https://doi.org/10.1016/j.landusepol.2018.12.031

Embodied pasture land use change in China 2000-2015: From the perspective of globalization

Shan Guo[a], Li Jiang[b,1], Geoffrey Q.P. Shen[c,*]

[a] *Department of Land Management, School of Public Administration and Policy, Renmin University of China, Beijing, China*

[b] *School of Applied Economics, Renmin University of China, Beijing, China* [c] *Department of Building and Real Estate, The Hong Kong Polytechnic University, Hong Kong, China*

Abstract

Rapid population increase, urbanization, and dietary changes present an increasing requirement for pasture lands for food processing in China. Globalization increases worldwide economic links. The displacement of pasture lands from one place to another occurs when goods are traded among industries and regions, thereby shifting pressures on local pasture land resources. This paper applies a systems input–output model to examine how pasture lands in China are used to meet the demands of domestic consumption and international trade over the period of 2000–2015. Agriculture and Food Processing were the two major sectors that contributed to the largest volume of embodied pasture land for fulfilling household demands in 2015. Although the total consumption-based pasture land use in China is fluctuating, embodied pasture land intensities exhibited a decreasing trend in 2000–2015, thereby showing the effort of China to improve pasture land use efficiency. Regarding trade patterns, the Agriculture sector is the largest net importer of pasture lands in China, while the Garment sector is the largest net exporter. We also find that China is a net exporter of embodied pasture lands through the study period. This systematic analysis of pasture land use in China is critical in customizing and prioritizing policy recommendations for sustainable pasture land management in China.

1. Introduction

As China is urbanized, globalized, and industrialized, its land use issues have elicited considerable attention, particularly in the remarkable economic growth period since the reform and opening up of this country (Li et al., 2017; Wu et al., 2017a). With approximately 34% of agricultural lands in China dedicated to livestock production, pasture land is an important resource that can be used to complement the land requirements for food production (Weindl et al., 2017). Despite efforts to address this problem, pasture land degradation continues to occur in China due to overgrazing, urban land expansion, misuse for farming, and the unregulated collection of fuel and herbal plants (Chuai et al., 2016). Increasing food demand due to rapid urbanization and globalization has raised a lot of concerns with respect to protecting pasture lands in China (Bai et al., 2004; Huang et al., 2017; Kang et al., 2007; Lin and Ho, 2003). Urbanization in China makes diets become increasingly various, represented by an increase of meat and dairy products (Delgado, 2003; Popkin, 1999). This dietary change is likely to lead to a significant increase in pasture land requirements. Due to pasture land degradation and increasing land demands, several direct strategies for pasture land protection, such as appropriate pasture management and grazing principles, have been implemented in many countries or regions worldwide (Dorrough et al., 2004; Sanderson et al., 2004). For example, European Union Rural Development Policy encouraged appropriate grazing patterns and paid attentions on the farming system with high ecological values (Plieninger et al., 2015). However, such direct strategies may become less effective in protecting pasture land use under globalization because the global interconnectedness and interdependence of various economies can transfer local pasture land use pressure to other economies (Lambin and Meyfroidt, 2011; Rulli et al., 2013). Pasture land protection in China has become a more complexed issue with the accelerated globalization of the economy. Despite the importance of this issue, there has been no study that focuses on pasture land protection in China in the context of globalization. To fill this literature gap, the current study analyzes sustainable pasture land use in China under the setting of economic globalization.

To examine the influence of globalization on pasture land sustainable utilization and management, the concept of “embodied pasture land” is presented to determine the total (including direct and indirect) pasture land required for the complete production process of goods or services by tracing back the entire supply chain (Würtenberger et al., 2006). This concept can be used to measure the displacement of pasture land pressure from one place to another when trading activity occurs. The earlier studies on land use embodied in trade could be dated back to the proposition of the concept of Ecological Footprint, which is defined as the total productive land required to produce all the resources consumed by human beings around the globe (Rees, 1992, 1996). Afterward, the concept was further improved to depict the causal relationship of consumption and land use occupation, which is termed as embodied land (Würtenberger et al., 2006). A large body of literature focuses on the embodied land use in various regions have emerged (Chaudhary and Kastner, 2016; Infante-Amate et al., 2018; Saikku and Mattila, 2017). However, studies on the specific land use category, especially pasture land, considering the different attributes of land utilization types are insufficient.

