Applied Energy xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Transnational city carbon footprint networks – Exploring carbon links between Australian and Chinese cities

Guangwu Chen [a], Thomas Wiedmann [a,b], Yafei Wang [c,*], Michalis Hadjikakou [a]

[a] Sustainability Assessment Program (SAP), UNSW Water Research Centre, School of Civil and Environmental Engineering, UNSW Australia, Sydney, NSW 2052, Australia
[b] Integrated Sustainability Analysis (ISA), School of Physics A28, The University of Sydney, NSW 2006, Australia
[c] School of Statistics, Beijing Normal University, Beijing 100875, People's Republic of China

HIGHLIGHTS

- A trans-national, multi-region input-output analysis for cities is presented.
- We examine the carbon footprint network of ten cities.
- The balance of emissions embodied in trade discloses a hierarchy of responsibility.
- We model how emissions reductions spread through the city carbon networks.
- Implications on the Chinese and Australian carbon trading schemes are discussed.

ARTICLE INFO

Article history:
Received 5 April 2016
Received in revised form 6 August 2016
Accepted 9 August 2016
Available online xxxx

Keywords:
Cities
Carbon footprint
Carbon trading
City carbon footprint network
City carbon map
Multi-region input-output modelling

ABSTRACT

Cities are leading actions against climate change through global networks. More than 360 global cities announced during the 2015 Paris Climate Conference that the collective impact of their commitments will deliver over half of the world's urban greenhouse gas emissions reductions by 2020. Previous studies on multi-city carbon footprint networks using sub-national, multi-region input-output (MRIO) modelling have identified additional opportunities for addressing the negative impacts of climate change through joint actions between cities within a country. However, similar links between city carbon footprints have not yet been studied across countries. In this study we focus on inter-city and inter-country carbon flows between two trading partners in a first attempt to address this gap. We construct a multi-scale, global MRIO model to describe a transnational city carbon footprint network among five Chinese megacities and the five largest Australian capital cities. First, we quantify city carbon footprints by sectors and regions. Based on the carbon map concept we show how local emissions reductions influence other regions' carbon footprints. We then present a city emissions 'outsourcing hierarchy' based on the balance of emissions embodied in intercity and international trade. The differences between cities and their position in the hierarchy emphasize the need for a bespoke treatment of their responsibilities towards climate change mitigation. Finally, we evaluate and discuss the potentially significant benefits of harmonising and aligning China's carbon trading schemes with Australia's cap and trade policy.

1. Introduction

Major cities around the world are concentrating their efforts to tackle climate change through global networks. The Compact of Mayors was launched under the leadership of the world's global city networks (C40,[1] ICLEI,[2] UCLG[3]), with support from UN-Habitat, the UN's lead agency on urban issues. The potential reductions of urban greenhouse gas (GHG or "carbon") emissions of the Compact of Mayors initiative are up to 3.7 gigatons (Gt) annually by 2030 [1]. More than 360 global cities announced at the Paris Conference that the collective impact of their commitments will deliver over half of the world's urban emissions reductions by 2020 [2].

Previous studies of city carbon footprint networks using multi-regional input-output (MRIO) consumption-based accounting (CBA) have demonstrated that cities – similar to nations – are linked to significant trans-boundary emissions through trade

* Corresponding author.
E-mail address: ywang@bnu.edu.cn (Y. Wang).

[1] Cities Climate Leadership Group (C40).
[2] ICLEI – Local Governments for Sustainability (ICLEI).
[3] United Cities and Local Governments (UCLG).

http://dx.doi.org/10.1016/j.apenergy.2016.08.053
0306-2619/

[3–5]. This opens up new opportunities for designing climate change mitigation policies. A recent study on carbon footprint linkages between five major Australian cities has shown that more than half of the nation's carbon footprint (CF) is associated with these five cities, and that 43–71% of the cities' CF is from emissions embodied in imports [6]. In comparison, the consumption of four Chinese provincial municipalities not only causes a large amount of emissions within their own territories, but also imposes many more emissions on their surrounding provinces via interregional supply chains [3]. A recent, comprehensive review on city carbon footprints based on consumption-based accounting (CBA) has been provided by Wiedmann et al. [7], which includes [5,8–19], while a summary on corresponding research based on the community-wide infrastructure footprint (CIF) method can be found in [20–25], with the most recent progress described in [25–29].

Around one fourth of global CO_2 emissions is associated with the production of goods and services which are exported and used to satisfy demand from countries other than those where the CO_2 is emitted [30]. A recent study suggests that the rapid growth of exports in carbon-intensive goods from Australia to China in the first decade of the 21st century has slowed global GHG emissions growth, owing to the significantly lower carbon intensity of goods produced in Australia compared to those produced in China [31]. International trade, even when transport-related emissions are factored into the calculation, therefore has the potential to lower global emissions if specific goods are produced in the location where environmental impacts are lowest [32,33].

