Land Use Policy 76 (2018) 201–214

Contents lists available at ScienceDirect

Land Use Policy

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

An overview of arable land use for the world economy: From source to sink via the global supply chain

X.D. Wu[a], J.L. Guo[a,1], M.Y. Han[b,c], G.Q. Chen[a,*]

[a] Laboratory of Systems Ecology and Sustainability Science, College of Engineering, Peking University, Beijing 100871, PR China
[b] Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, PR China
[c] Key Laboratory of Regional Sustainable Development Modeling, Chinese Academy of Sciences, Beijing 100101, PR China

ARTICLE INFO

Keywords:
Arable land use
Embodiment accounting
Primary inputs
Source
Sink
Trade imbalance

ABSTRACT

As an extension of a previous work (Chen and Han, 2015a), this study explored the arable land use of the world economy from source of exploitation to sink of final consumption via the global supply chain, by means of embodiment accounting that includes the indirect feedbacks associated with both intermediate and primary inputs. In magnitude, the global transfer of arable land use is estimated to be around 40% of the total direct exploitation. The connections as well as imbalances of major economies in intermediate and final trades of arable land use are discussed. Canada, Australia, Argentina, Pakistan and African regions turn out to have a massive deficit of arable land use in both intermediate and final trades. In contrast, the United States, Japan, Mainland China, the United Kingdom, Germany and France obtain a surplus of arable land use in both intermediate and final trades by land displacement in those net exporters. Indices in terms of arable land use self-sufficiency rate by source and that by sink are devised. For India as the biggest source region, around 20% of the arable land resources exploited locally are for final consumption abroad. For the United States as the largest sink region, around 40% of its arable land use originates from foreign regions led by Canada. For Japan as the biggest net importer in both intermediate and final trades, over 90% of its arable land use comes from foreign economies led by African and Asian regions. For sustained development, regions are suggested to be more adapted to the global supply chain based on their behaviors in both intermediate and final trades of arable land use.

1. Introduction

Arable land, defined as land suitable for growing crops (OxfordDict, 2018), remains the precondition for delivery of food that feeds all humans. Arable land has been entitled as “mother” in some eastern countries such as China and India that were rooted on agricultural foundation since ancient times (Long, 2014). Similarly, in some western country like France, physiocrats such as Franois Quesnay and Anne Turgot have attached supreme importance to arable land by regarding agriculture as the sole source of the wealth of nations (Quesnay, 1758; Turgot, 1793).

Nowadays arable land use has been greatly threatened. The world is changed along with the overwhelming wave of urbanization and booming population. Much that once was is gone. According to Cameron et al. (2015), the world's arable land area has encountered a drastic decline by one-third during the last four decades, due to soil erosion, chemical and physical deterioration, desertion and encroaching human inhabitation (Hubacek and Sun, 2001; Lasanta et al., 2017; Weinzettel et al., 2013). Currently, a number of policies have been implemented worldwide for purposes of sustainable use of arable land resources, such as the red line set in the *Eleventh Five-Year Plan of China* that regulates the minimum (180 million hectares exactly) of domestic total arable land area (StateCouncil, 2006), the *Common Agricultural Policy* in the European Union (Grant, 1997) and *Soil and Water Resources Conservation Act* (USC, 1977) in the United States.

Nevertheless, a local perspective is mostly adopted in these policy packages to view the arable land use of a region. In fact, within the globalized world, interregional trade not only transfers good or services from one region to another, but could become an effective means for a region to invisibly acquire arable land use from other areas. As the sliced-up global supply chain leads to the separation of production and consumption (Dunford, 2017; Dunford et al., 2016; Meng et al., 2016), one region may enjoy the welfare denoted by land resources via importing massive land-intensive goods or services from regions outside its territorial border, which is sometimes referred to as “land grab” (Cecilie and Anette, 2010; Gorgen et al., 2009). For those developed

* Corresponding author.
E-mail address: gqchen@pku.edu.cn (G.Q. Chen).
[1] The author contributed equally as the 1st author.

https://doi.org/10.1016/j.landusepol.2018.05.005
Received 28 February 2018; Received in revised form 5 May 2018; Accepted 5 May 2018

economies with affluent lifestyles, the consumption-oriented development mode is associated with a heavy dependency on both domestically-manufactured as well as foreign goods or services to fulfill the residential demands. As a result, a burden is placed on both their domestic and foreign arable land resources (Verhoeve et al., 2015). For instance, according to Yu et al. (2013), the land use hidden in the imported commodities of Japan is in magnitude several times as much as Japan's direct land exploitation.

With the virtual shrinking of spatial distances and accelerating instant communication, this interregional transfer of arable land use will become more frequent since all world regions are being integrated into a united organism (Han and Chen, 2018). The production model of iPhone may be an illuminating example, which makes full use of the global supply chain to integrate the resources and technology all over the world. Currently, iPhone has several hundred suppliers for its elements all over the world (Apple, 2018; Chen et al., 2017; Minasians, 2017): R&D department in the United States is in charge of the product design; manufacturers in Japan are in charge of the production of major parts; corporations in Korea supply electronic chips; producers in Singapore, Malaysia, Thailand and Philippines provide back-end components; Foxconn factories in Mainland China assemble iPhone products and ship it to the United States for online sales to the world consumers. Therefore, in order to have a deep understanding of the arable land use of a region, it is necessary to put all world regions in the global context to explore the panorama of the trade connections between them in terms of arable land use transfer.