To calculate embodied pasture land use in China, input-output analysis (IOA) is adopted in this study. IOA is a well-developed methodology that enables resource flows to be allocated to the final user by tracing an interconnected economic network (Leontief, 1970). Based on biophysical balance, this methodology provides a powerful tool that quantitatively calculates embodied resource flows by sector. Numerous studies have contributed to the knowledge of resource utilization and environmental emissions based on IOA (Chen et al., 2013; Guo and Shen, 2014; Lenzen, 2009; Meng et al., 2018b; Su and Ang, 2014; Wang et al., 2018; Wiedmann et al., 2007). This approach is widely implemented in land use at the global, national, regional, and organizational scales, which indicates its significance in policy implications (Chen and Han, 2015; Han and Chen, 2018; Meng et al., 2018a; Wu et al., 2018). Based on this method, further efforts are required to understand global socioeconomic and

China's pasture land interconnections in order to develop sustainability solutions (Liu et al., 2015).

The present study aims to systematically explore sustainable pasture land use in China from the perspective of "embodied land", given the complexed globalized economic network of the country. Emphasis is placed on an embodiment analysis of pasture land use in China relying on time series input-output data and high sectoral resolution. Based on the results of this analysis, we intend to demonstrate how pasture lands in China are used to meet the demands of domestic consumption and international trade over the period of 2000–2015 and provide relevant policy implications.

2. Methodology and data

2.1. *Algorithm*

This paper applied a systems input-output model to account China's embodied pasture land flows along the global supply chains. The ecological input-output model was theorized and developed based on Leontief's earlier input-output work in the 1970s, for which he was awarded a Nobel Prize (Leontief, 1970). Then based on the biophysical balance, the systems input-output model was developed to calculate the sectoral embodied pasture land flows along with the economic flows. Integrating direct pasture land flows and economic flows, an ecological input-output table is an important tool for analyzing the embodied pasture land hidden behind the interconnected economic network system.

The symbols in the systems input-output table (Table 1) are defined as the followings: z_{ij} = Inter-sector economic flows from Sector i to

Sector j; x_j = Total output value of Sector j; f_j = Final consumption of Sector j; e_{xj} = Export value of Sector j; l_j = Direct pasture land use by Sector j; ε_j = Embodied pasture land intensity of Sector j.

Embodied pasture land intensity is defined as the sum of direct and indirect pasture land use required for the complete production process of per unit of goods or services. Based on the biophysical balance for the pasture land flows hidden behind the economic flows, the formula can be derived as below based on the systems IO table (as shown in Table 1).

$$\varepsilon_j x_j = \sum_{i=1}^{n} \varepsilon_i z_{ij} + l_j, \quad (1)$$

Then, the matrix form of Eq. (1) can be formulated as

$$\boldsymbol{\varepsilon X} = \boldsymbol{\varepsilon Z} + \boldsymbol{l} \quad (2)$$

$\boldsymbol{l} = [l_j]_{1\times n}$, the direct pasture land use matrix;

$\boldsymbol{\varepsilon} = [\varepsilon_j]_{1\times n}$, the embodied pasture land intensity matrix;

$\boldsymbol{Z} = [z_{ij}]_{n\times n}$, the intermediate input matrix;

$\boldsymbol{X} = [x_{ij}]_{n\times n}$, in which $i, j \in (1, 2, ..., n)$, $x_{ij} = x_j$ $(i = j)$ and $x_{ij} = 0$ $(i \neq j)$., the total output matrix.

Based on the above derivation, the embodied pasture land intensity could be formed as

$$\boldsymbol{\varepsilon} = \boldsymbol{l}(\boldsymbol{X} - \boldsymbol{Z})^{-1} \quad (3)$$

Embodied pasture land flows in consumption and trade activities are calculated according to the above embodied pasture land intensity database. The implications and calculations of embodied pasture land in production, consumption, import, export, and trade balance are explained in the followings.

For the embodied pasture land in production and consumption activities, this study calculates production-based and consumption-based pasture land use. Production-based pasture land use could be defined as the direct pasture land use happened in the production process, which is widely used in pollution emission and resource usage accounting during the recent past years, expressed as EPLP (Chen and Zhang, 2010). Consumption-based pasture land use is the total, including direct and indirect, pasture land use related to consumption activities (Cadarso et al., 2012), which is the pasture land occupied along the chains of the production process and the whole supply chain and finally allocated to the final consumers, notated as EPLC.