Cities are not only engines of economic growth and innovation, but also hotspots of consumption, and they inevitably have to satisfy local demand though domestic and global trading, making them responsible for significant environmental impacts beyond their boundaries. The reduction of emissions embodied in trade is therefore crucial in designing urban carbon mitigation policies. In Australia, 29–39% of the carbon footprint (CF) of the five Australian capital cities is from emissions embodied into overseas imports [6]. Similarly, in the Chinese city of Xiamen, 40% of the CF comes from overseas [24]. However, no previous study has yet assessed emissions embodied into trade between cities in different countries, even though emissions transferred between countries have attracted significant academic attention in recent years [32,34–37]. The necessity to move towards transnational MRIO models with nested city regions, allowing links between consumption and production across cities, regional areas and nations, has been highlighted as a key requirement for future footprint research [38]. The present study is a comprehensive first step addressing this requirement.

It is now well established that considering direct emission reductions alone (such as under the Kyoto Protocol) while neglecting outsourced emissions, renders any carbon mitigation efforts less effective [37,39–42]. In a similar fashion, global cities should also conduct the same analysis if local governments are to adopt holistic, full supply chain mitigation efforts. More and more cities are aiming at achieving carbon neutrality [43]. The Australian Government is planning to extend its Carbon Neutral Program that currently allows to certify organisations, products, services and events as carbon neutral, so that whole cities can be certified as carbon neutral as well [44]. This raises vital questions as to how much cities outsource their emissions to other cities through their global carbon networks and what the net emissions hierarchy between cities is. Addressing these questions outlines responsibility of cities for emissions and promotes collaborative actions for climate change mitigation.

In this study, we employ a multi-scale MRIO model to analyse the transnational flow of embodied GHG emissions between four Chinese province-level municipalities (Beijing, Tianjin, Shanghai and Chongqing), a special Chinese administrative region (Hong Kong) and the five largest Australian capital cities (Sydney, Melbourne, Brisbane, Adelaide and Perth). We tailor the model setup to suit a highly relevant case study, since China is now Australia's largest two-way trading partner in goods and services. China is the largest destination for Australian exports of materials and goods as well as the largest source of merchandise imports into Australia [45]. The China Australia Free Trade Agreement (ChAFTA), which came into force on 20 December 2015 [45], is expected to further influence the intensity and transfer of embodied environmental impacts between these two countries [46]. The China-Australia case study aims to investigate how joint actions could be designed in order to maximise global GHG mitigation. Calculating the balance of emissions embodied in trade offers a city hierarchy of net carbon transfers. Based on the city carbon map concept [7], we model how carbon reductions in a city influence other regions through carbon networks. In the final section we discuss the implications of Chinese and Australian carbon trading schemes and the common benefits of matching both.

2. Materials and methods

We include four Chinese provincial municipalities, Hong Kong and the largest five Australian capital cities in a globally closed multi-regional input-output table (MRIOT) with 25 sectors. The boundaries of Hong Kong and the four Chinese provincial municipalities are defined by their administrative area, which include both urban and rural areas (see population and areas in Table S1 of the Supplementary Material, SM). To make boundaries comparable with Chinese cities, we choose the Australian city's boundary based on the Greater Capital City Statistical Areas (GCCSAs) published by the Australian Bureau of Statistics [47]. The GCCSAs is designed to include not only the urban area of the city but also the small towns and rural areas surrounding the city, thus covering a population which regularly socialise, shop or work between the cities and its surrounding areas.

In the Eora database, the global MRIO tables for 2009 already include China, Hong Kong and Australia (http://worldmrio.com). The national tables of China and Australia are further replaced by detailed city MRIO tables from previous work. Following the approach taken in [48] to link 30 Chinese provinces (including the four provincial municipalities) with 185 countries in a global MRIOT (see more details in the SM). The trade links between Australian cities and the rest of the world is established in the same way (for details see papers [6,7,49]). We allocate the international import to local (city-scale) economies according to the share of local industrial intermediate use and the export to overseas destinations according to the share of local industrial intermediate supply. This implicitly assumes that international inputs are proportional to local inputs and exports are proportional to local supplies (see Fig. S1 in the SM). Precedents of such approaches estimating international trade between regional economies have been described in [50,51].

All city input-output tables are nested in the final MRIOT, with the rest of China (RoC) representing the domestic 'hinterland' of Chinese cities and the same applies for the rest of Australia (RoA). The rest of the world (RoW) is aggregated into one region to represent the global hinterland. While the resulting 13-region MRIOT is purpose-built for this study, the foundations of the underlying large-scale MRIO were laid in previous work on global and sub-national MRIOTs that required substantial data mining, compilation and optimisation [48,52–54].

Data for estimating GHG emissions of the four Chinese provincial municipalities are mainly taken from the 2010 Chinese Energy Statistics Yearbook and the 2010 Statistical Yearbooks of Beijing Shanghai, Tianjin and Chongqing [55]. Provincial CO_2e emissions