumer responsibility for the CH_4 emissions of some central and western regions such as Shanxi.

4 Concluding remarks

While much attention is currently focused on China's CO_2 emissions, CH_4 emissions and related mitigation at different scales deserves more attention due to the importance of CH_4 in China's GHG emissions inventory (Zhang et al., 2011). This paper presents an interprovincial input–output analysis of China's regional CH_4 emissions embodied in final demand and interregional trade in 2007, with the recently available multi-regional input–output table, and relevant emissions data. The emissions accounting under the consumption-based responsibility principle can systematically reflect regional contributions to China's CH_4 emissions.

There are remarkable regional disparities in embodied CH_4 emissions among the eastern, central, and western regions. Generally speaking, eastern regions have higher embodied emissions; and the eastern area contributes the largest percentage (48.2%) to national total embodied emissions. Guangdong has the largest embodied CH_4 emissions among all of the 30 regions, followed by Jiangsu, Sichuan, Shandong, Henan, and Zhejiang. As to the composition of emissions, energy-related CH_4 emissions are the leading emission type in 14 regions, while CH_4 emissions from agricultural activities are dominant in the other 16 regions. The CH_4 emissions embodied in consumption are the leading final demand category in most regions, accounting for 40%–60% of the total embodied emissions, followed by the CH_4 emissions embodied in investment, which contribute about 20%–50% to embodied CH_4 emissions for most regions.

The shares of CH_4 emissions embodied in exports are especially high in some eastern coastal regions. For embodied emissions by sector, *Agriculture* holds the top CH_4 emissions embodied in final demand, accounting for 23.9% of national total embodied emissions. *Construction*, *Food Production and Tobacco Processing*, and *Other Service Activities* are the following three sectors, contributing 15.8%, 14.0%, and 8.6% to the national total, respectively. CH_4 emissions from agricultural activities are the leading emission type in 6 sectors; and CH_4 emissions from energy activities lead in the other 24 sectors.

Interregional trade has an obvious impact on regional embodied CH_4 emissions. In 2007, the CH_4 emissions embodied in interregional trade are, in magnitude, up to 72.8% of China's total direct emissions. The central area contributes the largest share (46.0%) to total CH_4 emissions embodied in interregional exports, followed by the eastern area (33.4%), and the western area (20.6%). Meanwhile, the eastern area accounts for 67.9% of total CH_4 emissions embodied in interregional imports. The largest interregional emission exporter is Shanxi, followed by Hebei, Henan, Guizhou, and Anhui. Guangdong and Hebei are the leading interregional emission importers, followed by Jiangsu, Zhejiang, Shanghai, and Shandong. Most regions of the eastern area (except for Guangxi) are net importers of embodied CH_4 emissions, while most regions in the central and western areas (except for Jilin, Hubei, Gansu, Qinghai, and Chongqing) are net exporters. Agricultural activities, energy activities, and waste management comprise 30.7%, 65.6%, and 3.7% of the total CH_4 emissions embodied in interregional trade, respectively. Responsible for 77.2% of the total emissions embodied in interregional trade are the 7 sectors of *Coal Mining and Dressing*, *Agriculture*, *Food Production, Food Processing and Tobacco Processing*, *Smelting and Pressing of Ferrous and Nonferrous Metals*, *Electric Power, Steam and Hot Water Production and Supply*, *Chemical Industry*, and *Petroleum Processing, Coking, and Nuclear Fuel Processing*.

In light of the large scale of interregional trade, China's regional CH_4 emissions vary obviously along with different accounting principles. The CH_4 emissions of most eastern regions increase remarkably when the production-based accounting principle is changed to the consumption-based accounting principle. In Shanghai, Tianjin, and Beijing, the consumption-based embodied emissions values are 13.9, 8.5, and 7.9 times larger than values for production-based direct emissions, respectively. Zhejiang, Guangdong, and Jiangsu also have prominent consumption-based emissions, which are 3.9, 3.1, and 2.4 times those of the production-based emissions, respectively.

