Ecological Informatics 26 (2015) 85–92

Contents lists available at ScienceDirect

Ecological Informatics

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

Energy-dominated carbon metabolism: A case study of Hubei province, China

Q. Yang [a,b], Shan Guo [c,d,*], W.H. Yuan [b,e], Qiping Shen [c], Y.Q. Chen [b], X.H. Wang [b], T.H. Wu [b], Zhan-Ming Chen [f], Ahmed Alsaedi [g], Tasawar Hayat [g,h,**]

[a] Hubei Key Laboratory of Industrial Fume & Dust Pollution Control, Jianghan University, Wuhan 430056, PR China
[b] Department of New Energy Science and Engineering, School of Energy and Power Engineering, Huazhong University of Science and Technology, Wuhan 430074, PR China
[c] Department of Building and Real Estate, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong
[d] State Key Laboratory of Turbulence and Complex Systems, College of Engineering, Peking University, Beijing 100871, PR China
[e] Mechanical and Aerospace Engineering, Rutgers, The State University of New Jersey, 57 U.S. Highway 1, New Brunswick, NJ 08901, USA
[f] Department of Energy Economics, School of Economics, Renmin University of China, Beijing 100872, China
[g] Nonlinear Analysis and Applied Mathematics (NAAM) Research Group, King Abdulaziz University, P.O. Box 80207, Jeddah 21589, Saudi Arabia
[h] Department of Mathematics, Quaid-i-Azam University 45320, Islamabad 44000, Pakistan

ARTICLE INFO

Article history:
Received 18 September 2013
Received in revised form 8 October 2013
Accepted 9 October 2013
Available online 23 October 2013

Keywords:
Ecological input–output analysis
Carbon metabolism
Production versus consumption
Hubei

ABSTRACT

As the largest CO_2 emitter, China sets regional CO_2 emission intensity reduction targets to distribute the tremendous emission reduction pressure. Therefore, a deep understanding of China's regional CO_2 metabolism, especially emission level is essential for achieving the emission mitigation target. From the production versus consumption perspectives, this paper uses Hubei as a case study to establish a concrete direct energy-dominated CO_2 metabolism inventory in 2002, 2005 and 2007, and further estimate CO_2 metabolism embodied in consumption and trade based on a system ecological input–output analysis. The comparison of production- and consumption-based CO_2 metabolism depicts a huge difference: the consumption-based CO_2 emissions are just 31.02%, 24.77% and 31.04% of the production-based CO_2 emissions in 2002, 2005 and 2007, which demonstrates that Hubei needs to share responsibilities both as a producer and a consumer, focusing not only on the improvement of production technology and energy efficiency but also on the adjustment of economic system structure and trade policies avoiding carbon leakage. Analysis of historical tendency presents that production- and consumption-based CO_2 metabolism of 2002–2005–2007 both experience an increasing trend, while the average embodied intensity of these three years shows a decreasing trend. In terms of trade balance, Hubei is a net CO_2 exporter of 0.36E + 07 t, 0.08E + 07 t and 1.11E + 07 t CO_2 in 2002, 2005 and 2007.

1. Introduction

The burning of fossil fuels is the primary cause of anthropogenic CO_2 emissions (Vitousek et al., 1997). International Energy Agency (IEA, 2013) reported that global energy-related CO_2 emissions hit record high in 2012, rising by 1.4% to 31.6 Gt. China contributed to the largest CO_2 emissions (7.9 Gt) in 2012, accounting for a quarter of worldwide emissions (IEA, 2013). However, China saw the smallest CO_2 emissions growing rate with 3.8% in 2012, showing its effort and effectiveness to reduce emissions through low-carbon technologies and policies (IEA, 2013). The Twelfth Five-Year Plan (2011–2015) is the first attempt for China to set a mandatory emission reduction target, i.e., reducing CO_2 emissions per unit GDP by 17% (NDRC, 2010a). To achieve this goal, China sets provincial CO_2 emission intensity reduction targets considering regional difference to distribute the tremendous emission reduction pressure, based on the top-down emission reduction approaches. Therefore, a comprehensive understanding of the regional carbon metabolism, especially emission level is a crucial part for China to achieve energy saving and emission reduction targets.