The production-based and consumption-based pasture land can be formulated as

$$EPLP_j = l_j \qquad (4)$$

$EPLC_j = \varepsilon_j f_j$ (5) $\boldsymbol{f_j}$ = final consumption from Sector j.

To reflect the trading pattern in terms of pasture land resources, embodied pasture land in imports (EPLI), embodied pasture land in exports (EPLE), and the difference between EPLE and EPLI, i.e., embodied pasture land trade balance (EPLB) (Chen and Chen, 2011) are regarded as important indicators. These three indicators can be calculated as

$\sum \varepsilon_j i_{mj}$ $EPLI_j =$(6)

$\sum \varepsilon_j e_{rj},$

$-$ $EPLE_j =$(7)

$EPLB_j = EPLE_j\ EPLI_j$, (8) i_m = imports from region m.

2.2. *Data sources*

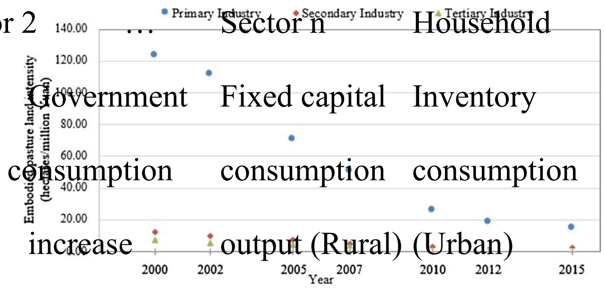
China's land use data have been released by the former Ministry of Land Resources since 1999. China has launched two national land surveys since 1984 and was preparing for the third land use survey since 2017. The first land survey was started in May 1984 and ended at the end of 1997. The long delay for this land survey was because of the limited supported funds and lack of awareness of basic land surveying work. The second land survey was started in July 2007 and ended in

Table 1

The basic structure of the systems input-output table.

Input		Intermediate use			Final consumption
Intermediate inputs	Sector 1	z11	…	z1n	f1
	Sector 2	…	…	…	…
	…				
	Sector n	zn1	…	znn	fn
Direct pasture land use		l1	…	ln	

Output	Sector 1	Sector 2	…	Sector n	Household consumption (Rural)	Household consumption (Urban)	Government consumption	Fixed capital formation	Inventory increase	Export	Total output



2009. In other years, land change survey was launched yearly to make a fine adjustment. The land use data limitation is the constant adjustment of statistical coverage of land use data.

Specific reports related to land use data include China Communiqué of Land and Resources (1999–2016), China Land & Resources Almanac (1999–2012), and China Land and Resource Statistical Yearbooks (2005–2016). China's pasture land use data during 2000–2015 applied in this paper are sourced from China Communiqué of Land and Resources and China Land and Resource Statistical Yearbooks to make sure the data integrity.

The National Statistical Bureau of China publishes national inputoutput tables every five years. To date, there are twelve official inputoutput tables for China in total, including the input-output tables for 1987, 1990, 1992, 1995, 1997, 2000, 2002, 2005, 2007, 2010, 2012 and 2015. The new official input-output table was compiled at the years ending with 2 and 7 (like 1987 and 1992). Based on each original IO table, the extended IO table was completed after 3 years (like 1990 and 1995). With the input-output table and pasture land use data in China, we conduct a comprehensive time-serial study on embodied pasture land use change in China for the period of 2000–2015. We use the indicator of GDP deflators to adjust price level to the baseline year of 2000 (Table A1).

The data limitations related to economic data is the late availability of IO tables since it is very time-consuming of compiling IO tables by collecting a great amount of original economic data and making the complex and highly accurate model. In this study, the latest available IO tables for 2000–2015 have been used to analyze China's time-serial embodied pasture land use.

3. Results and discussions

3.1. *Time series analysis*

3.1.1. *Temporal change in efficiency*

Fig. 1 shows the embodied pasture land intensities between 2000 and 2015. The embodied intensities during the 15-year period generally show a downward trend, which declines from 22.53 hectares/million Yuan to 2.24 hectares/million Yuan. However, the average annual decrement rate decreases from 2.37 hectares/million Yuan to 0.12

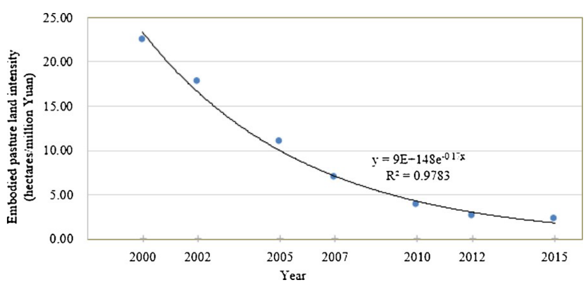


Fig. 1. Embodied pasture land intensity.2000–2015.

