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# Investigating low-carbon crop production in Guangdong Province, China (1993–2013): a decoupling and decomposition analysis

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ABSTRACT

Low-carbon crop production is a way of raising yield gains in an ecologically and ethically responsible manner in the agricultural sector. Guangdong Province, one of China's major commodity grain production bases, is confronted with considerable challenges in promoting crop production while developing a low-carbon economy with limited croplands. Based on a decoupling index and decoupling stability analysis, this study investigated the dynamic variations of low-carbon development in a crop production system. The Logarithmic Mean Divisia Index method is employed to explore the drivers of the carbon footprint of Guangdong's crop production system from 1993 to 2013. The results indicated the following: (1) increased crop production output is not always positively correlated with an increased carbon footprint; (2) weak decoupling is the main tendency between carbon footprint and crop production; (3) the decoupling stability coefficients show that the threat of high-carbon-emission crop production does exist; and (4) the agricultural economy level is the determining factor for the growth of the carbon footprint in crop production, but agricultural investment, urbanization and technical progress contribute to the reduction of the carbon footprint in Guangdong Province. This study decomposed and quantified the driving factors of the total carbon footprint of a crop production system and provided insights into the potential for low-carbon crop production in Guangdong Province.

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## 1. Introduction

In recent years, the threats posed by global climate change, which is mainly caused by the emission of greenhouse gases (GHG), have become widely recognized by the international community. Many countries have devoted great attention to addressing the issues. According to the report of the Food and Agriculture Organization (FAO), agriculture is now the second largest source of GHG emissions (FAO, 2009). China's agricultural GHG emissions grew from 605 million tons (Mt) of carbon dioxide equivalents ($CO_{2\text{-eq}}$) in 1994 to 820 Mt $CO_{2\text{-eq}}$ in 2005 (NCCC, 2004, 2009). In turn, the increase of GHG emissions impacted hydrological and meteorological processes (Wu et al., 2012), agricultural productivity (Islam et al., 2012) and irrigation water demand (Valipour, 2012, 2014, 2015). In the agriculture industry, crop production, which utilizes tangible and intangible inputs to produce goods and services, is the most important sector.

The term carbon footprint (CF) is a commonly recognized phrase frequently referred to the total of GHG emissions caused by all inputs in a life cycle of production or consumption, including direct and indirectly emissions (Finkbeiner, 2009; Wiedmann and Minx, 2007). With increasing awareness of climate change, CF has been recognized as an important indicator of GHG emissions management (Wright et al., 2011) and CF assessment has been widely applied in agriculture (Cheng et al., 2015). The CF of crop production is used to measure the total amount of GHG emissions from agricultural materials used in crop production, crop protection and farm equipment operation in a single cycle (Adler et al., 2007; Cheng et al., 2015). Assessing the CF of crop production provides insights into the contribution of crop production to climate change and identifies possible GHG mitigation options (Yan et al., 2015). The rapid growth of the CF from crop production has brought public

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attention to low-carbon agricultural development worldwide (Knudsen et al., 2014; Khanali et al., 2016). As for China, Cheng et al. (2011) evaluated the CF of crop production in China during 1993–2007 and estimated the mean value of the overall CF to be 2.86 ± 0.29 t $CO_{2\text{-eq}}$ $hm^{-2}$ $y^{-1}$. Lin et al. (2015) found that the total CF had doubled during 1979–2009 in China's agricultural system. Yan et al. (2015) quantified the CF of crop production in eastern China, and found that the CF varied among climate regions, which can be explained largely by the differences in inputs of nitrogen fertilizers and mechanical operations to support crop management. Wang et al. (2016) assessed CF of winter wheat in North China Plain and pointed out reducing electricity for irrigation, decreasing nitrogen and phosphorus fertilizer application rates, and lowering direct nitrous oxide emissions are the priority measures that will result in low-carbon crop production.

Carbon efficiency (CE), defined as the total crop production per unit of carbon cost, is used to evaluate the cost-effectiveness at the expense of the CF for a production system (Cheng et al., 2011). Some scholars argue that improving CE is one important way to reduce the CF of crop production (Lal, 2004; Canadell et al., 2007). Under the low-carbon crop production policy of China, the CE of crop production has improved about 40% during 1993–2002, while showed a decreasing trend during 2003–2007 (Cheng et al., 2011). This approach has been well brought out the latent potential for develop low-carbon crop production system in China.

