Four System Boundaries for Carbon Accounts

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Abstract

Knowing the carbon emission baseline of a region is a precondition for any mitigation effort, but the baselines are highly dependent on the system boundaries for which they are calculated. On the basis of sectoral energy statistics and a nested provincial and global multi-regional input-output model, we calculate and compare four different system boundaries for China's 30 provinces and major cities. The results demonstrate significant differences in the level of emissions for the different system boundaries. Moreover, the associated emissions with each system boundary varies with the regional development level, i.e. richer areas outsource more emissions to other areas, or in other words boundary 4 emissions are higher than boundary 1 emissions for rich areas and vice versa for poor areas. Given these significant differences it is important to be aware of the implications the choice of an accounting system might have on outcomes.

Keywords: Carbon emissions, carbon footprint, Consumption-based emission, multi-regional input-output analysis, Embodied emissions, China

Introduction

Climate change is an important factor impacting ecosystems in many ways. For example, global warming could force species to migrate to higher latitudes for survival (Thomas and Lennon, 1999) and lead to increased risk of extinction for species (Thomas et al., 2004). The IPCC in its fifth assessment report (AR5) affirmed that greenhouse gases (GHGs), in particular carbon dioxide emissions, from anthropogenic activities has been the dominant cause of the observed global warming since the mid-20th century (IPCC, 2013). Carbon as the basic element that supports living systems, is critical for the global ecology and human sustainability (Post et al., 1982). Carbon embodied in both organic and inorganic matter can be affected by natural process as well as anthropogenic activities, thus understanding the carbon flows within the human-environment nexus will help to promote human well-being while protecting the earth's living systems (Kyoto Protocol, 2010; Stern et al., 2006), and proper accounting for carbon becomes key.

Given that human induced carbon dioxide emissions are the major contributor to global warming , understanding regional and urban carbon flows becomes a precondition for the mitigation of greenhouse gas emissions Energy consumption and carbon emission benchmarks are considered as an important step supporting regional carbon flow studies and carbon emission mitigation policies (Kennedy et al., 2009; Kennedy et al., 2011b). Recently, numerous low carbon energy development initiatives and emission mitigation actions have been introduced at regional and city levels in response to a lack of successful international negotiations on carbon emission mitigations for nations. More than a thousand cities and regions worldwide have pledged to reduce greenhouse gas (GHG) emissions at the local scale (Betsill and Bulkeley, 2006; International Council of Local Environmental Initiatives (ICLEI), 2008; Lenzen et al., 2004), regional mitigation actions such as ‘‘Cities for Climate Protection’’ (CCP)(Betsill and Bulkeley, 2004) and the “The C40 Cities Climate Leadership Group (C40)”(Román, 2010) are booming and the literature (Ramaswami et al., 2012) (Sovacool and Brown, 2010) on regional carbon emissions is growing quickly.

However, establishing appropriate and consistent system boundary and calculation processes for the calculation of carbon emissions remains challenging especially at the regional level. Regions can have varying boundaries of emission accounting depending on definitions and purpose of the analysis. Non-centralized or lacking statistics and huge discrepancies among economic development levels can lead to uncertainty with regards to carbon emissions (Sovacool and Brown, 2010). Moreover, regions have intensive interactions across system boundaries, such as domestic and international transportation, inter-regional electricity transmission and flows of other goods and services and purchased power supply generated outside the boundary, and those cross boundary activities can significantly affect the carbon emissions calculations dependent on the extent of boundary chosen (Liu et al., 2012c). The "carbon footprints" (Hammond, 2007; Hertwich and Peters, 2009; Minx et al., 2009; Weidema et al., 2008; Wiedmann and Minx, 2008), defined as the direct and indirect carbon emissions associated with consumption within a certain boundary, could contribute to upstream carbon emissions outside the boundary. Such "embodied emissions" or "consumption-based emissions" (Davis et al., 2011; Peters and Hertwich, 2008; Peters et al., 2012) will dramatically affect the regional emission baselines. For example, without considering the emission embodied in imports, carbon emission decreased in Beijing during 2008-2010, however Beijing's carbon footprint calculated by consumption-based emissions shows a fast increase in the period (Feng et al., 2014b).

Initiatives such as the Greenhouse Gas Protocol and International Council of Local Environmental Initiatives (ICLEI) suggested three different scopes of regional carbon emission: scope 1 emissions are referred to as territorial emissions (Kennedy et al., 2010; Kennedy et al., 2011b); scope 2 emissions are emissions embodied in electricity produced and imported or purchased from outside the boundary (International Council of Local Environmental Initiatives (ICLEI), 2008; Kennedy et al., 2010; Kennedy et al., 2011a; Liu et al., 2012c); and scope 3 emissions refers to emissions embodied in imported products and services (International Council of Local Environmental Initiatives (ICLEI), 2008; Kennedy et al., 2010; Kennedy et al., 2011a). Together with the "consumption based accounting" (emissions embodied in imports minus emissions embodied in exports) (Davis and Caldeira, 2010; Peters, 2008) which has been widely used for estimates of national carbon footprints, we identified 4 different system boundaries (Table 1 and Table 2) for regional emission accounting :

System boundary 1: scope 1 emissions.