ex1 x1

… …

exn xn

Fig. 2. Embodied pasture land intensity by three major industries.2000–2015.

hectares/million Yuan. It is expected that the potential of increasing efficiency through pasture land protection is moderately limited in the future. Therefore, there is a great challenge for the

Chinese government to develop a sustainable pasture land management mode considering trade and consumption structure upgrade.

The changes in sectoral embodied pasture land intensity in China in 2000–2015 are illustrated in Fig. 2. This indicates that the embodied pasture land intensity of the primary industry declines substantially from 123.90 hectares/million Yuan to 15.01 hectares/million Yuan. This reduction can be attributed to the improved efficiency associated with pasture land use of the livestock industry. The embodied pasture land intensities of the secondary and tertiary industries are significantly low, decreasing slightly from 12.13 hectares/million Yuan to 1.89 hectares/million Yuan and from 7.35 hectares/million Yuan to 0.84 hectares/million Yuan. The intra-industry comparison reveals that the three major industries significantly differ in 2000. The variance decreases in the following years mainly because of the technical innovations adopted by the livestock industry. These new technologies substantially increase the efficiency of China's pasture land use in the livestock industry. However, the reduction in the secondary and tertiary industries is limited.

3.1.2. *Temporal change in trade pattern*

Considering the temporal change in trade pattern, China is a net exporter of pasture land in 2000–2010 (as shown in Fig. 3), thus demonstrating that China is a pasture land supplier for the globalized economy. China's EPLB significantly varies in 2000–2010, and the

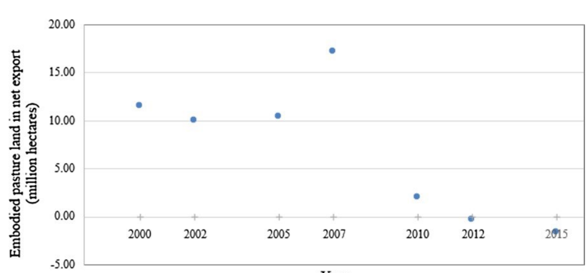


Fig. 3. Embodied pasture land in trade balance.2000–2015.

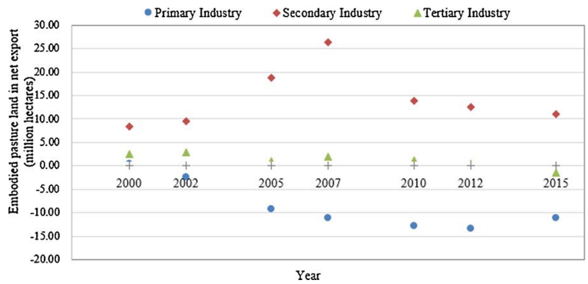


Fig. 4. Embodied pasture land in trade by three main industries.2000–2015.

largest EPLB of 17.24 million hectares is obtained in 2007. The fluctuation is likely due to the change in China's international trade pattern, particularly for dairy products. Nevertheless, this instability reached a trade balance position in 2012, and China became a net importer in 2015, as the import of dairy products had been increasing at an annual increasing rate of 42% since 2009.

The embodied pasture land in trade for three main industries demonstrates a large difference as shown in Fig. 4. The changing trend of embodied pasture land in trade by three main industries is similar to that of pasture land: the primary industry was a net exporter in 2000, and changed to a net importer during 2002–2015 because of the high demand for dairy products brought about by rapid urbanization, rising incomes, and westernization of diets. Embodied pasture land in net export of secondary industry sharply rose from 2002 to 2007, and then it significantly decreases after 2007. This phenomenon can be attributed to the fast industrialization of China and a large number of exports of manufactured goods. However, the environment-friendly manufactured products are currently undergoing an encouraging reduction in the secondary industry's net export. The tertiary industry maintains a trade balance during the concerned years, and this balance can be attributed to its property of not being a pasture resource-intensive industry.