The academic history of virtual land transfer in trade may be traced back to 1965 when Borgstrom (1965) raised the notion of “Ghost Acreage” to describe the cropland use induced to produce the traded agricultural products. Later in 1996, the concept of ecological footprint was introduced by Wackernagel and Rees (1996) to analyze the bioproductive area of land that is directly and indirectly required to sustain the resource consumption of a region, which has been widely applied in subsequent studies (Erb, 2004; McDonald and Patterson, 2004; Wackernagel et al., 1999; van den Bergh and Verbruggen, 1999). As pointed out by some scholars, the ecological footprint is a highly aggregated indicator by putting the different kinds of resources into a unified measurement (Qiang et al., 2013). Besides, the interdependency between the economic activities finds no reflection in the ecological footprint accounting (Wiedmann et al., 2006). Hence, other concepts termed as “virtual land” (Würtenberger et al., 2006) and “land displacement” (Meyfroidt and Lambin, 2009) have been proposed to specifically analyze the land use embedded in interregional trade, which have been extensively applied for economies on different scales (Chen and Han, 2015b; Guo and Shen, 2015; Hubacek and Sun, 2001; Meier et al., 2014; Meyfroidt et al., 2010; Verhoeve et al., 2015; Wilting and Vringer, 2009). Especially, by introducing global multi-regional input–output (MRIO) tables that have been in recent years unveiled for the world economy, a number of studies have been carried out to trace the interregional transfer of virtual land though the global supply chain (Weinzettel et al., 2013; Wilting and Vringer, 2009; Yu et al., 2013), which reveal the remarkable amount of land use embedded in trade. According to Weinzettel et al. (2013), the land displacement through international trade was estimated to be strikingly in magnitude up to around a quarter of the global land use of the world economy in 2004.

These global studies have contributed greatly to increasing our knowledge on interpreting the arable land use embedded in the interregional trade flows, while they do not distinguish the arable land use embodied in intermediate trade and that in final trade. Statistics by Johnson and Noguera (2011) have highlighted the dominant role played by intermediate trade, which accounts for over two-thirds of the global total trade volume. In view of this, by means of the embodiment accounting supported by multi-regional input–output accounts, Chen and Han (2015a) have for the first time directed equal attention to arable land use embodied in trade of intermediate products (namely goods or services used for production activities) as well as that embodied in trade of final products (namely goods or services used as final demand). The results reveal that global total trade volume of arable land use is in magnitude equivalent to around one-third of global total arable land use, while intermediate trade volume of arable land use is twice as much as the final trade volume. The products used as final demand are regarded as sinking into the society in the work by Chen and Han (2015a), which does not take into consideration of the external feedback from the society to the economic system. For the world economy, final demand not only includes consumptive activities including household consumption, government consumption, and consumption of non-profit organization serving household, but also covers fixed capital formation, changes in inventories, and valuables acquisition. Those that could be treated as the sink of arable land use are the goods or services used for final consumption (including household consumption, government consumption, and consumption of non-profit institutions serving households), which are supposed to be “consumed” and ultimately leave the economic system (Chen and Chen, 2013a). While for the products used as the rest of final demand (final demand excluding final consumption), they are capital goods that will get back into the economy as primary inputs in support of economic production (Marx, 1867; Bullard and Herendeen, 1975b). Bullard and Herendeen (1975b) have made preliminary attempts to include indirect feedback associated with capital goods when undertaking embodied analysis for the United States economy. Similarly, regarding arable land use accounting of the world economy, apart from the indirect feedback associated with intermediate inputs, due attention shall be paid to arable land use embodied in the capital goods that will enter the economy in the form of primary inputs.

As an extension of a previous work (Chen and Han, 2015a), this study analyzes the interregional transfer of arable land use from source of exploitation to sink of final consumption for the world economy by using typical statistics. By incorporating the indirect feedbacks associated with both primary and intermediate inputs, an embodiment accounting model is developed from the one in the previous study. Arable land use embodied in interregional trade is presented, with intermediate and final trade imbalances being discussed in detail for major economies.

2. Methodology and data source

2.1. Embodiment accounting

By integrating the embodiment theory in systems ecology by Odum (1983, 1995) into the biophysical balance model raised by the energy research group (Bullard, 1975; Bullard and Herendeen, 1975; Hannon et al., 1983; Herendeen, 1973, 1974, 1978, 1981, 2004) in the University of Illinois, Chen and his colleagues have generalized the embodied energy accounting to embodiment accounting, which has become a well-established tool in tracking the ecological endowments such as energy use (Chen and Chen, 2011c; Wu and Chen, 2017b, 2018), land use (Chen and Han, 2015b; Chen et al., 2018; Han and Chen, 2018), water use (Chen and Chen, 2013b), carbon emissions (Chen and Chen, 2011a,b; Chen and Zhang, 2010; Zhang and Chen, 2010) and mercury emissions (Chen et al., 2016; Li et al., 2017), embodied in interregional trade flows within the world economy.

For the world economy as simulated by the global MRIO account, it is regarded to be consist of m world regions with each region comprised of n economic sectors, as presented in Table 1. The embodiment accounting model developed in this study for the world economy and the one in the previous work are both illustrated in Fig. 1. For the embodiment accounting model raised in the previous work, the biophysical balance for an economic sector is that resource use embodied in the sectoral output is equal to the sum of resource use embodied in the goods or services used as intermediate inputs into this sector plus the exogenous resource inputs from the environment, just as illustrated in Fig. 1(a). While the exogenous resource inputs coming from the