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Composition and spatiotemporal distribution of the agro-ecosystem carbon footprint: A case study in Hebei Province, north China

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ABSTRACT

Agriculture is one of the largest source of greenhouse gas (GHG), in order to explore the structure and change of the agro-ecosystem carbon footprint (CF), based on a hybrid economic input-output and life cycle assessment (EIO-LCA) method, this study analyzed the composition and spatiotemporal distribution of the agro-ecosystem CF and discussed its main affecting factors taking Hebei Province in China as a case study. The results indicated that the total agro-ecosystem CF was 174.97 million tons in four years (1997, 2002, 2007 and 2012), and it firstly increased from 26.39 million tons in 1997 to 65.57 million tons in 2007 and then decreased to 51.31 million tons in 2012. The CF caused from energy consumption accounted for approximately 72.49% of the total agro-ecosystem CF, while the chemical consumption shared relatively less CF (17.18%). Among the 11 prefecture-level cities in Hebei, Shijiazhuang had a highest average agro-ecosystem CF with a value of 6.52 million tons p.a., Tangshan had the highest average net CF and net CF density with the corresponding values were 5.55 million tons p.a. and 6.87 t/ha, respectively, and Cangzhou had the highest carbon-emission intensity with a value of 5.04 t/10,000 RMB, however, Zhangjiakou had the lowest values of the above four factors with the corresponding values of 1.00 million tons p.a., 0.69 million tons p.a. and 0.97 t/ha, and 3.00 t/10,000 RMB, respectively. The economic growth had a great influence on the carbon-emission intensity of agro-ecosystem, the intensity of energy consumption had a positive correlation with the carbon-emission intensity, while the level of agricultural investment and farmer per-capita income were negatively correlated with the carbon-emission intensity. Therefore, reducing energy consumption, developing clean energy and improving agricultural investment to develop rural economy are imperative to slow the agro-ecosystem carbon emission.

1. Introduction

Agriculture is the second largest source of greenhouse gas (GHG) emissions (FAO, 2009), emitting approximately 13.5% of the total global GHG, including 25% of CO_2, 50% of CH_4 and 70% of N_2O (Montzka et al., 2011). Concurrently it represents a CO_2 sink (Mansour and Jejcic, 2017). In China, agriculture emitted approximately 17% of the national total GHG, including 50% of the total CH_4 and 92% of the total CO_2 emissions in 2000 (Liu et al., 2010). Conversely, as the economy develops and the population grows, increasing energy, chemical fertilizers, pesticides and agricultural films were instituted to maintain the grain yield, which further exacerbated the GHG emissions. To increase food production, Chinese agriculture has moved to higher-energy and higher carbon-input systems with limited arable land in recent decades (Dong et al., 2013).

As an important method of assessing the environmental impact to human activities, the carbon footprint (CF) concept was

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proposed to present the total amount of CO_2 and other GHGs emitted over the full life cycle of a process or product (UK POST, 2006; BSI, 2008; ISO/TS, 2013), which can measure the appropriation of natural resources by humans to indicate how human activities can impose burdens and impacts on global sustainability (Council of the European Union, 2006; Hoekstra, 2008). Presently, CF has become a hot topic in the environmental field (Wang et al., 2010; Aroonsrimorakot et al., 2013; Yang et al., 2014; Huang et al., 2017; Vergé et al., 2016; Zhang et al., 2016; Ali et al., 2017; Christiane et al., 2017). There are three main methods to calculate the CF, i.e. economic input-output (EIO) method (Leontief, 1970; Miller and Blair, 1984; Hertwich and Peters, 2009; Weber and Matthews, 2008; Wood and Dey, 2009), but it is was not suitable for the analysis of microscopic systems because it only used the average carbon emission intensity data; life cycle assessment (LCA) method (ISO, 2006; BSI, 2008; Schmidt, 2009; Guinée et al., 2009; Schulz, 2010) that existed boundary problems because it only takes the direct and a few indirect effects into account, and its results had truncation errors (Lenzen, 2001); and hybrid LCA (i.e. EIO-LCA) method which combined the advantages of EIO and LCA methods (Heijungs and Suh, 2002; Suh and Huppes, 2005; Suh and Nakamura, 2007; Lenzen and Crawford, 2009).