3.1.3. Consumption-based embodied pasture land use The production- and consumption-based embodied pasture land in 2000–2015 is presented in Fig. 5. The pasture land area in China decreases by 16.84% from the 2000 year (263.85 million hectares) to the 2015 year (219.42 million hectares). China's pasture area is an important driving factor, which makes China the fourth largest producer of cattle and the largest producer of sheep (CAY, 2018; Wirsenius et al., 2010). The Chinese government has formulated a variety of programs to prevent grass degradation.

The consumption-based embodied pasture land flows slightly increase from the 2000 year (244.27 million hectares) to the 2005 year (262.15 million hectares), then it sharply decreases in the 2010 year (202.81 million hectares), and it slightly increases in 2015 (222.85 million hectares). The change is mainly attributed to the structural adjustment of consumption and the trading of dairy products. The consumption-based pasture land use is basically smaller than the

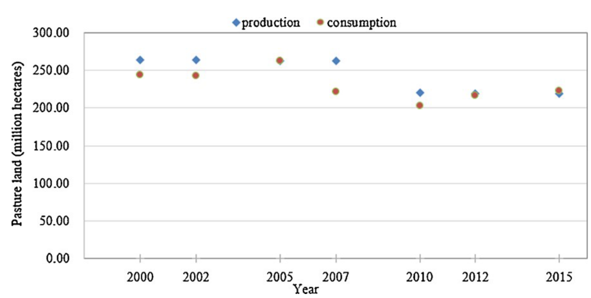


Fig. 5. Production-based versus consumption-based embodied pasture land use.2000–2015.

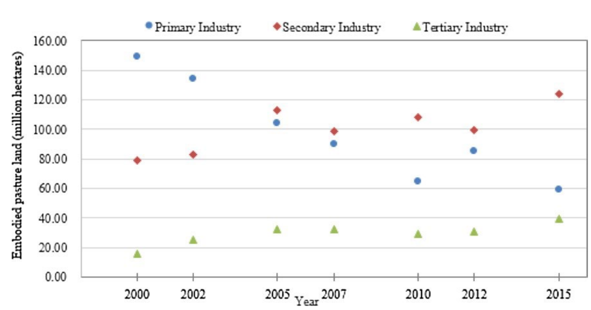


Fig. 6. Consumption-based embodied pasture land use by three major industries.2000–2015.

production-based pasture land use in 2000–2015, but the trade balance could be observed in 2005, 2012 and 2015. This suggests that China has suffered the consequences for paying a high pasture land resource cost to satisfy consumption outside its boundary previously. However, with great efforts in protecting the environment and ecology, we expect that the situation of sacrificing resources will be alleviated significantly.

From the perspective of consumption (see Fig. 6), the primary industry takes advantage of the largest EPLC in 2000–2002. However, EPLC by the secondary industry overtakes the primary industry in 2005 because of China's rapid urbanization process. Beginning in 2010, the secondary industry decreases and the primary industry starts to increase. This phenomenon may be attributed to the increasing demand for dairy products caused by the rising incomes and westernization of diets. The tertiary industry's (or service industry's) EPLC shows a fluctuation in growth, but there is a gap between the tertiary industry and the primary and secondary industries. Service industries are often regarded as "non-material" and "environment-friendly" (Fourcroy et al., 2012; Smith, 2005), but they still occupy pasture land indirectly through interregional trade (Ge and Lei, 2014). They would be paid more attentions in the future with the development of service industries, though there is still a gap between the service industry and other industries.

3.2. *Industrial analysis*

3.2.1. *Intensity*

Fig. 7 presents the industrial embodied pasture land intensities in China in 2015. The detailed sectoral or industrial classification is displayed in Table A2. The largest embodied pasture land intensity appears in Sector 1 (Agriculture) with the value of 25.93 hectares/million Yuan, followed by Sectors 6 (Food Processing), 7 (Textile Industry), and 31 (Hotels, Catering Service) with the intensities of 13.24, 10.15, and 7.66 hectares/million Yuan. These four sectors are directly bound up with the necessities of daily living and are highly correlated with dairy products. The average pasture land intensity of primary industry is 8

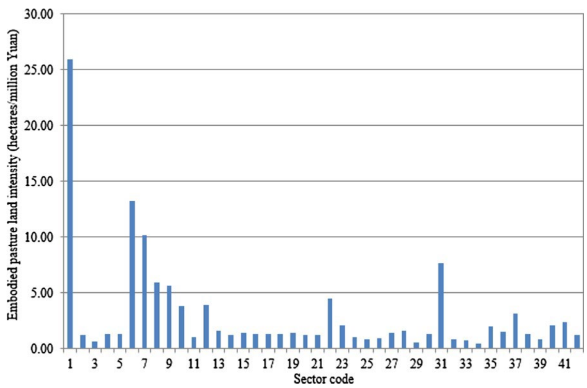


Fig. 7. Embodied pasture land intensity by sector in 2015.

