Ecological Indicators 97 (2019) 141–149

Contents lists available at ScienceDirect

Ecological Indicators

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

Composition and spatial difference of agro-industry carbon footprint in Hebei province, North China

Luyue Xie[a,b], Qian Xue[c], Zaijian Yuan[d,*]

[a] *Academy of Mathematics and Systems Science, Chinese Academy of Sciences, Beijing 100190, PR China*
[b] *School of Economics and Management, University of Chinese Academy of Sciences, Beijing 100190, PR China*
[c] *Hebei University of Science & Technology, Shijiazhuang 050018, PR China*
[d] *Guangdong Key Laboratory of Integrated Agro-environmental Pollution Control and Management, Guangdong Institute of Eco-environmental Science & Technology, Guangzhou 510650, PR China*

ARTICLE INFO

Keywords:
Input-output table
Agro-industry
Carbon footprint
Spatial difference
Influence coefficient

ABSTRACT

To learn the regional carbon footprint of agro-ecosystem from the perspective of industrialization can help to clarify the responsibility of energy saving and carbon emission reduction in various industrial sectors. Using the input–output table of Hebei province in 2012, this study discussed the structure of the regional agro-industry carbon footprint (ACF) and its spatial difference, taking the prefecture level city as the basic spatial unit. The results indicated that the ACF was approximately 1.05×10^8 tons in 2012, which accounted for 6.7% of the total carbon footprint in Hebei. In all agro-industries, the fertilizer manufacturing industry produced the largest proportion ACF, which accounted for 23.7% of the total ACF. The gross domestic products (GDPs) of wood products, papermaking industry and agricultural food processing industry were relatively low, but their ACFs were large. The influence and induction of the fertilizer and pesticide manufacturing industries to other agro-industries were strong. The ACFs of wood, bamboo, rattan, palm and grass products manufacturing; paper and paper products manufacturing; fertilizer manufacturing; pesticide manufacturing; and agriculture, forestry, animal husbandry, and fishery special machinery manufacturing industries had significant spatial difference at the prefecture-level city spatial scale. The results from this study will be helpful for the adjustment of agro-industrial structure to develop low-carbon and energy-saving and emission-reduction agriculture in Hebei.

1. Introduction

According to the analysis by the Food and Agriculture Organization, agriculture contributes a significant share of greenhouse gas (GHG) emissions which has become the second largest source of GHG emissions (FAO, 2009), and it represents CO_2 source. Specifically, agriculture emitted 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). Therefore, reducing GHG emissions in agriculture is essential in the future (Mansour and Jejcic, 2017). In China, agriculture emissions contributed to 17% of the national total GHG emissions (Dong et al., 2008).

As an important measure index of the environmental impact to human activities, the carbon footprint (CF) has become a hot topic in the environmental field (Wang et al., 2010; Aroonsrimorakot, et al., 2013; Yang, et al., 2014; Zhang, et al., 2016; Ali, et al., 2017). The CF concept was 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 (Hoekstra, 2008) and indicates how human activities can impose burdens and impacts on global sustainability (Council of the European Union, 2009). Matthews et al. (2008) suggested that the life-cycle assessment (LCA) and input–output (I-O) methods can be combined to study CF to track all the activities of an industry supply chain, which can comprehensively reflect the information contained in the CF.

Presently, the agricultural CF has attracted the attention of scholars, which focused on the effects of agricultural management on GHG emissions (Druckman and Jackson, 2009; Perry et al., 2008) and the CF of agricultural products (Vergé et al., 2009; Pathak et al., 2010; Cheng et al., 2011, 2015; Cucek et al., 2012; Al-Mansour and Jejcic, 2017; Huang et al., 2017). Knudsen et al. (2014) compare the CF of different organic arable crop rotations with different sources of nitrogen supply. The result showed that the CF of the crops from the ‘Biogas’ rotation

---

* Corresponding author.
E-mail address: zjyuan@soil.gd.cn (Z. Yuan).

https://doi.org/10.1016/j.ecolind.2018.10.002
Received 30 December 2017; Received in revised form 30 August 2018; Accepted 3 October 2018
1470-160X/

was significantly lower than of other crop rotations per kilogram cash crop, and the green manure crops made great contributions to reduce CF. Reducing the application of nitrogen fertilizers can significantly mitigate GHG emissions in the agricultural sector (Cheng et al., 2011; Chen et al., 2017). In China, agriculture has moved to higher-energy and higher carbon-input systems in order to increase food production by the limited arable land (Dong, et al., 2013). The direct and indirect carbon emissions of agricultural energy, the carbon emissions of the agrochemical inputs in the whole life cycle and the emissions in the wasted deposal were the three main sources of the GHG emissions in the agricultural industry (Han et al., 2012; Zeng, 2013; Huang and Mi, 2011; Dong et al., 2013). Moreover, the carbon footprint of the agro-ecosystem has shown an increasing trend in China (Duan et al., 2011; Wang et al., 2016). With the development of agricultural industrialization, modern agriculture has broken through the traditional agricultural fields and continuously spread to the procedures of the production inputs, agricultural products processing, agricultural products circulation and service. But the assessing CFs of products cannot give the best strategy for mitigating greenhouse gas emissions (Ponsioen and Blonk, 2012). In addition, the current study of agricultural CF rarely refine to the industrial sectors from the angle of industrialization.

