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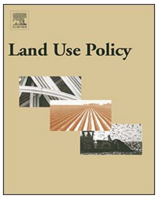

Global arable land transfers embodied in Mainland China’s foreign trade

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ABSTRACT

The process of globalization increases spatial separation of basic resources in terms of demand and supply across multiple countries/regions, thereby leading to the shift of environmental pressure mainly triggered by population expansion and economic growth via global supply chains. To comprehensively analyze Mainland China’s arable land use issues, the present work illustrates its arable land transfers embodied in foreign trade based on a multi-regional input-output analysis. In total, the trade volume of Mainland China’s arable land transfers is revealed in magnitude up to 70% of its direct arable land area. With a distinction between production- and consumption-based transfers, Mainland China exports 27.18 Mha (million hectares) of embodied arable land to other economies, while it imports 48.35 Mha of embodied arable land, making it a large force for agricultural industry development and arable land utilization in regions such as ASEAN, EU27, and Africa. The relations, pressures, and structures of embodied arable land related to Mainland China are clearly depicted from the global perspective. With detailed embodied arable land transfer profiles, it is practical to comprehensively analyze Mainland China’s arable land utilization via supply chains from the global perspective for essential policy implications in reasonably reshaping Mainland China’s economic structures and trade patterns.

1. Introduction

The ever-increasing global food demand, mainly triggered by population expansion and economic growth (Schneider et al., 2011), has exerted great pressure on arable land use, particularly in China (Rulli et al., 2013b; Tilman et al., 2011). Although China has a total land area of some 960 Mha (million hectares) (The State Council of the People's Republic of China, 2008), only about 14.8% is cultivated with field crops and horticultural products (Fan et al., 2013; Qiang et al., 2013). With the largest population in the world, China has only one-third of global average arable land area per capita, being faced with the risk of insufficient food supply, arable land area shrinking, and built-up land occupation (Fischer et al., 1998; Word Bank, 2009).

To guarantee self-food supply, China’s government set a “red line” in the 11th Five-Year Plan to ensure that the total arable land area never shrinks to less than 120 Mha, which is considered the strictest farmland protective policy in the world. However, since global trade flows are expanding with new degrees of connectedness among economies, arable land associated with trade flows shows major implications for the way we conceptualize and explore land use profiles (Huang et al., 2011; Qiang et al., 2013; Tilman et al., 2011). To satisfy food demands, land grabbing, the same as water grabbing through commodity trade, has been deemed as an effective measure to ease land use pressure to some extent (Rulli et al., 2013).

The earliest study of land use embodied in trade dates to 1965, when Borgstrom (1965) proposed the concept of Ghost Acreage to analyze the area of land used to grow plants for other regions. Subsequently, Wichelns and Erb derived the concept of virtual land from virtual water and ecological footprint respectively (Erb, 2004; Wichelns, 2001). Afterwards, Würtenberger et al. (2006) conducted an analysis for the land use hidden in the trade of agricultural products and defined virtual land as the productive areas hidden in imported or exported agricultural goods. The concept was further updated and improved on the basis of the physical accounting by Gerbens-Leenes et al. (2002). Subsequently, a series of studies made contributions to the field of land use accounting with the aid of international food trade data on global (Kastner et al., 2011, 2012; Wilting and Vringer, 2009) and regional scales (Kastner and Nonhebel, 2010; Kissinger and Rees, 2009; O’Brien et al., 2015).

In addition to the above studies, the input-output analysis (IOA) method, originally developed by Leontief (1986), plays a significant role in describing the economic relationship between economies and sectors (Peters and Hertwich, 2008; Yu et al., 2013). It was widely employed for exploring the economic interdependency of different

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economies and was frequently applied to assessing resource and environmental issues through assigning resource flows and environmental impacts to final demand (Chen and Chen, 2010; Peters and Hertwich, 2008). Systems IOA, another accounting method that originated with Leontief's input-output model (Leontief, 1986) together with Odum's ecological and general systems theory (Odum, 1983), was explicitly illustrated by Costanza et al. in the 1980s (Costanza, 1980; Costanza and Herenden, 1984; Herenden, 1974) and rigorously developed to investigate various ecological elements (Chen and Chen, 2013; Chen et al., 2012; Guo et al., 2012; Han et al., 2015b, 2017; Li et al., 2013; Shao and Chen, 2013). The input-output data were also analyzed combined with ecological network analysis to build socio-economic networks (Chen and Chen, 2012a; Chen et al., 2014; Fang and Chen, 2015).