System boundary 2: scope 1 + 2 emissions.

System boundary 3: scope 1 + 3 emissions.

System boundary 4: consumption based emission (carbon footprint)

Research conducted based on scopes 1, 2, 3 and consumption-based emissions have shown that in a globalized world, carbon emissions embodied in purchased electricity and imported goods and services could account for large proportions of carbon footprint of nations or regions, especially for more developed places outsourcing production and pollution (Davis et al., 2011; Feng et al., 2013; Guan et al., 2014b; Liu et al., 2012c). In addition, calculation of scope 2, and scope 3 emissions is widely used at the enterprise level and has become an important indicator for guiding low carbon policies and actions (Downie and Stubbs, 2013; World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD), 2014). There is also a booming literature using different scopes for regional carbon emission calculation (Hillman and Ramaswami, 2010; Liu et al., 2011; Minx et al., 2013; Peters, 2010). However, comparison of different regional emission accounting boundaries based on all the scope 1, 2, 3, and consumption based emissions are rarely conducted. In fact, different accounting boundaries have been widely used for regional carbon accounts(Kennedy et al., 2011b; Liu et al., 2012c; Ramaswami et al., 2012), thus the clear definition and comparison is urgent needed.

Understanding the effects of different system boundaries on carbon accounting at regional level (provincial level) is crucial for the carbon emissions mitigation and low carbon development in China, the largest carbon emitter, with its 2013 carbon emissions being higher than the emissions from the US and the EU together (Global Carbon Project, 2014). China is now responsible for 50% of global coal consumption and for about 80% of the global annual increase of carbon emissions from fossil fuel consumption and cement production (Boden, 2013; Liu et al., 2013b) and thus plays a central role for mitigation of carbon emissions, globally. Regional carbon emissions baselines are especially important for China for a range of reasons: First, China is a vast country with significant spatial variations in its regional development, resource endowment and the environment. For example, the difference of carbon emission intensity (emissions per unit of economic output) among China's provinces is up to tenfold (Liu et al., 2012b). Secondly, sky-rocketing but differential carbon emission growth in China over the last decade resulted in the fact that carbon emissions in certain provinces could be equivalent to total emissions in major developed countries; for example, annual CO_2 emissions in Shandong province are about 750 million tons in 2010 (Guan et al., 2012), equivalent to total annual emissions of Germany, the sixth largest emitter in the world. Finally and most importantly, the Chinese government has set itself the ambitious target of reducing the carbon intensity (carbon emission per unit of GDP) by 45% by 2020 against the level in 2005, this intensity targets act as China's central mitigation measures, directly allocated to individual provinces (Liu et al., 2013a). The research shows that more developed provinces perform better than under-developed provinces for achieving the intensity reduction targets, however such targets are mainly achieved by "outsourcing" manufacturing and pollution from developed regions to the underdeveloped regions (Feng et al., 2013), this could result in higher total emissions. In other words, China's current regional mitigation baselines only consider the system boundary 1 emissions, neglecting indirect emissions embodied in trade that reduce the regional system boundary 1 emissions in certain regions but contribute to the nation's total emissions.

The character of China's mitigation policy and emission status offers the opportunity to understand the impacts of different system boundary emissions on emission mitigation policy, by comparing them at the certain regions. Different system boundaries of carbon accounting leads to different policy strategies. In this study we calculated four different system boundaries emissions for China's 30 provinces (excluding Tibet and Taiwan) for 2007.

2 Methods

Cross-boundary exchange of energy supply, goods and services results in 4 different regional carbon emissions boundaries (See Table 1 and Table 2 for the definition).

Calculation of system boundary 1 emissions

System boundary 1 carbon emissions refer to territorial emissions produced by fossil fuel combustion and industrial process. These are calculated by multiplying sectoral fossil fuel energy consumption by the associated emission factors (Guan et al., 2012).

$$\text{Emission} = \sum\sum\sum(Activity\ \ data_{i,j,k} \times Emission\ \ factor_{i,j,k})$$

(1)

Notes: i: fuel types, j: sectors, k: technology type.

Calculation of system boundary 2 emissions

System boundary 2 carbon emissions are system boundary 1 emissions plus the emissions from power generation of imported electricity. For calculating system boundary 2 emissions, the emission factor for imported electricity needs to be calculated by considering the corresponding emissions of power generation. For China's power supply system, the electricity is supplied by regional grids, with current six grids covering 30 mainland provinces, thus the emission factors of electricity supplied by each grid could be calculated as:

$$\text{Emission factor(electricity)} = \sum Emission_l \div \sum E_l$$

(2)

Where $Emission_l$ represents the emissions of electricity for l gird, $Emission_l$ can be calculated by the aggregate of the emissions from provinces served by the l state grid. E_l is the total electricity supply for l state grid, which contains the electricity from power plants, renewable energy (including wind, solar, hydro power and bio energy) and nuclear energy. The data of electricity consumption in 2007 is taken from 2008 Statistics Yearbook for each province; the calculation of direct emissions from power generation is based on the method for system boundary 1 carbon emissions.