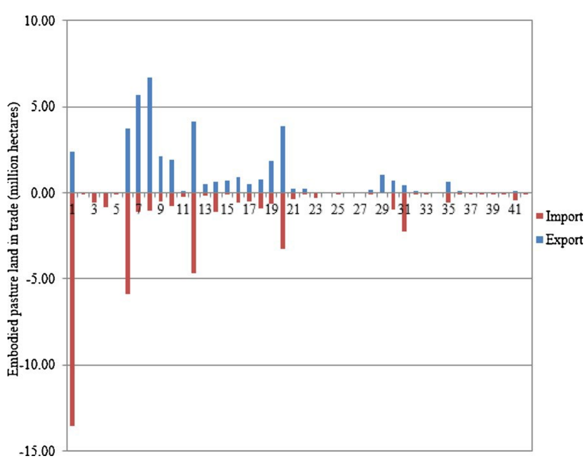


Fig. 8. Embodied pasture land in trade by sector in 2015.

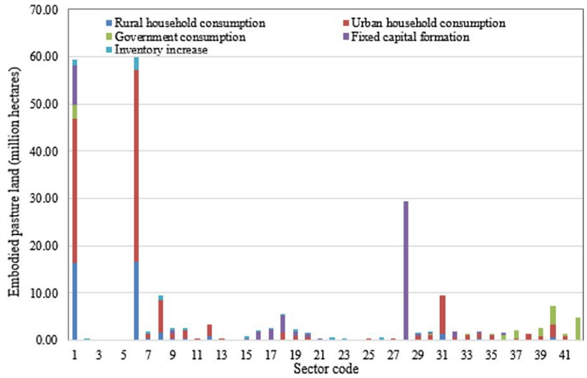


Fig. 9. Embodied pasture land in consumption by sector in 2015.

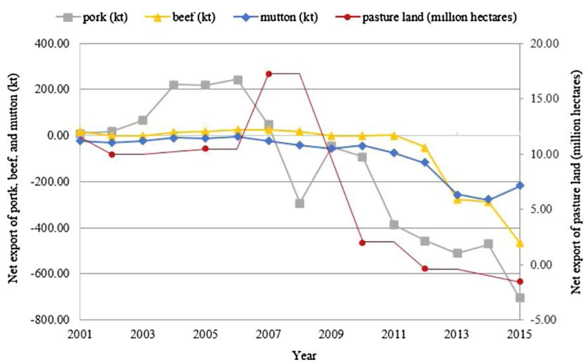


Fig. 10. Net export of pasture land, pork, beef, and mutton.

times greater than that of secondary industry and 18 times greater than that of tertiary industry. The enormous between-industry difference indicates that the industrial and consumption structure adjustments significantly impact the sustainable pasture land use management in China.

3.2.2. *Trade*

Fig. 8 presents China's embodied pasture land distribution in trade in 2015. For EPLI, Sector 1 (Agriculture) imports the largest pasture land (13.54 million hectares), followed by Sectors 6 (Food Processing, 5.91 million hectares), 12 (Chemical Products, 4.70 million hectares), and 20 (Instruments, Meters, 3.24 million hectares). For EPLE, Sectors 8 (Garments), 7 (Textile

Industry), and 12 (Chemical Products) are the top three largest importing sectors with the trade values of 6.79, 5.70, and 4.16 million hectares, respectively. For industrial pasture land embodied in trade balance, Sector 1 (Agriculture) is China's largest net importer of embodied pasture land with the value of 11.16 million hectares, while Sector 8 (Garments) is the highest net exporter with the value of 5.64 million hectares. In the past decade (2000–2010), China constantly played the role of the net exporter, as it transferred many pasture land-intensive products (like dairy products). Notably, China became a net importer of pasture land in 2015 (EPLI of 40.55 million hectares, and EPLE of 42.11 million hectares). This suggests that the country has entered the period of becoming a net importer of pasture land, and it should bear responsibility for occupying the pasture land in other international regions.