Land use accounting has developed quickly since the end of 20th century, and a number of studies provided insights into China's specific land use embodied in trade (Chen and Han, 2015b; Hubacek and Sun, 2001; Yu et al., 2014; Zhou and Imura, 2011). As a useful tool, IOA was widely adopted for water and land use accounting in different scales, in terms of global (Chen and Han, 2015a; Weinzettel et al., 2013; Yu et al., 2013), national (Guo et al., 2014; Guo and Shen, 2015; Hubacek and Giljum, 2003; Thormark, 2002), and urban scales (Han et al., 2015a; Li and Chen, 2014; Liu et al., 2017). Among these studies, Chen and Han (2015b) studied China's land-related issues based on time series land use data and input-output tables. Yu et al. (2013) and Weinzettel et al. (2013) elaborated on the land use displacement around the world, showing the great significance of global land use assessment. Based on the global multi-regional input-output database, further studies were conducted to shed light on global arable land relations with complex global supply chains (Chen and Han, 2015a; Marselis et al., 2017).

Existing studies on land resources accounting contributed comprehensively, but the analyses on economies' embodied arable land transfers, particularly the trade pressures and structures, are still lacking. Even though overall effects on land use by international trade were preliminarily estimated, the concrete resolution of land use in terms of global supply chains remains to be explored. To fill the gap, a systematic analysis on China's arable land use regarding global supply chains is to be comprehensively performed with a deep understanding of trade relations, pressures, and structures between Mainland China and the rest of the world.

In this context, this study conducts an embodiment analysis on Mainland China's arable land use profiles based on the multi-regional IOA method. To the best of our knowledge, this work is so far the most comprehensive embodiment analysis on embodied arable land's trade relations, pressures, and structures in Mainland China, attempting to form a better understanding of arable land use profiles from a global perspective. The remainder of the paper proceeds as follows: Section 2 articulates the method employed in this study; Section 3 analyzes the detailed results; Section 4 discusses the policy implications; and Section 5 draws the conclusion.

2. Method and materials

To quantify and analyze the embodiment of resources in different economic activities, input-output tables, in particular multi-region input-output tables, are well-employed for exploring economic interdependency of different economies and frequently applied to assess human induced energy and environmental issues, including energy consumption (Chen and Chen, 2013; Xia et al., 2017), greenhouse gas emissions (Chen et al., 2013; Peters and Hertwich, 2008; Shao et al., 2016), water use (Chen and Chen, 2012b; Lenzen et al., 2013a), and land displacement (Chen and Han, 2015a; Weinzettel et al., 2013; Yu et al., 2013). Based on multi-regional input-output tables, the method applied integrates ecological endowments into economic networks based on the physical balance of resources use to reveal the resources profiles associated with economic flows.

The extended multi-regional input-output table, profiling both monetary and resources flows of the global economy, is divided into m regions, each with n sectors, as presented in Appendix Table A.1 in Supplementary material. Here, Mainland China is one of the economies among the 189 economies in this study.

For the global economy, the physical balance for resources use of Sector i in Region r requires:

$$u_i^r + \sum_{s=1}^{m}\sum_{j=1}^{n} \varepsilon_j^s z_{ji}^{sr} = \varepsilon_i^r x_i^r \tag{1}$$

where u_i^r denotes the direct utilization of resources into economic Sector i in Region r, ε_j^s denotes the embodied intensity of Sector j in Region s, z_{ji}^{sr} denotes the output from Sector j in Region s for intermediate input to Sector i in Region r, and x_i^r denotes the gross output of Sector i in Region r given as:

$$x_i^r = \sum_{s=1}^{m}\sum_{j=1}^{n} z_{ij}^{rs} + \sum_{s=1}^{m} f_i^{rs} \tag{2}$$

where f_i^{rs} denotes the output from Sector i in Region r for the final demand of Sector i in Region s.

