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Spatio-temporal patterns of energy consumption-related GHG emissions in China's crop production systems

Wei Zhen[a], Quande Qin[a,b,c,*], Yi-Ming Wei[b,c,d]

[a] College of Management, Shenzhen University, Shenzhen 518060, China
[b] Center for Energy & Environmental Policy Research, Beijing Institute of Technology, Beijing 100081, China
[c] School of Management and Economics, Beijing Institute of Technology, Beijing 100081, China
[d] Collaborative Innovation Center of Electric Vehicles in Beijing, Beijing 100081,China

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ABSTRACT

This paper aims to reveal the spatio-temporal patterns of energy consumption-related greenhouse gas (ECR-GHG) emissions in China's crop production systems (CPSs). The relevant crop production data from 31 provinces during 1997–2014 are utilized. In order to fully reflect the energy consumption and ECR-GHG emissions in CPSs, energy balance techniques are adopted from a consumption perspective. The driving factors behind ECR-GHG emissions are identified by means of a Logarithmic Mean Divisia Index analysis at both national and provincial levels. The results are as follows: (1) The yield of China's CPS is not positively correlated with energy consumption, and China's CPS has the relatively high potential to conserve energy and reduce ECR-GHG emissions; (2) Most of China's provinces have experienced enormous growth in ECR-GHG emissions; however there are relatively significant regional disparities; (3) ECR-GHG emissions from CPSs were mostly derived directly from the consumption of chemical fertilizers and diesel oil; (4) Areal productivity is the determining factor in the growth of ECR-GHG emissions, whereas the emission coefficient and energy mix are the main inhibiting factors; (5) Energy intensity has not achieved its full potential to decrease ECR-GHG emissions. This study provides insights into the potential for sustainable crop production in China.

1. Introduction

During the past two decades, China has experienced spectacular economic growth, which has come with high levels of fossil energy consumption (Wang et al., 2014). Significant emissions of major greenhouse gases (GHG), including nitrous oxide (N_2O), methane (CH_4) and carbon dioxide (CO_2), are being released into the atmosphere due to energy consumption (Schneider et al., 2007). China currently ranks as the world's largest GHG emitter now. China has enacted a number of laws and regulations to disaggregate energy savings and emission reductions in each region and industry.

The role of agriculture cannot be underestimated in the context of climate change (Robaina-Alves et al., 2014). China is one of the largest agricultural countries in the world, and its agricultural industry is responsible for approximately 11% of the nation's total GHG emissions (NCCC, 2012). The crop production system (CPS) is the most important production sector in the agriculture industry. In China, this system is now forced to confront the problem of increased dependency on energy sources such as chemical fertilizers, electricity, diesel oil, etc. (Karkacier et al., 2006). Energy consumption in the CPS increased rapidly in response to corresponding increases in population and the limited supply of arable land (Cao et al., 2010; Khoshnevisan et al., 2013b). These factors have encouraged a tendency toward intensive energy use in the CPS, as a means to maximize yield, minimize labor-intensive practices, or both (Esengun et al., 2007; Ghorbani et al., 2011). However, energy consumption leads to adverse environmental impacts, such as increasing the potential for global warming, degrading soil quality, and contributing to water, soil and air pollution (Nemecek et al., 2011a). Among these adverse environmental impacts, issues surrounding energy consumption-related GHG (ECR-GHG) emissions have become particularly prominent over the past two decades (Schramski et al., 2011; Khoshnevisan et al., 2013a, 2013b). The central government has issued practical policies targeted reducing ECR-GHG emissions in CPSs (Wang et al., 2015). In order to achieve effective policy-making it is important to understand the evolution of ECR-GHG emissions and the related driving forces of spatio-temporal patterns in China's CPSs.

In recent years, the issues of ECR-GHG emissions in CPSs have become a hot topic (Nemecek et al., 2011a, 2011b; Pishgar-Komleh et al., 2012; Yousefi et al., 2014; Zhang et al., 2015). These above-

* Corresponding author at: College of Management, Shenzhen University, Shenzhen 518060, China.
E-mail address: qinquande@gmail.com (Q. Qin).

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named studies illustrated that the use of fossil energy increased rapidly, and the related GHG emissions derived from the production and use of fossil energy comprise a major portion of the total emissions of CPSs. These related studies contributed to an understanding of the relationship between energy consumption and the related GHG emissions in CPSs. Due to the imbalanced development of China's CPSs, the spatial and temporal features of ECR-GHG emissions from CPSs must be examined as an important factor for policy-making. Furthermore, previous studies (Liu et al., 2012; Kang et al., 2014; Xu et al., 2014) treated the agricultural sector in a similar manner as other economic sectors in terms of analyzing the factors that influence ECR-GHG emissions. CPSs have certain features that differ from those of other production sectors in terms of ECR-GHG emissions (Margarita and Victor, 2014). Modern crop production is characterized by high inputs of fossil energy types, which are consumed as “direct energy” (the fuel and electricity used on the farm) and as “indirect energy” (the energy used beyond the farm for the manufacturing of fertilizers, plant protection agents, machines, etc.) (Hülsbergen et al., 2001). Previous studies treated CPSs as a common production sector. These studies estimated the ECR-GHG emissions of CPSs by using sector-specific energy consumption data from the Energy Balance Sheet. These data do not account for indirect energy consumption, which may underestimate the ECR-GHG emissions from CPSs. For example, the energy consumption associated with the production of pesticides, agricultural machinery, plastic film and chemical fertilizers was not taken into account in crop production-related emissions. Instead, these processes were accounted for in the various, specific manufacturing industries. Moreover, the agricultural energy consumption data of these studies originated from the Chinese Energy Balance Sheet. These related data include not just farming, but forestry, animal husbandry, fishery and water conservancy. As such, this data cannot accurately reflect the quantity of energy consumption in CPSs. Thus, we believe that previous studies (e.g., Liu et al., 2012; Kang et al., 2014; Xu et al., 2014) did not fully reveal the panorama of energy consumption and ECR-GHG emissions in CPSs.