Carbon metabolism, in this paper, specially indicates the carbon conversion, carbon transfer and carbon emission in social and economic activities. Some methods as the general guidelines for regional carbon emission accounting, like Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories (IPCC, 2006), the International Council for Local Environmental Initiatives (ICLEI, 2008), Greenhouse Gas Protocol for GHG Accounting Tool for Chinese Cities (WRI et al., 2013), Greenhouse Gas Regional Inventory Protocol (Carney, 2003), etc. have helped a large number of regions to establish their greenhouse gas (GHG) emission inventories. These inventories are more likely to focus on emissions generated by producing activities within a particular jurisdiction, like fuel combustion, industrial processes, fugitive missions, etc. (IPCC, 2006) based on production accounting

* Correspondence to: S. Guo, Department of Building and Real Estate, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong. Tel.: +86 27 87558598.
** Correspondence to: T. Hayat, Nonlinear Analysis and Applied Mathematics (NAAM) Research Group, King Abdulaziz University, P.O. Box 80207, Jeddah 21589, Saudi Arabia. Tel.: +86 27 87558598.
E-mail addresses: shan.guo@connect.polyu.hk (S. Guo), tahaksag@yahoo.com (T. Hayat).

1574-9541/$ – see front matter
http://dx.doi.org/10.1016/j.ecoinf.2013.10.001

principle, which pays attention typically on local production emissions but not considers all the emissions (including direct and indirect emissions caused by the whole chain of production) allocated to the final consumers (Wiedmann, 2009). Therefore, consumption accounting principle is put forward to estimate carbon emissions associated with consumption. In terms of the accounting method, input–output analysis is recognized as a sound methodology for carbon accounting from a perspective of consumption (Costanza, 1980; Dai et al., 2012; Lenzen, 1998; Peters, 2010; Peters and Hertwich, 2008; Weber et al., 2008; Wiedmann et al., 2007). In general, the difference in essence between production accounting principle and consumption accounting principle is related to the emission responsibility subject (producers or consumers), i.e. those who benefit from these carbon emissions should bear corresponding responsibilities (Davis and Caldeira, 2010).

According to the above two principles, many studies have made great contributions to China's regional carbon transfer and emissions, which can be categorized as multi-regional and single-regional analyses divided by the scope of study area. Multi-regional analysis aims to compare the carbon emissions for each province in China and clarify the relationship between spatial distribution of carbon emissions and interprovincial trades. Based on the production accounting principle, numerous studies focus on multi-regional direct emissions (Clarke-Sather et al., 2011; Du et al., 2012; Geng et al., 2011b; Lei et al., 2011; Zhao et al., 2012). Meng et al. (2011) and Liu et al. (2012) analyze the characteristics of China's regional CO_2 emissions and develop a detailed sectoral GHG inventory for 30 provinces during 1997–2009, respectively. Based on the consumption accounting principle, some researchers concentrate on embodied emissions (including both direct and indirect emissions) based on the multi-regional input–output model (Liang et al., 2007; Su and Ang, 2010, 2011; Wiedmann, 2009; Zhou and Imura, 2011). For example, Guo et al. (2012) clarify 30 provinces' embodied CO_2 emissions from geographical and sectoral dimensions in 2002. Meng et al. (2013) calculate CO_2 emissions embodied in China's inter-regional trade for 2002 and 2007.

Compared with multi-regional analysis, single-regional analysis pays more attention to the whole carbon emission picture of single region. Studies on China's single-regional carbon emissions provide efficient data support for achieving emission reduction targets within a specialized region (Chen and Zhu, 2013; Dhakal, 2010; Geng et al., 2011a; Vause et al., 2013; Zhang et al., 2011). From the perspective of production accounting principle, Shao et al. (2011) estimate energy-related industrial CO_2 emissions in Shanghai from 1994 to 2009. Bi et al. (2011) establish a GHG emission inventory in Nanjing for 6 emission sources from 2002 to 2009. Xi et al. (2011) present 25 sectors' GHG emission inventories of Shenyang and allocate emissions in 13 districts and counties of Shenyang in 2007. For consumption accounting principle, Beijing's embodiments of emissions have been discussed in a series of studies (G.Q. Chen et al., 2013; Guo and Chen, 2013; S. Guo et al., 2012a, 2012b). Li et al. (2013) present a systematic carbon accounting in a case study of Macao for the years 2005–2009. Harris et al. (2012) compare the difference of "consumption emissions" and "production emissions" using Hong Kong as a case study.

