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Carbon footprints of food production in China (1979–2009)

Lin Jianyi [a, b, 1, 4], Hu Yuanchao [a, b, 2, 4], Cui Shenghui [a, b, *], Kang Jiefeng [a, b, 3], Xu Lilai [a, b, 2]

[a] Key Laboratory of Urban Environment and Health, Institute of Urban Environment, Chinese Academy of Sciences, Xiamen 361021, China
[b] Xiamen Key Lab of Urban Metabolism, Institute of Urban Environment, Chinese Academy of Sciences, Xiamen 361021, China

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ABSTRACT

A carbon footprint accounting of food production is useful for acquainting policy makers with both the potentials and the challenges of GHG mitigation in agriculture. In this study, a hybrid Economic Input-Output and Life Cycle Assessment (EIO-LCA) model was developed to investigate the carbon footprint of Chinese food production from 1979 to 2009. The change patterns and compositions of emission sources, impacts of urbanization, carbon footprint and carbon emission factors of 15 food types were examined. Research results indicate that the total carbon footprint of food production had doubled in those three decades, alongside rapid urbanization. The emission sources showing the most dramatic increases were synthetic fertilizer, direct energy use, enteric fermentation and manure management. Among all types of food, the carbon footprint of rice production increased most, and the carbon footprint of milk, bovine meat, fruit and vegetable production also grew rapidly due to increasing yields. There was an overall decreasing trend for carbon emission factors of rice, vegetable, fruit and animal-food production from 1979 to 2009. Notably, the carbon emission factors of most vegetable food production rebounded after hitting bottom in 1999 due principally to enhanced agricultural input. Compared with the U.S.A., China had a higher ratio of indirect carbon footprint in its food production system, which showed high material input and energy intensity. China had smaller carbon emission factors from rice and pigmeat production, but larger carbon emission factors from bovine meat production than the U.S.A., indicating the relative strengths and weaknesses of Chinese food-production technology. Mitigation solutions rely upon better balancing the dietary structure, improving the productivity of animal foods, and reducing agricultural inputs, especially synthetic fertilizer.

1. Introduction

Accounting for up to one third of the global greenhouse gas emissions (Vermeulen et al., 2012), GHG emissions of food production have nearly doubled from year 1961–2011 (FAOSTAT, 2014), and possibly will have increased to 130 percent by 2050 (FAO, 2014) due to the continuing population growth and rapid urbanization (Tilman et al., 2011). As the largest food producer and consumer, China is also responsible for more agricultural GHG emissions than any other country (FAOSTAT, 2014). Emissions grew rapidly from 605 Mt CO_2e in 1994, to 820 Mt CO_2e in 2005 (NCCC, 2004, 2009), with an average annual growth rate of 2.8%. China is also the largest fertilizer consumer (Zhu and Chen, 2002), causing N_2O emissions to increase from 0.18 Mt in 1978 to 0.41 Mt in 2010 (Cui et al., 2013). Food production emissions will inevitably continue to grow in the coming years, for the National Development and Reform Commission has planned to stabilize food production and increase meat supply (SCPRC, 2014) to satisfy China's increasing food demand. In order to achieve sustainable agricultural development, we must precisely quantify the environmental impact of food production and its change patterns so as to balance food security and climate change mitigation. Studies have shown that, the climate change impact of production portion took 62–75% in the whole life cycle of food from farm to table (Virtanen et al., 2011). In China, the value was as high as 85% (Wang and Qi, 2013).

* Corresponding author. Key Laboratory of Urban Environment and Health, Institute of Urban Environment, Chinese Academy of Sciences, Xiamen 361021, China. Tel.: +86 592 6190957; fax: +86 592 6190977.
E-mail addresses: jylin@iue.ac.cn (L. Jianyi), ychu@iue.ac.cn (H. Yuanchao), shcui@iue.ac.cn (C. Shenghui), jfkang@iue.ac.cn (K. Jiefeng), llxu@iue.ac.cn (X. Lilai).
[1] Tel./fax: +86 592 6190658.
[2] Tel.: +86 592 6190664; fax: +86 592 6190977.
[3] Tel.: +86 592 6190678; fax: +86 592 6190977.
[4] Contributed equally to this work.

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Carbon footprint (CF) refers to the greenhouse gases (GHG) emissions caused by an activity or a product during its lifecycle, including direct and indirect emissions (Wiedmann and Minx, 2007). With increasing awareness of climate change, CF has been recognized as a valuable indicator of GHG emissions management, and CF calculations have become increasingly popular at different scales for products, individuals/households, organizations, communities, and countries (Wright et al., 2011). The methodologies of CF accounting can be grouped into three principal approaches: bottom-up-based Process Analysis (PA), top-down-based Environmental Input-Output Analysis (EIOA), and the hybrid EIO-LCA method, which combines the merits of the first two methods (Lin et al., 2013; Wiedmann and Minx, 2007). The hybrid EIO-LCA is also called hybrid LCA method (Zhang et al., 2013; Suh et al., 2004), and is widely used in environmental impact assessment in different scales because it makes the inventory more reliable. In this method, the requirement of the most important lower stages is allowed to be obtained by the specific and accurate bottom-up PA method, while the higher order requirement can be covered by the top-down EIOA method.