Thus, emission embodied in imported electricity can be calculated by using the emission factor multiplied the import electricity.

Calculation of system boundary 3 and 4 emissions

The system boundary 3 emission is the system boundary 1 emission plus the emissions embodied in imported products and services. The system boundary 4 emission is the system boundary 1 emission plus the emissions embodied in imports minus emissions embodied in exports. Thus the calculation of emissions embodied in imports and exports is critical for compiling system boundary 3 and 4 emissions.

Environmentally extended multi-region input-output analysis (MRIO) analysis has been frequently adopted for calculation of international trade related emissions (Duchin, 1992; Hertwich and Peters, 2009; Peters and Hertwich, 2008; Shui and Harriss, 2006). In this study we adopt MRIO to calculate lifecycle (i.e. all upstream) emissions embodied in imports and exports.

In the MRIO framework, different regions are connected through inter-regional trade, T^{rs}. The technical coefficient sub-matrix A^{rs} consists of $\{a_{ij}^{rs}\}$ and is given by $a_{ij}^{rs} = T_{ij}^{rs}/x_j^s$, in which T_{ij}^{rs} is the inter-sector monetary flow from sector i in region r to sector j in region s; x_j^s is the total output of sector j in region s. The final demand matrix is (y_i^{rs}), where y_i^{rs} is the region's s final demand for goods of sector i from region r. Let $x = (x_i^s)$. Using familiar matrix notation and dropping the subscripts, thus

$$A = \begin{bmatrix} A^{11} & A^{12} & \cdots & A^{1n} \\ A^{21} & A^{22} & \cdots & A^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ A^{n1} & A^{n2} & \cdots & A^{nn} \end{bmatrix} \quad ; \quad y = \begin{bmatrix} \sum_s y^{1s} \\ \sum_s y^{2s} \\ \vdots \\ \sum_s y^{ns} \end{bmatrix} \quad ; \quad x = \begin{bmatrix} x^1 \\ x^2 \\ \vdots \\ x^n \end{bmatrix} \quad ;$$

(3)

The MRIO framework can be written as

$$x = Ax + y \tag{4}$$

By solving x we have

$$x = (I - A)^{-1}y \tag{5}$$

where $(I - A)^{-1}$ is the Leontief inverse matrix captures the supply chain inputs to satisfy one unit of final demand in monetary value; I is the identity matrix.

We extend the MRIO model with a vector of sectoral CO_2 emission coefficients, k:

$$k = [k_1 \quad k_2 \quad \cdots \quad k_n]$$

Therefore, the total CO_2 emissions embodied in goods and services used for final demand for all regions can be calculated by:

$$CO_2^{tot} = k(I - A)^{-1}y \tag{6}$$

where CO_2^{tot} is the total CO_2 emissions embodied in goods and services used for final demand ; *k* is a vector of CO_2 emissions per unit of economic output for all economic sectors in all regions.

While Equation 6 captures well the total life-cycle emissions associated with the final demand of a region, it may not be able to distinguish the emissions from domestic production and import. To calculate the emissions embodied in import of region *s*, we modify Equation 6 to:

$$CO_2^{imp} = \ k_{\sim s}(I - A)^{-1}y^{\cdot s} \tag{7}$$

where CO_2^{imp} is the total embodied emissions in import of region *s*; $k_{\sim s}$ is a vector of sectoral CO_2 emission coefficients for all other regions but with zeros for the emission coefficients of region s; $y^{\cdot s}$ is the final demand vector of region *s*.

$$CO_2^{exp} = \ k_s(I - A)^{-1}y^{s\cdot} \tag{8}$$

where CO_2^{exp} is the total embodied emissions in export of region *s*; k_s is a vector of sectoral carbon emission coefficients for the region s but with zero for the emission coefficients of other regions; $y^{s\cdot}$ is the final demand vector of total sectoral final demand of other regions but excluding the final demand of region *s*.

Therefore, system boundary 3 emissions are the boundary 1 emissions plus the total embodied emissions in import, CO_2^{imp}. The system boundary 4 emissions are the total consumption-based carbon emissions: CO_2^{tot}.

Data sources

Sectoral fossil fuel energy consumption data were taken from the 2008 Statistics Yearbook (National Bureau of Statistics of China, 1996-2012) from each province; in this research we consider 20 types of fossil fuels and 44 sectors. The clinker production data used for calculating cement production emission were taken from the Chinese Statistics Yearbook (National Bureau of Statistics, 2013); emissions of cement production for provinces are based on our previous emission estimates (Guan et al., 2012). The methodologies for conducting full inventories of China's provincial carbon emissions are consistent with previous research (Chen and Zhang, 2010; Liu et al., 2012b).

We adopted the global multi-regional input-output (MRIO) model from the Global Trade Analysis Project (GTAP, 2012) (Peters et al., 2011) which have data for 129 countries and regions with each region comprising 57 economic sectors. China's domestic MRIO comprises 30 sub-regions with 44 sectors for each region; China's domestic MRIO is compiled by Weidong Liu and coauthors from Chinese Academy of Sciences (Liu et al., 2012a). We aggregated the sectors and linked China's domestic MRIO with the global MRIO (Feng et al., 2013).