There exist both spatial and temporal variations in the resource availability, agricultural technology and farm practices in China. However, the previous studies did not include a temporal analysis of the low-carbon development status of crop production at the regional level. Moreover, understanding the drivers of the CF of crop production at the regional level is helpful to determining the potential for emissions reductions. Guangdong Province, one of China's major commodity grain production bases, is faced with increasing GHG emissions in the crop farming system due to rapid economic development and a surging population. Rapid urbanization, especially in the region of Pearl River Delta, has converted large amounts of arable land into land for construction purposes. In the face of a shrinking area of cultivated land and a decline in agricultural labor, Guangdong Province must rely heavily on energy consumption and chemical inputs to maintain its crop production. Under this situation, Guangdong Province faces the double challenges of improving yield gains while reducing GHG emissions from crop production. The development of low-carbon crop production systems can help produce food in an ecological and ethically responsible manner (Dong et al., 2013; Khanali et al., 2016).

Decoupling is defined as breaking the link between “environment bads” and “economic goods” (OECD, 2002). In this paper, the decoupling theory is used to identify the low-carbon development status for crop production. The existing literature on crop production system has mainly focused on decoupling irrigation water (Yu, 2008) and the water footprint (Zhang and Yang, 2014) from crop yield growth. Less attention has been placed on exploring the links between increasing crop production and CF, crop productivity (crop yield per unit area) and CE. Methane ($CH_4$) and nitrous oxide ($N_2O$) are both covered in the Kyoto Protocol and expressed in terms of the warming potential of $CO_2$ and are the most important GHGs in crop production (Xu and Lan, 2016). These two GHGs should be used in the determination of the total CF in crop production.

The Logarithmic Mean Divisia Index (LMDI) method is a widely accepted analytic tool to identify the relative impacts of different factors (Xu et al., 2014; Song et al., 2015; Yan and Fang, 2015) and policy making for regional environmental issues. Moreover, the LMDI can demonstrate the effects of each sector on the changes in the driving factors (Ang, 2004). For this reason, the LMDI was adopted to analyze the driving factors of the total CF in crop production in this paper. We analyzed the dynamic changes in the CF of crop production in Guangdong Province from 1993 to 2013. The dynamic variations of low-carbon development in the crop production system were examined based on the decoupling index and the decoupling stability analysis. The driving factors of the total CF were decomposed and quantified by the LMDI method. The results of this study provide detailed insights into the potential for low-carbon crop production in Guangdong Province.

Organization of the rest of this paper is as follows: Section 2 briefly introduces the methods in detail. Section 3 describes the data source. Section 4 reports the results and analyzes dynamic variations of low-carbon crop production of Guangdong Province between the years of 1993 and 2013. In Section 5, some important findings from are discussed. Finally, Section 6 draws the conclusions.

## 2. Methods

### 2.1. Estimation of CF in crop production

The CF of crop production mainly originates from eight sources: the production of diesel oil, pesticides, plastic film, fertilizers, electricity for irrigation, diesel oil combustion, and fertilizer consumption-induced $N_2O$ and $CH_4$ emissions from rice paddies (Cheng et al., 2011, 2015). In the present study, the estimation of the CF of crop production was obtained according to the following equation:

$$CF = \sum E_i = \sum T_i \times EF_i \quad (1)$$

where $CF$, $E_i$, $T_i$ and $EF_i$ denote the total CF of crop production, GHG emissions from source $i$, the amount of GHG source $i$ and the emission factors of source $i$. The Global Warming Potential (GWP) provides a common unit of measure, which allows analysts to quantify emissions estimations and compare the global warming impacts of different gases. The GWP has been the default metric with which to transfer different GHGs to what are often called “$CO_2$ equivalent emissions” (Shindell et al., 2009). The calculation of the CF is performed by finding “$CO_2$ equivalent emissions” for a 100-year time horizon of a given GHG. In the present study, the GWPs of $CO_2$, $CH_4$ and $N_2O$ in a 100-year time horizon were 1, 25 and 298 (IPCC, 2006). Table 1 describes the emission factors of different sources.

### 2.2. Decoupling analysis

Zhang (2000) first proposed the use of decoupling analysis to handle environmental problems. In 2002, this method was presented as an indicator by the OECD (2002). The notion of decoupling was recognized as an important conceptualization of successful economy-environment integration. We used $D_{CF\text{-}Y}$ for decoupling the CF from crop production and $D_{CE\text{-}PY}$ for decoupling CE from the crop productivity. These indices are computed using Eqs. (2) and (3).

$$D_{CF-Y} = \frac{\%\Delta CF}{\%\Delta Y} = \frac{CF_i/CF_{i-1} - 1}{Y_i/Y_{i-1} - 1} \quad (2)$$

$$D_{CE-PY} = \frac{\%\Delta CE}{\%\Delta PY} = \frac{CE_i/CE_{i-1} - 1}{PY_i/PY_{i-1} - 1} \quad (3)$$

where $CF$, $Y$, $CE$ and $PY$ represent the total CF, total crop production, carbon efficiency and crop productivity, respectively. The superscripts $i$ and $i\text{-}1$ represent the last phase and the base period. $\%\Delta CF$,

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