Food production can be classified simply into vegetable food production and animal food production, each of which can be subdivided into different food types. GHG sources of food production CF include emissions of agricultural inputs production, animal feed production, farming production process and energy use in farming production. There have been a number of studies on food production CF from different perspectives. For vegetable foods, CFs of tomato and wheat production have been quantified via activity data and emission factors using different calculation systems (Röös et al., 2010, 2011), and the CF of cane sugar and its driving forces were analyzed (Fisher, 2013). For animal food, the production CFs of livestock products (hog meat, beef and dairy) (Hermansen and Kristensen, 2011), and specific foods like milk (Flysjö et al., 2011), beef (Cederberg et al., 2011) and seafood (Vázquez-Rowe et al., 2013; Winther et al., 2009) were analyzed using the PA method. The environmental footprints of water and energy use in food production systems have been studied from local, national and global perspectives (Khan and Hanjra, 2009; Khan et al., 2009). Fertilizer input CF has been highlighted by many scholars and deserves more attention. Methane from ruminant animals is also significant in animal food production (Flysjö et al., 2011). The environmental impact of specific processed food products were also analyzed to guide the consumers to make environmentally responsible decisions. For example, the carbon emission factors (CEF) of bread, pie, cheese (Martindale et al., 2008; Jensen and Arlbjørn, 2014), and average daily climate impact of Finnish diet (Virtanen et al., 2011). Moreover, all food types were included in the comprehensive assessment using the Environmental Input-Output Analysis method, enabling the discussion of CF change patterns and mitigation solutions (Smith et al., 2008; Weber and Matthews, 2008). CF of a certain production process (Wu et al., 2013) was also studied to reveal the carbon emissions embodied in foods.

In the above studies, PA and EIOA were the most widely used methods of studying food production CFs; however, both methods have their merits and drawbacks. Specifically, the PA method is helpful for drawing a micromesh picture of the environmental impact on individual products from cradle to grave, but the collection and processing of the massive amounts of data are time-consuming. The definition of a system boundary is also subjective to a certain degree and may lead to difficulties when evaluating the CF of large entities (Tukker and Jansen, 2006). Furthermore, the collected emission factors will remain unchanged despite improvements in production technology. As for EIOA method, the whole economic system is defined as the boundary, and the calculation of CF is fulfilled comprehensively and robustly. But at the sector level, it has limitations on the accessibility to micro systems such as products and processes.

In this research, a hybrid EIO-LCA method that takes advantage of the strengths of both methods was used to estimate the CFs of food production (including 15 food types) in China from 1979 to 2009, and to identify the important contributors and production efficiency-enhancing technologies. In addition, an attempt was made to compare carbon emission coefficients among food production of different types. This study was hoped to offer some helpful insights into the discussion of dietary choices as well as provides some theoretical supports for the decision makers to recognize and improve low-carbon food production. The text is organized as follows: a) the calculating methodology and data; b) the research results and discussions of case studies; c) the conclusions of this study.

2. Material and methods

2.1. System boundary

The geographical boundary of this study is Mainland China, excluding the Hong Kong, Macau and Taiwan areas. We calculated the CF of only the food produced within China rather than imported food. The CF of food production contains CH_4 and N_2O emissions from farming production (planting and breeding industries), CO_2 emissions of direct energy use, production of agricultural inputs, and CO_2, CH_4 and N_2O emissions from feed production. We classified food into two categories—vegetable foods and animal foods—according to the FAO food balance sheet and other data availability. Vegetable foods include rice, wheat, maize, starchy roots, sugar crops, pulses, oil crops, vegetables, and fruits. The CF sources of vegetable food production include CO_2 from agricultural production inputs (such as fertilizer, pesticide, etc.), CH_4 from rice paddies, N_2O from fertilizer applications and CO_2 from direct energy use. Animal foods include bovine meat, milk (excluding butter, similarly hereinafter), mutton, goat meat, pigmeat, poultry meat, and eggs. The CF of animal foods includes agricultural inputs (such as animal housing, veterinary medicine, etc.), CH_4 from enteric fermentation, CH_4 and N_2O from manure management and embodied CF in feed (feed CF).

2.2. CF calculation method

The hybrid EIO-LCA method was introduced by Heijungs and Suh (2002, 2006) and Heijungs et al. (2006). Such an approach allows preservation of the detail and accuracy of bottom-up approaches in lower-order stages, while higher-order requirements are systematically and holistically covered by the input–output part of the model. In this study, we estimated the CF of farming production (direct CF) in the PA method, and the CF of agricultural production inputs (indirect CF) as in EIOA method, as shown in Fig. 1. Feed grain was a special case, in which CF originated from the production of vegetable foods for consumption by animals.

2.2.1. Direct carbon footprint accounting

The direct CF (C_{direct}) sources of planting industry are rice paddies, fertilizer applications including synthetic fertilizer, manure and crop residues, and direct energy use (electricity, diesel, gasoline, coal). The direct CF sources of breeding industry are enteric fermentation, manure management and direct energy use. Farming production CF was calculated with the IPCC method (Eggleston et al., 2006), multiplying the activity data with emission factors (EF). The function can be written as:

$$C_{\text{direct}} = \text{EF} \times \text{Activity} \quad (1)$$

To make the various emission sources comparable, we applied the global warming potential (GWP), which is the most commonly