Examining the driving forces behind ECR-GHG emissions is the key to taking effective energy conservation and GHG reduction measures in CPSs (Sanchez and Stern, 2016). The Logarithmic Mean Divisia Index (LMDI) technique is a widely accepted analytical tool, one which can be used to identify the relative impacts of different factors (Ang, 2005; Ma and Stern, 2008; Mulder et al., 2014; O'Mahony et al., 2013; Xu et al., 2014; Zha et al., 2010; Zhao et al., 2012; Zhang and Da, 2015). The Kaya-Porter identity, an extension of the Kaya identify, was introduced to address GHG emissions from CPSs (Bennetzen et al., 2012, 2016a, 2016b). The Kaya-Porter identity provides an effective tool for understanding the components of GHG emissions from crop production (Bennetzen et al., 2012). In view of the characteristics of China's CPSs, an extended Kaya-Porter identity was applied to quantify and explain the major driving forces of ECR-GHG emissions. In this paper, the final consumption point is used as a basis for estimating ECR-GHG emissions. The energy balance technique developed by Hülsbergen et al. (2001) is also employed to estimate energy consumption and ECR-GHG emissions.

The goal of this study is to conduct an in-depth comparative analysis of the entire nation and 31 provinces based on their ECR-GHG emissions from CPSs during the period 1997–2014 in China. The features of this paper can be summarized as follows: (1) This paper reveals the panorama of energy consumption and ECR-GHG emissions in CPSs to a certain degree; (2) This paper explores the driving forces behind ECR-GHG emissions and investigates regional disparities from the spatial patterns; (3) This paper provides the pertinence policies and suggestions for sustainable crop production development in China. We summarize our contributions as follows: (1) From a consumption perspective, this paper analyzes the evolution of ECR-GHG emissions in China's CPS during the period from 1997 to 2014, and investigates the spacial features of the ECR-GHG emissions from CPSs at the national and provincial level, respectively; (2)A new extended Kaya-Porter identity, which considering the most important factors in China's CPSs, such as chemical fertilizer consumption structures and the energy mix, is proposed; (3) A LMDI decomposition method is employed both national and provincial levels to determine the driving force of ECR-GHG emissions in China's CPSs.

The rest of this paper is organized as follows: Section 2 briefly introduces the methodology in detail. Section 3 describes the data sources. Our research results are presented in Section 4. Policy implications are discussed in Section 5. Finally, we draw our conclusions in Section 6.

2. Methods

2.1. Estimation of energy consumption in CPSs

We estimated the energy consumption in CPSs, taking a consumption-based perspective. In this study, energy consumption was calculated using the energy balance technique described by Hülsbergen et al. (2001), Tzilivakis et al. (2005) and Rathke and Diepenbrock (2006). All fossil energy consumption of agricultural production inputs (APIs) (except for manpower, animal power and solar energy inputs) are included. The total amount of fossil energy of APIs used in a CPS has both direct and indirect components. Direct energy consumption includes the diesel oil used on farms and the electricity used for irrigation. Indirect energy consumption includes the energy used in the production of farm machinery, chemical fertilizers, pesticides and plastic film. The calculation of energy consumption is based on Eq. (1):

$$EC_i^T = \sum_j EC_{ij}^T = \sum_j IT_{ij}^T \times ECC_j \tag{1}$$

where EC_i^T refers to the total energy consumption of a CPS in province i in year T, EC_{ij}^T represents the total energy consumption of API type j in province i in year T, IT_{ij}^T denotes the quantity of API type j in province i and ECC_j refers to the energy conversion coefficient of API type j.

In particular, energy consumption in the production of agricultural machinery was estimated using Eq. (2):

$$EC_{AM_i}^T = \sum_n EC_{AM_{in}}^T = \sum_n AM_{in}^T \times ECC_n \times DR \tag{2}$$

where $EC_{AM_i}^T$ refers to the total energy consumption in the production of agricultural machinery in province i in year T, $EC_{AM_{in}}^T$ denotes the energy consumption in the production process of agricultural machinery n in province i in year T, AM_{in}^T refers to the total quantity of agricultural machinery n in province i in year T, ECC_n represents the energy conversion coefficient of agricultural machinery n, and DR refers to the depreciation rate of agricultural machinery, which was set to 10% (Chen, 2002).

2.2. Estimation of ECR-GHG emissions

In this study, ECR-GHG emissions are given in Eq. (3). The totals include both direct emissions and indirect emissions. ECR-GHG emissions from a CPS, including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), were all converted into carbon dioxide equivalents by multiplying each form of emission by its global warming potential (GWP) parameters, which are 1, 25 and 298 for CO_2, CH_4 and N_2O, respectively (IPCC, 2006).

$$GHG_i^T = \sum_j GHG_{ij}^T = \sum_j IT_{ij}^T \times EF_j \tag{3}$$

In Eq. (3), GHG_i^T represents the total ECR-GHG emissions of a CPS in province i in year T, GHG_{ij}^T refers to the ECR-GHG emissions of API type j in province i in year T, IT_{ij}^T denotes the quantity of API type j in province i, and EF_j refers to the emissions coefficient of API type j.

ECR-GHG emissions caused by the production of agricultural