3. Results

Boundary 1-4 emissions of China's regions

Total system boundary 1 emissions of 30 provinces are 7,204Mt CO_2 in 2007. East coast regions have higher system boundary 1 emissions. Shandong, Hebei, Jiangsu, Guangdong and Henan provinces together account for about 40% of national total system boundary 1 emissions. Shandong province has the highest boundary 1 emissions (726Mt CO_2), which would rank as No.7 of global emitters. In terms of economic sectors, across provinces, power generation and metal/non-metal production take the lion's share (85% on average) of the total system boundary 1 carbon emissions, other emissions come from services (8%), transportation (6%) agriculture (2%) and household consumption (4%). (Figure 1).

In terms of per capita system boundary 1 emission, less developed provinces such as Inner Mongolia, Shanxi and Ningxia have even higher per capita system boundary 1 emissions than richer cities such as Beijing and Shanghai. In addition, the emission intensity (emissions per unit GDP) in Inner Mongolia, Shanxi and Ningxia is several times of the level of more developed provinces (Municipalities) such as Beijing, Shanghai and Tianjin. Inner Mongolia, Shanxi and Ningxia are the energy and resources bases of China and these provinces produce carbon intensive inputs for the whole country. Half of the metal and cement and 40% of the electricity produced in Inner Mongolia are exported to other provinces. One quarter of China's coal is produced in Shanxi, while a large proportion is sold to other provinces. Moreover, economic growth of these provinces is mainly driven by capital investment in infrastructure (Guan et al., 2014a) contributing significantly to the high carbon intensive economy in these provinces.

In terms of system boundary 2 emissions, there are 11 provinces that import electricity from other regions with total emissions embodied in imported electricity accounting for 247 Mt CO_2 (i.e. 9% of total emissions from power generation in China). Thus the system boundary 2 emissions are higher than in system boundary 1 emissions in these 11 provinces. In general the rich regions are major importers of electricity, top five richest provinces (measured by per capita GDP) together account for 50% of total emissions embodied in cross-regional electricity transportation. This unbalanced inter-provincial emissions transfer is mainly driven by the geographic disparity of energy producers and energy consumers in China. China's developed coastal regions cannot achieve self-sufficiency of electricity, since most of China's primary energy sources, especially coal reserves, are located in inland western regions; another factor is the associated air pollution that eastern provinces are avoiding through electricity imports. The "West to East Electricity Transmission" project, which promotes electricity production in western China to meet the soaring demand of eastern China, has been recognized as China's national energy development strategy. Inter-provincial transfer of electricity will certainly expand in the future and their share in the total carbon emissions of China's power sector will also be very much likely to increase, since many of China's new mega coal power plants are under construction in northwest regions (Zhang and Anadon, 2014; Zhang et al., 2014).

System boundary 3 emissions of 30 provinces account for 9,837 Mt CO_2 in 2007, which is equivalent to about 136% of the total system boundary 1 carbon emissions for the 30 provinces. This is caused by 2,633 Mt CO_2 that are embodied in imports, of which about 92% are from domestic imports and 8% from international imports. Among provinces, Shandong has the highest system boundary 3 emissions (876 Mt CO_2). Again, the five richest provinces together account for 32% of total scope 3 emissions from 30 provinces.

System boundary 4 emissions account for 5,764 Mt CO_2 in 2007, which is 20% less than the system boundary 1 emissions on average (Figure 2). This implies that China's emissions embodied in exports are larger than the emissions embodied in imports. For provinces, only seven provinces (Shanghai, Beijing, Tianjin, Zhenjiang, Jiangxi, Chongqing and Jilin) with their system boundary 4 emissions higher than their system boundary 1 emissions, implies these regions are net emission importers. Shanghai, Beijing, Tianjin and Zhejiang as the top four richest regions (measured by per capita GDP) in China are the major importers of these trade embodied emissions. While the difference between system boundary 1 and system boundary 4 emissions is from the "net" emission embodied in trade, the four top richest regions (Shanghai, Beijing, Tianjin and Zhejiang) contributed 70% of the total difference (1,440 Mt CO_2) between system boundary 1 and system boundary 4 emissions. Particularly, system boundary 4 emissions for Beijing (the capital city with per capita GDP listed as the 2nd among 30 regions) could be twice of its system boundary 1 emissions. In contrast the system boundary 4 emissions are less than system boundary 1 emissions in less developed regions such as Yunnan, Guizhou, Qinghai and Ningxia as they are the net exporters of carbon intensive goods. This illustrates that the highly developed regions are the major 'consumers' of emissions embodied in trade.

Figure 3 compares the trends of per capita emissions of system boundary 1-4 emissions and GDP per capita. Ningxia, Shanxi and Inner Mongolia show every high per capita emission in both system boundary 1-4 emissions due to their energy intensive economy.