The diagram of physical balance of resources use in Sector i in Economy r is presented in Fig. 1.

Introduce the following denotations of

$$\mathrm{U} = \begin{bmatrix} \begin{pmatrix} u_1^1 \\ \vdots \\ u_n^1 \end{pmatrix} \\ \vdots \\ \begin{pmatrix} u_1^m \\ \vdots \\ u_n^m \end{pmatrix} \end{bmatrix} \quad \mathrm{E} = \begin{bmatrix} \begin{pmatrix} \varepsilon_1^1 \\ \vdots \\ \varepsilon_n^1 \end{pmatrix} \\ \vdots \\ \begin{pmatrix} \varepsilon_1^m \\ \vdots \\ \varepsilon_n^m \end{pmatrix} \end{bmatrix} \quad \mathrm{Z} = \begin{bmatrix} \begin{pmatrix} z_{11}^{11} & \dots & z_{1n}^{11} \\ \vdots & \ddots & \vdots \\ z_{n1}^{11} & \dots & z_{nn}^{11} \end{pmatrix} & \cdots & \begin{pmatrix} z_{11}^{1m} & \dots & z_{1n}^{1m} \\ \vdots & \ddots & \vdots \\ z_{n1}^{1m} & \dots & z_{nn}^{1m} \end{pmatrix} \\ \vdots & \ddots & \vdots \\ \begin{pmatrix} z_{11}^{m1} & \dots & z_{1n}^{m1} \\ \vdots & \ddots & \vdots \\ z_{n1}^{m1} & \dots & z_{nn}^{m1} \end{pmatrix} & \cdots & \begin{pmatrix} z_{11}^{mm} & \dots & z_{1n}^{mm} \\ \vdots & \ddots & \vdots \\ z_{n1}^{mm} & \dots & z_{nn}^{mm} \end{pmatrix} \end{bmatrix}, \text{and}$$

$$\hat{X} = \begin{bmatrix} \begin{pmatrix} x_{11}^{11} & \dots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \dots & x_{nn}^{11} \end{pmatrix} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \begin{pmatrix} x_{11}^{mm} & \dots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \dots & x_{nn}^{mm} \end{pmatrix} \end{bmatrix}.$$

The above equation thus can be expressed in a matrix form as:

$$U + EZ = E\hat{X} \tag{3}$$

With the direct inputs matrix U, intermediate inputs matrix Z, and

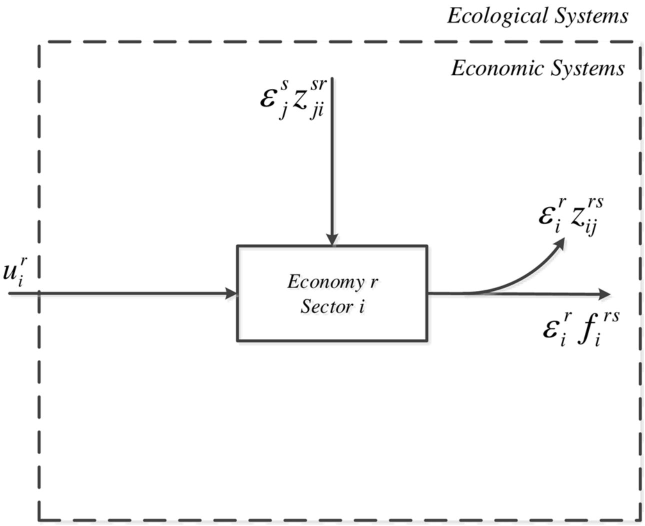

Fig. 1. Physical balance of resource use.