Hebei is a big agricultural province in China, which contributed approximately 5.5% of the country's total grain production (Yuan and Shen, 2013). To maintain a stable and high crop yield, the excessive use of pesticides and chemical fertilizers aggravated agricultural carbon emissions. The main aims of this study were to: (1) calculate the ACF and analyze its composition in Hebei province, (2) analyze the relationship between the agro-industry departments by the influence coefficient and induction force coefficient of the ACF, and (3) discuss spatial distribution of ACF at the prefecture-level city scale.

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 73 million and a GDP of 2.66×10^{12} RMB, which included 5.09×10^{11} RMB farming, forestry, animal husbandry and fishery output value (2012), 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 province is located in a temperate and continental monsoon climate zone with a mean annual precipitation of approximately 500 mm, and 70% of the precipitation occurs between June and September. The mean annual temperature is 15 °C, and precipitation and temperature decrease from southeast to northwest. The main crops in the province are wheat, maize, rice, soybean, potato and millet.

2.2. Data and methods

2.2.1. Data

The input–output data were obtained from the input–output table of Hebei (2012), which was provided by the Statistics Bureau of Hebei Province. The total assets of industry and enterprise employees' data and the added energy consumption data of the industry scale unit came from the Hebei Economic Yearbook and Hebei Statistical Yearbook of each prefecture level city (2013). The energy consumption data of industry was obtained from the Hebei energy statistics yearbook (2013).

2.2.2. Compilation of agro-industry input–output table

Based on the input–output table of Hebei (2012), various industries were split and merged by referring to the related definition of agro-industry (Lai et al., 2006; Davis and Goldberg, 1957) (Table 1), and the agro-industry input–output table was subsequently compiled (Table 2).

2.2.3. Calculation of the ACF based on input–output model

The calculation procedure is as follows, the first step is to calculate the Leontief inverse matrix L according to Table 2:

$$L = (I-A)^{-1} \tag{1}$$

where I is the unit matrix, and A is the direct consumption coefficient matrix.

The second step is to calculate the row vector (CEI) of the carbon emission intensity of each industry sector, i.e. the carbon emissions per unit value output.

$$CEI_i = CE_i/X_i \tag{2}$$

where CEI_i is the carbon emission intensity of industry i, CE_i is the carbon emission, and X_i is the output.

The third step is to obtain the total demand matrix (T) of the carbon emissions according to the diagonalization of the carbon emission intensity vector and multiplication of the Leontief inverse matrix in the left of the equation,

$$T = CEI \times (I-A)^{-1} \tag{3}$$

The fourth step is to obtain the carbon emission matrices of final consumption, capital formation and transfer according to the compound multiplier algorithm, which were calculated by multiplying the carbon emission M_L and the diagonal matrix and its grouping matrix of the final consumption, capital formation and transfer (including export and outflow) of each department:

$$CE_{FC} = T \times CEI_{FC} \times \begin{pmatrix} 1 \\ 1 \\ \vdots \\ 1 \end{pmatrix}, CE_{CAF} = T \times CEI_{CAF} \times \begin{pmatrix} 1 \\ 1 \\ \vdots \\ 1 \end{pmatrix}, CE_{CAT} = T \times CEI_{CAT} \times \begin{pmatrix} 1 \\ 1 \\ \vdots \\ 1 \end{pmatrix} \tag{4}$$

where CE_{FC}, CE_{CAF} and CE_{CAT} are the carbon emission matrices of final consumption, capital formation and transfer, respectively. CEI_{FC}, CEI_{CAF} and CEI_{CAT} are the carbon emission intensity of final consumption, capital formation and transfer, respectively. FC, CAF and CAT are the final consumption, capital formation and capital transfer of each department, respectively.

The fifth step is to calculate the carbon emission demand of import trade, which needs to split the import and inflow value tables to distinguish the transferred values (including import and inflow) used for the final demand, as well as the indirect demand transferred values. The calculation process of the direct carbon emission matrix corresponding to the direct use of the products outside the local province, and the carbon emission matrices (M_{cei}^1, M_{cei}^2, $\cdots M_{cei}^n$; where n is the number of industry sectors) of the products corresponding to each department of other provinces, were calculated as the same as the fourth step. The calculation process of carbon emission by the indirect use of products outside the local province was as follows:

$$M_{Icei} = [M_{cei}^1, M_{cei}^2 \cdots\cdots M_{cei}^n] \times \gamma \times \begin{pmatrix} 1 \\ 1 \\ \vdots \\ 1 \end{pmatrix} \tag{5}$$

where M_{Icei} is the carbon emission by the indirect use outside the local province of industry i, r is the adjustment factor, which represented the ratio of the investment from other provinces to the final use of the industry sectors.

The sixth step is to calculate the influence coefficient ($ICACF$) and induction force coefficient ($IFCACF$) of the ACFs. The ICACF is used to measure the impact or driving effect of an agro-industry on other agro-industries. The $IFCACF$ is to illustrate the strength of an industry in promoting economic development, which reflected the requirement of the complete supply degree provided by other industries when it