To further uncover the relationship between the regional development (measured by per capita GDP) and the carbon emission from different boundaries (measured by per capita emission), we present regression analysis to show the relationship between per capita GDP and per capita system boundary 1-4 emissions. The results show that the correlation with per capita GDP is gradually increasing from per capita system boundary 1 emission to per capita system boundary 4 emission (Figure 4). This confirms findings from other studies (e.g. (Prell C., 2014)Peters et al.,2011; Davis and Caldeira, 2010; Feng et al., 2013) showing that rich countries/regions tend to import more emission intensive but low value added goods from poorer regions, outsourcing their emissions, which is also reflected in our results with higher per capita GDP in Chinese provinces having higher system boundary 3 and 4 emissions per capita. In rich regions embedded emissions in imports account for up to 80% of the total consumption-based emissions of the region (e.g. Beijing and Shanghai)(Feng et al., 2014a).

Due to the emissions embodied in imports and exports system boundary 3 emissions (scope 1+3) are higher than system boundary 4 emissions (scope 1+3-emission embodied in exports), system boundary 2 emission (scope 1+2) and system boundary 1 emission (scope 1). The higher the development of a region and dependence on global supply chains and imports the higher the emissions associated with increasing system boundaries (Figure 3).

The impacts of different emission boundaries on China's regional emission targets

Regional emission accounts provide important baselines for mitigation strategies. China allocates emission intensity targets for each individual province, and examines intensity reduction targets through its 5-Year Plans. These intensity reduction targets range within 5 percentage points (Table 3). For example, the eastern coast regions (such as Beijing and Shanghai) have been allocated intensity reduction of 20% in 2005-2010, in contrast the central and western regions have been allocated intensity reduction of 15%. However, by adopting system boundaries, the intensity difference of each region could be more than 70% in 2007. For example, the system boundary 4 emission (footprints) in Inner Mongolia only equals to 40% of its system boundary 1 emissions. In contrast, the system boundary 4 emissions of Beijing equals to 175% of its system boundary 1 emissions. Thus the achievements of intensity reduction targets will be considerably different when using system boundary 2,3 or 4 emissions as baselines, instead of using system boundary 1 emissions.

As discussed above, the difference of emission system boundaries among rich and poor regions is mainly caused by emissions embodied in trade, illustrating "out-sourcing" of energy intensive manufacturing from developed regions to poorer regions but is also a fact of globalization and specialization. On the one hand, the outsourcing of manufacturing increases the spatial distance of the supply chain, thus further increase the emissions of the whole systems through moving production to places with lower labor costs and usually less efficient technologies and through increasing transport related emissions. On the other hand, the decrease of territorial emission from developed regions are bought at the expense of an increase of upstream emissions.

A practical problem is that, in most cases, consumption based emissions are out of control of local government, because large parts of consumption based emissions take place in other regions. But in order to avoid such leakages regional mitigation policies have to consider the emissions embodied in trade among regions. For the case of current mitigation policy in China, one supplementary measure could be to introduce the additional intensity reduction targets based on system boundary 2,3 and 4 emissions, so the mitigation result by final demand energy saving and control approaches can be encouraged. For example, China issued the project on compiling the provincial carbon emissions inventories to server as the baseline for domestic cap and trade system, the emission embodied in import electricity has been considered as well. Comparing with current mitigation strategy that focuses on boundary 1 emissions, the additional perspective has advantages. First, the boundary 2-4 accounting allocate more emission quota and associated mitigation responsibilities to the rich regions, where rich regions in general have more advanced technology and more efficient manufacturing, this could help to promote the total efficient of whole country. Secondly, considering the consumption (system boundary 2-4) in addition to the production (system boundary 1) helps to mitigate the carbon emissions along the whole supply chain, and cost of emission mitigation can be reduced. For example, measured by system boundary 1 emissions, several provinces implemented electricity blackouts in 2009 in order to achieve the intensity reduction target for 2005-2010, while through the conservation measures of final consumer(for example, energy saving plan for household and government consumption), such blunt instrument can be avoid. Understanding 2-4 system boundary emissions is also crucial for highlighting the importance of demand-side efforts for carbon mitigation, e.g., energy and resources conservation by consumers, recycling and reuse of waste products, and shifting towards more sustainable lifestyles.

4 Conclusions

In this study, we explored 4 different system boundaries emissions for China's 30 provinces in 2007. The results show differences among different emissions boundaries. In general, the more developed regions tend to the net consumer of the emissions that embodied in trade, resulting in higher system boundary 2, 3 and 4 emissions compared to their system boundary 1 emissions.

The different emission boundaries could dramatically affect the achievements of China's current regional mitigation targets. Our results show that measured by different system boundaries, the emission intensity could change up to 70% for certain regions, thus the achievement of regional intensity reduction targets under China's mitigation plan can be different. However, current mitigation baseline is based on system boundary 1 emissions and without considering the other boundaries. Thus, it is important to understand the multi-boundary emissions as the baselines for addressing mitigation policies.