Located at the middle reaches of Yangtze River, Hubei province is the economic center as well as the transport hub of central China. With an average annual growth rate of 11.3%, Hubei's gross domestic product (GDP) in 2012 was as much as 2225.02 billion Yuan, which was 3.5% higher than the average value in China (HSY, 2012). The energy consumption in Hubei was also dramatically increasing with the boom of the local economic, from 66.29 to 123.29 million tons of standard coal equivalent over the period of 2005–2011 (CESY, 2013). With the growing energy consumption, Hubei released the new energy conversation and carbon reduction target: According to China's Twelfth Five Year Plan issued by the National Development and Reform Commission (NDRC), Hubei is expected to reduce the carbon emission per unit of GDP by 17% and energy consumption per unit of GDP by 16% from 2010 to 2015 (NDRC, 2010b). Obviously, this target made Hubei facing tremendous pressures to save energy and reduce emissions. To implement this target, a series of policies have been developed in Hubei: NDRC approved Hubei as a low-carbon economy pilot area; Wuhan, the capital of Hubei province, was selected as the "two-type (resource-saving and environment-friendly) society" pilot reform area; and, combining with the Development Planning of New Energy Industries 2009–2020 published by the National Energy Bureau (NEB), Hubei has set up its own new energy scheme based on the resource advantages, such as the rich amount of underground water and good agricultural resources, to develop hydropower, nuclear energy and biomass energy (NEB, 2009). However, due to insufficient understanding of regional and sectoral emission levels, the tough targets and various relevant policies are hard to be effectively implemented, even leading to such extreme energy saving actions, like switching off power and limiting electricity supply in several Chinese provinces in 2010. Moreover, the urbanization rate of Hubei has reached 53.50% in 2012 (HSY, 2012). Along with the rapid development of urbanization, it's easy to support the development of energy-intensive industries to push the economy, but ignoring the environmental issues (Chen and Chen, 2012). Therefore, it's very important to establish a sustainable development way according to a sound scientific carbon metabolism database, focusing on carbon transfer and emissions between different districts and also different sectors by the system ecological accounting in Hubei.

From the perspective of production, Hubei along with Guangdong, Liaoning, Yunnan, Zhejiang and Tianjin, was brought into the national compilation of the Provincial Greenhouse Gas Emissions Inventory in 2005, which was successfully accomplished in 2011 (NDRC, 2010a). However, relatively little attention has been focused on the consumption-based carbon emission footprints in most provinces. To analyze China's regional carbon metabolism, especially emissions from the production versus consumption perspectives, this paper uses Hubei as a case study to establish a concrete direct energy-dominated CO_2 metabolism inventory in 2002, 2005 and 2007, and further estimate CO_2 emissions embodied in consumption and trade based on a system ecological input–output analysis.

This paper is organized as follows. Section 2 elaborates production- and consumption-based methodological aspects of IPCC guidelines and carbon metabolism based on system ecological input–output analysis, as well as the latest available economic and environmental data sources. Section 3 presents the direct CO_2 emission inventory and corresponding consumption-based embodiment analyses for Hubei in 2002, 2005 and 2007. Finally, we draw our conclusions in Section 4.

2. Methodology and data

2.1. Methodology

IPCC guideline (IPCC, 2006) is the universal standard for calculating the direct national carbon emission inventories, which provides suggestions on methods and default values of emission factors for assessing CO_2 emissions. CO_2 emissions are mainly driven from fossil fuel combustion, while the energy-related CO_2 transfer and emissions are the research targets of this paper. Considering the data availabilities in the regional studies, this paper uses the most basic method, i.e. IPCC tier 1 method, to estimate the energy-related CO_2 emissions, which can be calculated as the product of energy consumption and default emission factors applicable to all combustion processes, both stationary and mobile. Finally, the regional production-based emission inventory could be established.

In an attempt to model the embodiment of carbon transfer, a system ecological input–output model is used in this paper. In the light of Odum's ecological and general system theory (Odum, 1983, 2000), the system ecological model provides a quantitative methodology to represent the sectoral embodied ecological flows along with economic flows based on the physical balance. Currently, this model has been widely used for accounting carbon metabolism and resources use at global (Chen, 2011; Chen and Chen, 2011a,b; Z.M. Chen et al., 2013), national (Chen and Chen, 2010; Chen and Zhang, 2010; Chen et al., 2010; Hawdon and Pearson, 1995; Zhang et al., 2013) and regional scales