The agro-ecosystem is an important source of GHG emissions, many scholars have studied the agro-ecosystem CF in recent years. Knudsen et al. (2014) compared the CF of different organic arable crop rotations with different sources of N supply using LCA method. The results showed that the CF of the crops from 'Biogas' rotation was significantly lower than that of other crop rotations, and the green manure crops made great contributions to reduce the CF. Huang and Mi (2011) quantified the CF of the agricultural system in Zhejiang Province using the EIO-LCA methods. The results indicated that the carbon emissions from the consumption of electricity, diesel oil and coal accounted for 28.89% of the total agricultural system CF; the natural accumulation of livestock manure and straw burning produced 28.13% CF; and pesticide, fertilizer and agricultural film produced 27.56% CF (including 22.72% CF produced by fertilizer application). Zhang and Wang (2014) discussed the structure, efficiency and decision mechanism for agricultural carbon emissions in China using the whole life cycle method. Yang et al. (2015) analyzed the carbon absorption, emission and net sink of winter wheat in different water conditions by field experiment. Shrestha et al. (2014) analyzed the CF change of canola production in the Canadian Prairies, and found that the GHG emission intensities decreased by 40% on an area basis but the GHG emissions from canola production increased by 13%. Wang et al. (2016) estimated the CF of farmland ecosystem from 2002 to 2013 in Shandong Province. The results showed that the CF had a decreasing tendency, and there were obvious differences among the 17 cities on per unit area of CF. Duan et al. (2011) found the annual carbon absorption of crops in China from 1990 to 2009 was 525.60–676.13 Tg. Zhang et al. (2017) discussed the temporal and spatial differences of agro-ecosystem CF in He'nan Province from 2005 to 2014 and found that the average annual growth rate of CF was 2.7% and the CF caused by the fertilizer application accounted for 66.2% of the total. However, the current study of the agro-ecosystem CF was focused on certain regions with a lack of regional differences and neglected an analysis of its multiple influence factors.

Hebei is a big agricultural province in China with a grain yield of 3.5×10^{10} kg (accounting for 5.7% of the country's total) in 2017, where the agro-ecosystem was degraded because of people's predatory exploitation of land and the excessive use of pesticides and chemical fertilizers aggravated the environmental pollution and increased carbon emissions presently. It is urgent to reduce GHG emissions and develop clean energy in the agro-ecosystem (Lal, 2007). The main aims of this study were (1) to calculate and classify the agro-ecosystem CF of the agricultural activities in Hebei Province using the EIO-LCA method, (2) to analyze the composition and spatiotemporal distribution of the agro-ecosystem CF according to the panel data from 1997, 2002, 2007 and 2012 for 11 cities in Hebei, and (3) to discuss the influencing factors of the agro-ecosystem CF in Hebei. The results from this study will be helpful for developing low-carbon agriculture, energy saving and emission reduction in the agro-ecosystem.

2. Materials and methods

2.1. Hebei Province

Hebei Province (36°05′N–42°40N, 113°27′E–119°50′E, Fig. 1) is 190,000 km^2 in area, with a population of 74.7 million and a GDP of 3.18×10^{12} RMB (2016), and it is divided into 11 prefecture level cities. The topography consists of mountains, hills, and plateaus in the northwest, and a broad plain in the central and southeastern region. The main crops in the province are wheat, maize, rice, soybean, potato and millet.

2.2. Calculation of agro-ecosystem CF

The agro-ecosystem CF was calculated based on the EIO-LCA method (Lave et al., 1995; Hendrickson et al., 1998). In the agro-ecosystem, GHG emissions mainly included CO_2, N_2O and CH_4 that can be converted using the global warming potential (GWP) and unified-measured using the CO_2 equivalent (West and Marland, 2002), specifically, GWP (CO_2) = 1, GWP (CH_4) = 25 and GWP (N_2O) = 298. Therefore, the agro-ecosystem CF consists of the directly and indirectly emitted CO_2 equivalent (CO_2-eq) during the whole life cycle of agricultural production, and the calculation steps of the agro-ecosystem carbon footprint are as follows:

Layer1: Direct carbon emissions from agricultural production (DCEAP), including the direct CO_2 emissions from diesel oil combustion (CEDOC), CH_4 emissions from rice grown (MERG) and N_2O emissions from soil (NDES) due to the nitrogen application:

$$CF_{layer1} = \sum f_i e_i + n_i \quad (1)$$

where CF_{layer1} is the CF of the first layer, f_i is the carbon-emission coefficient of agricultural activity i, e_i is the diesel oil consumption, and n_i is CO_2 and CH_4 emissions from the responding agricultural activity and N_2O emissions from soil.

Layer2: Indirect carbon emissions from agricultural production

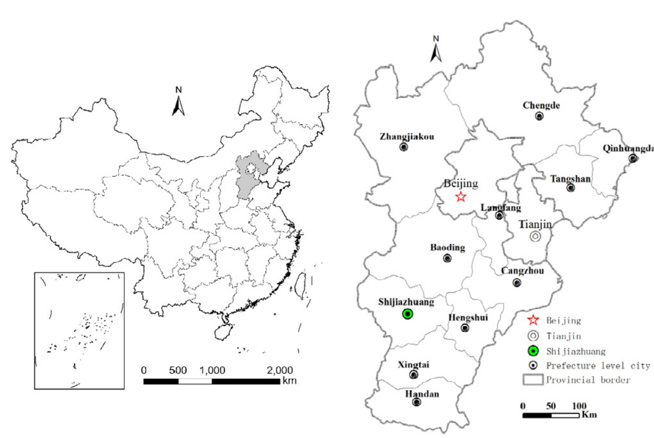

Fig. 1. Geographical position of Hebei Province.