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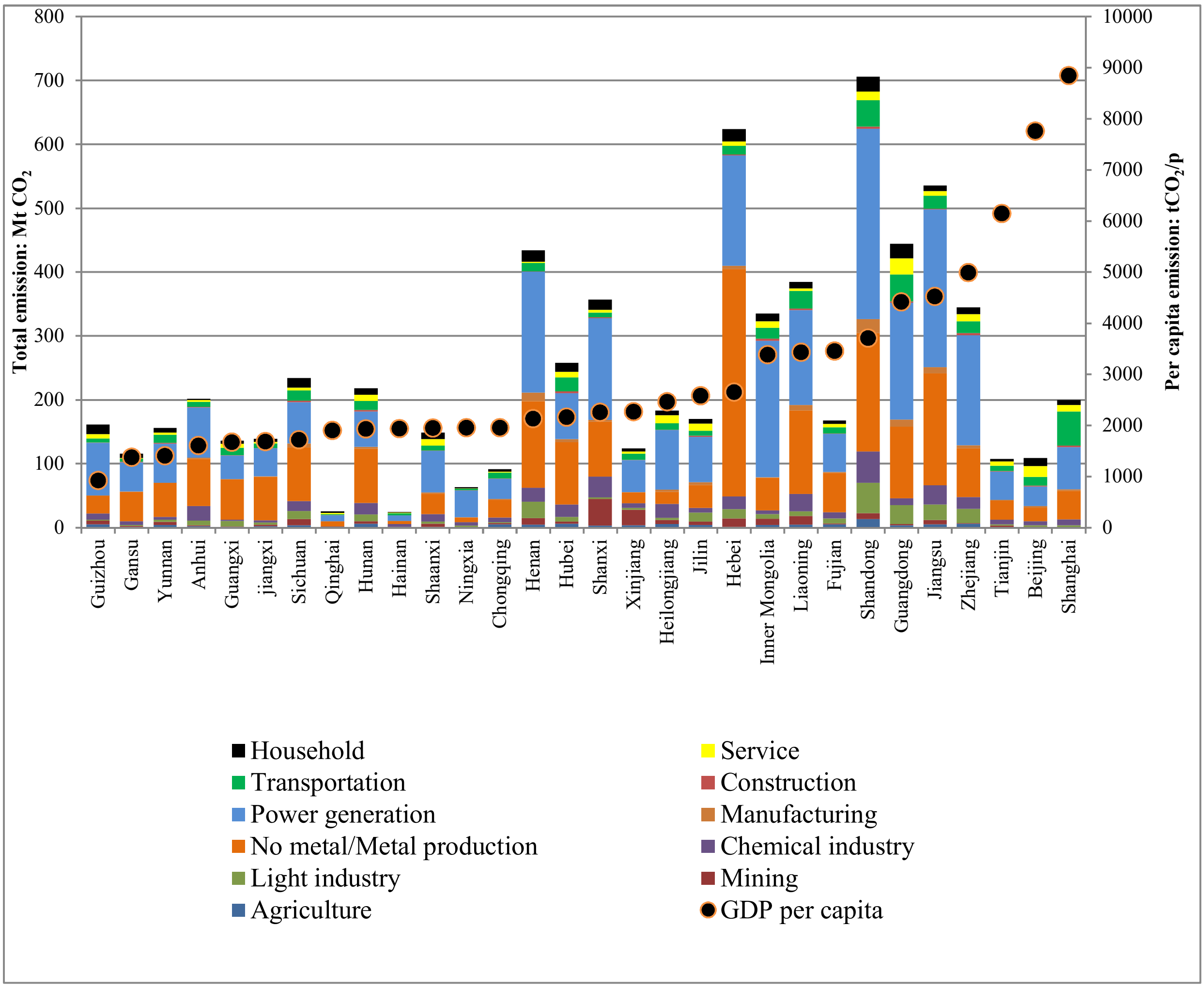
332 **Figures**



333 **Figure 1 System boundary 1 carbon emissions for China's 30 provinces**.

	System boundary 1	Mt CO2 System boundary 2	Mt CO2 System boundary 3	Mt CO2 System boundary 4	US dollar per capita GDP
Guizhou	162	162	196	98	922
Gansu	116	116	146	86	1379
Yunnan	156	156	205	114	1405
Anhui	202	202	285	171	1606
Guangxi	136	136	184	116	1674
jiangxi	139	141	212	168	1684
Sichuan	235	235	305	230	1719
Qinghai	25	25	39	29	1901
Hunan	219	224	282	184	1932
Hainan	24	24	30	22	1941
Shaanxi	149	177	233	134	1948
Ningxia	63	63	81	47	1953
Chongqing	92	102	145	108	1955
Henan	434	434	563	294	2135
Hubei	258	258	308	215	2161
Shanxi	357	357	398	189	2259
Xinjiang	124	124	173	102	2267
Heilongjiang	183	183	272	174	2464
Jilin	170	170	305	198	2584
Hebei	624	660	766	296	2650
Inner Mongolia	335	335	380	135	3386
Liaoning	384	410	466	239	3431
Fujian	168	168	224	133	3454
Shandong	706	706	876	541	3708
Guangdong	445	512	644	392	4420
Jiangsu	536	547	725	394	4524
Zhejiang	345	354	570	385	4988
Tianjin	108	118	205	121	6150
Beijing	109	152	246	191	7761
Shanghai	200	200	376	238	8849