In contrast, consumption-based values for embodied emissions for some central and western regions decrease accordingly. The embodied emissions of Shanxi, Inner Mongolia, Guizhou, Heilongjiang, Anhui, and Xinjiang are equal to only 22.2%, 36.8%, 44.6%, 60.8%, 63.7%, and 66.0% of the direct emissions, respectively. Correspondingly, regional emissions indicators such as per capita CH_4 emissions and CH_4 emission intensities are also affected distinctively. Therefore, to amend current end-reduction-oriented mitigation strategies, it is crucial to trace the geographical origins of China's CH_4 emissions, and to assess all possible paths to achieving regional CH_4 emission mitigation, under comprehensive consideration of both production-based and consumption-based emissions. Actually, the eastern regions should take more responsibility for CH_4 emissions in China, and can play a more important role in emission mitigation due to better economic conditions and advanced technologies.

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Appendix

Table A1 Sector information for input-output embodiment analysis

Code	Sector category
S1	*Farming, Forestry, Animal Husbandry, and Fishery (Agriculture)*
S2	*Coal Mining and Dressing*
S3	*Petroleum and Natural Gas Extraction*
S4	*Ferrous and Nonferrous Metals Mining and Dressing*
S5	*Nonmetal and Other Minerals Mining and Dressing*
S6	*Food Production, Food Processing and Tobacco Processing*
S7	*Textile*
S8	*Garments and Other Fiber Products, Leather, Furs, Down and Related Products*

(*Continued*)

Code	Sector category
S9	*Timber Processing, Bamboo, Cane, Palm & Straw Products, Furniture Manufacturing*
S10	*Papermaking and Paper Products, Printing and Record Medium Reproduction, Cultural, Educational and Sports Articles*
S11	*Petroleum Processing, Coking, and Nuclear Fuel Processing*
S12	*Chemical Industry*
S13	*Nonmetal Mineral Products*
S14	*Smelting and Pressing of Ferrous and Nonferrous Metals*
S15	*Metal Products*
S16	*Ordinary Machinery, and Equipment for Special Purposes*
S17	*Transportation Equipment*
S18	*Electric Equipment and Machinery*
S19	*Electronic and Telecommunications Equipment*
S20	*Instruments, Meters Cultural and Office Machinery*
S21	*Other Industrial Activities*
S22	*Electric Power, Steam and Hot Water Production and Supply*
S23	*Water and Gas Production and Supply*
S24	*Construction*
S25	*Transport and Storage Services*
S26	*Wholesale and Retail Trade*
S27	*Hotels and Catering Service*
S28	*Leasing and Business Services*
S29	*Research and Experimental Development*
S30	*Other Service Activities*

Table A2 Regional information for input-output embodiment analysis

Code	Regional information	Population/(10^4 head)	Regional GDP/(10^8 CNY)
Eastern area		**56,542**	**169,325.6**
R1	Beijing	1,633	9,353.3
R2	Tianjin	1,115	5,050.4
R3	Hebei	6,943	13,709.5
R4	Liaoning	4,298	11,023.5
R5	Shandong	9,367	25,965.9
R6	Jiangsu	7,625	25,741.2
R7	Shanghai	1,858	12,188.9
R8	Zhejiang	5,060	18,780.4
R9	Fujian	3,581	9,249.1
R10	Guangdong	9,449	31,084.4
R11	Guangxi	4,768	5,955.7
R12	Hainan	845	1,223.3
Central area		**44,252**	**70,481.9**
R13	Heilongjiang	3,824	7,065.0
R14	Jilin	2,730	5,284.7
R15	Inner Mongolia	2,405	6,091.1
R16	Shanxi	3,393	5,733.4
R17	Henan	9,360	15,012.5
R18	Anhui	6,118	7,364.2

(*Continued*)

Code	Regional information	Population/(10^4 head)	Regional GDP/(10^8 CNY)
R19	Hubei	5,699	9,230.7
R20	Hunan	6,355	9,200.0
R21	Jiangxi	4,368	5,500.3
Western area		**28,841**	**35,475.2**
R22	Xinjiang	2,095	3,523.2
R23	Gansu	2,617	2,702.4
R24	Ningxia	610	889.2
R25	Shaanxi	3,748	5,465.8
R26	Qinghai	552	783.6
R27	Sichuan	8,127	10,505.3
R28	Chongqing	2,816	4,122.5
R29	Guizhou	3,762	2,741.9
R30	Yunnan	4,514	4,741.3