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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.

1. 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, 2001). 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, 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 regard to carbon emissions (Sovacool and Brown, 2010). Moreover, regions have intensive interactions across system boundaries, such as

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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., 2014).

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, 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, 2011a; Liu et al., 2012c); and scope 3 emissions refer to emissions embodied in imported products and services (International Council of Local Environmental Initiatives (ICLEI), 2008; Kennedy et al., 2010, 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 (Tables 1 and 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 et al., 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 Tables 1 and 2 for the definition).

2.1. 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):

$$\text{Emission} = \sum\sum\sum(\text{Activity data}_{i,j,k} \times \text{Emission factor}_{i,j,k}) \quad (1)$$

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

2.2. 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