Figure 2 Comparison of provincial system boundary 1- 4 carbon emissions

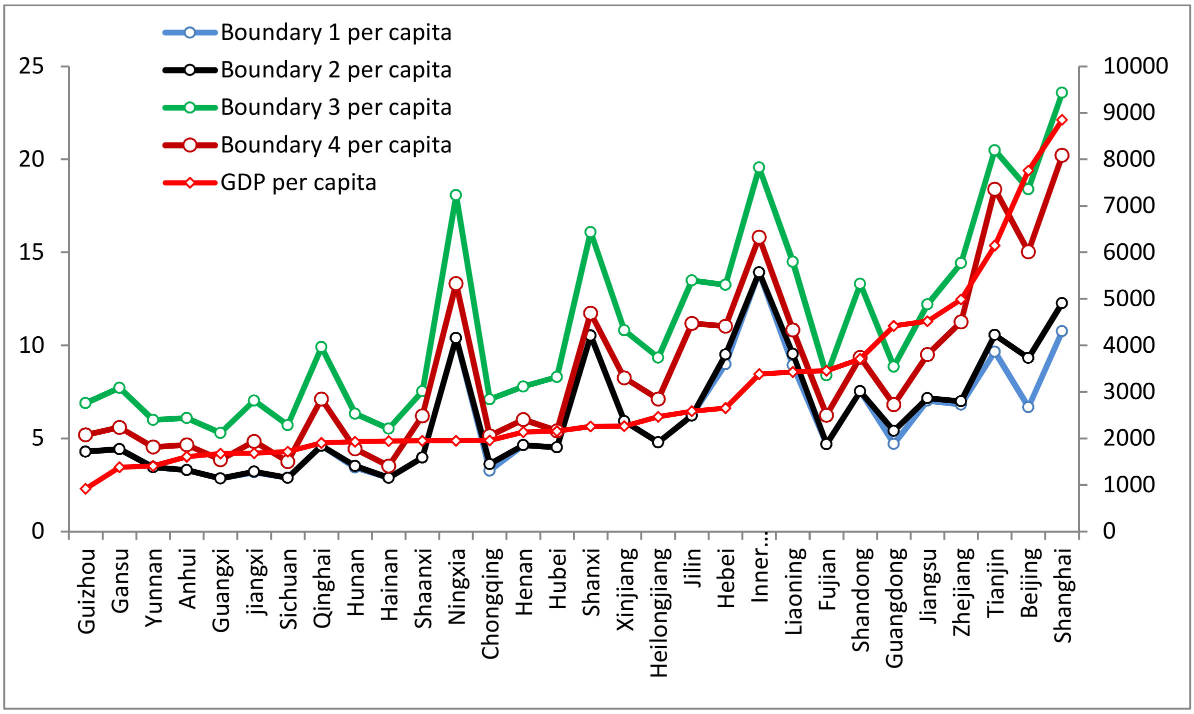
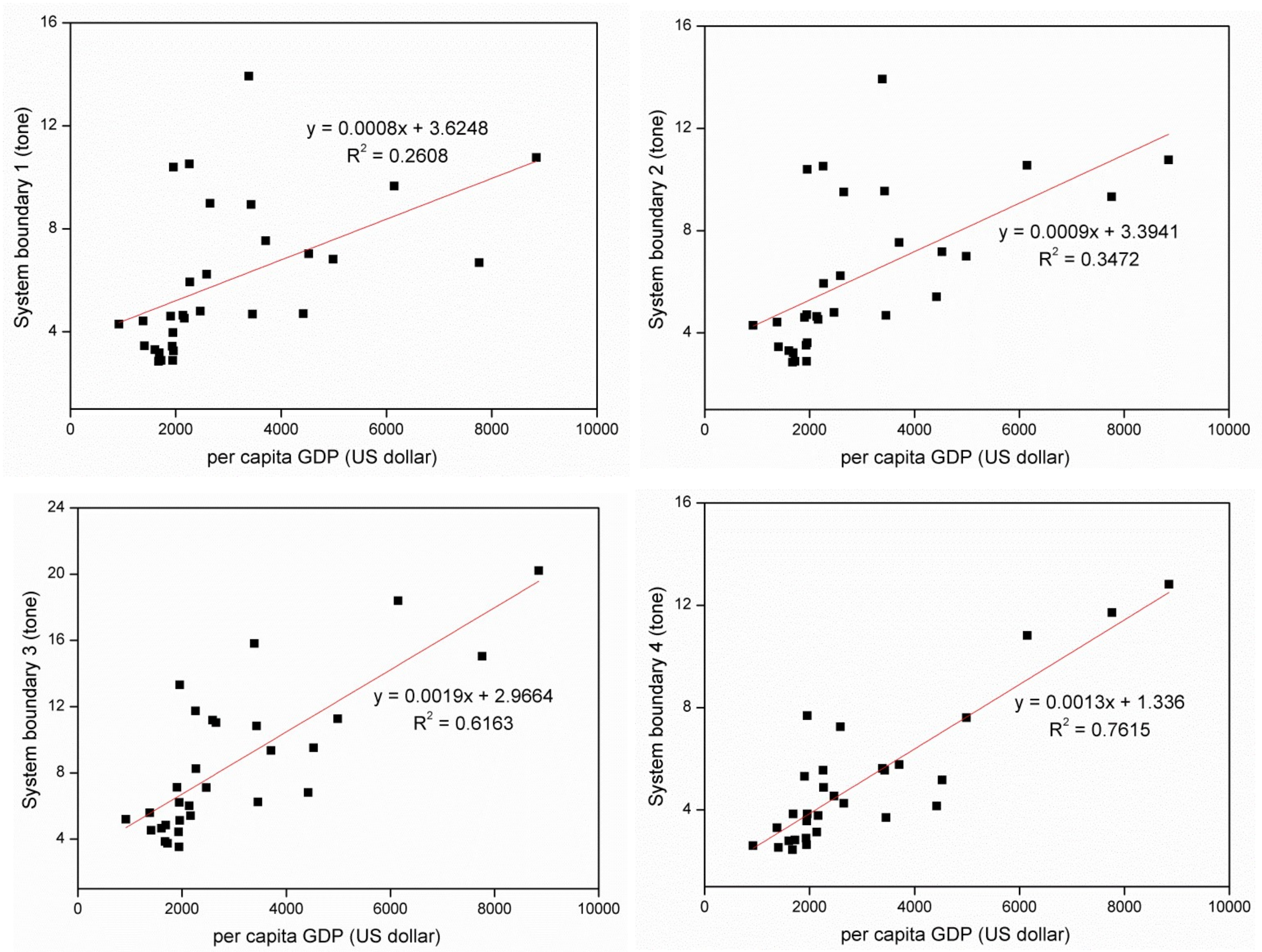


Figure 3 Per capita emissions of system boundary 1-4 and the per capita GDP for provinces.



$p < 0.001$

Figure 4: Relationships between per capita GDP and per capita system boundary 1-4 emissions

Table 1 Definition of Scope 1-4 footprints

Components	Emissions from in-boundary fossil fuel combustion and industrial process	Emissions from producing exports	Emissions from imported electricity	Emissions embodied in imports
Scope 1	■	■		
Scope 2			■	
Scope 3			■	■
Scope 4	■		■	■

Table 2 definition of system boundary 1-4

	Scope 1	**Scope 2**	**Scope 3**	**Scope 4**
System boundary 1	■			
System boundary 2	■	■		
System boundary 3	■	■	■	
System boundary 4				■

Table 3 Provincial emission intensity and targets

Province	Intensity reduction goal (2005-2010)	Intensity reduction goal (2010-2015)	Intensity goal achievement (2005-2010)	Intensity System boundary 1 (tCO2/1,000 dollar)	Intensity System boundary 4 (tCO2/1,000 dollar)	Difference of intensity (%)	GDP/p (US $ per capita)
Shanghai	20%	18%	20.00%	1.22	1.45	19.14	8848
Beijing	20%	17%	26.59%	0.86	1.51	75.05	7760
Tianjin	20%	18%	21.00%	1.57	1.76	12.03	6149
Zhejiang	20%	18%	20.01%	1.37	1.53	11.67	4988
Jiangsu	20%	18%	20.45%	1.55	1.14	-26.47	4523
Guangdong	16%	18%	16.42%	1.06	0.94	-11.74	4420
Shandong	22%	17%	22.09%	2.03	1.56	-23.33	3707
Fujian	16%	16%	16.45%	1.36	1.07	-20.90	3454
Liaoning	20%	17%	20.01%	2.61	1.62	-37.94	3430
Inner Mongolia	22%	15%	22.62%	4.11	1.66	-59.60	3385
Hebei	20%	17%	20.11%	3.39	1.61	-52.60	2650
Jilin	22%	16%	22.04%	2.41	2.81	16.35	2584
Heilongjiang	20%	16%	20.79%	1.95	1.84	-5.25	2463
Xinjiang	12%	10%	12.00%	2.62	2.15	-17.76	2266
Shanxi	22%	16%	20.66%	4.66	2.46	-47.21	2259
Hubei	20%	16%	21.67%	2.10	1.75	-16.49	2160
Henan	20%	16%	20.12%	2.17	1.47	-32.32	2134
Chongqing	20%	16%	20.95%	1.67	1.97	17.89	1954
Ningxia	20%	15%	20.09%	5.32	3.94	-26.06	1953
Shaanxi	20%	16%	20.25%	2.04	1.83	-10.03	1947
Hainan	12%	10%	12.14%	1.49	1.36	-8.74	1940
Hunan	20%	16%	20.43%	1.78	1.50	-15.65	1932
Qinghai	17%	10%	17.04%	2.42	2.79	15.22	1900
Sichuan	20%	16%	20.31%	1.68	1.64	-2.09	1719
Jiangxi	20%	16%	20.04%	1.89	2.28	21.01	1684
Guangxi	15%	15%	15.22%	1.71	1.46	-14.49	1674
Anhui	20%	16%	20.36%	2.06	1.74	-15.52	1606
Tibet	12%	10%	12.00%	no data	no data	no data	1513
Yunnan	17%	15%	17.41%	2.46	1.80	-26.64	1405
Gansu	20%	15%	20.26%	3.21	2.39	-25.40	1379
Guizhou	20%	15%	20.06%	4.66	2.83	-39.27	922

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