3.2.3. *Consumption*

EPLC of the 42 sectors of China in 2015 is shown in Fig. 9. Sectors 1 (Agriculture) and 6 (Food Processing) has the first and second largest embodied pasture land in consumption with the values of 59.88 and 59.37 million hectares, respectively. These great volumes are attributed to increasing food demand considering that pasture land can also support the production of dairy products. Sector 28 (Construction) embodies the third largest volumes of pasture land of 29.30 million hectares due to its huge fixed capital investment, which requires a large number of resources despite this sector's low embodied pasture land intensity of 0.16 hectares/thousand Yuan. In the meantime, Sector 31 (Hotels, Catering Service) shows a massive ELC with the value of 9.53 million hectares, which can be mainly attributed to urban household consumption of dairy products.

4. Discussions

4.1. *The impact of dietary changes associated with urbanization on China'spasture land use*

Urbanization leads to changes in dietetic consumption structure in China, which will then increase the stress on China's food production chain (Satterthwaite et al., 2010; Seto and Ramankutty, 2016). With China's rapid urbanization, the residents' dietary changes become the main incentive to land demands for cereal planting (Pingali, 2007).

Dietetic consumption structure has a significant change in China, especially with an increase of meat, eggs and dairy products (Delgado, 2003; Pingali, 2007; Popkin, 1999). Considering that the changing dietary structure requires much more pasture land, China's pasture land demands are likely to result in a significant increase in the future.

Regarding the relation of pasture land requirements and diet requires in China, Fig. 10 shows that the changing trend of food trade by three main meat categories, i.e., pork, beef, and mutton, during 2001–2015 is similar to that of pasture land: China tended to import more pork, beef, and mutton especially since 2006. This could be contributed by animal epidemic diseases happened in China in 2005 and 2006. China tends to import more pasture land as rapid urbanization, or as westernization of diets and rising incomes since 2006.

With increased demands for animal food, like pork, beef, and mutton, understanding how the pasture land is supplied and distributed to meet the consumption requirements in urban China becomes increasingly important. This paper provides new insight into China's pasture land resource usage and allocation in the context of globalization and urbanization. Future research may further explore the relationship among the change in China's food consumption patterns, pasture land requirements for food production, and global pasture land supply network. The difficulty is to assess or determine the proper livestock conversion efficiency of meat to grass and to pasture land. The livestock conversion efficiency of pork, meat, and button to grass and to pasture land is different.

4.2. *Comparison between embodied pasture land use and cultivated landuse in China*

Cultivated land and pasture land are the two important agricultural land use categories that mainly supply human food requirements; the former is primarily used for the production of plant-based food, whereas the latter can provide food from animals (e.g., meat and milk) (Röös et al., 2016). The diet in China has changed significantly with its booming economic growth. The increasing requirements for animalbased food lead to a high demand for pasture lands to produce a growing population of livestock, such as pigs. Therefore, a comparison of pasture land and cultivated land in China can provide significant insight into sustainable food consumption in the country with rapid urbanization and globalization. Guo et al. (2014) estimated embodied cultivated land use in China from the temporal and industrial perspectives. The following comparisons are conducted based on consistent supporting data by analyzing the differences in the results of the current study and the research of Guo et al. (2014).

The changing patterns of cultivated land and pasture land are similar based on the time series analysis. The land-use intensities of embodied cultivated and pasture lands in China during the periods of 1987–2012 and 2000–2015 exhibited a downward trend. In terms of trade balance, embodied cultivated and pasture lands varied considerably during the concerned period, with the highest values obtained in 2007. The fluctuation is closely associated with the evolution of the international agricultural trade structure of China. Despite the observed structural similarity between embodied cultivated and pasture lands in the trade sector, embodied pasture land in the import and export sectors are nearly twice the embodied cultivated land.

In terms of industrial analysis, the changing sectoral trends of cultivated and pasture lands are similar. Sector 1 (agriculture) achieves the highest intensity. Industries that provide basic necessities, including clothing, food, shelter, and transportation, consume a large amount of cultivated and pasture land resources. In addition, Sector 1 (agriculture) imports the largest embodied cultivated and pasture lands in China, while Sector 8 (garments) exports the largest embodied cultivated and pasture lands. However, the values of these indicators for pasture lands are nearly twice those for cultivated lands in terms of quantity. The contrasting results demonstrate that Chinese dietary practices tend to require a significant amount of animal products. The consumption of food that exerts considerable demands on pasture lands should be evaluated in future studies.

4.3. *Limitations of this study*

This study, which aims to evaluate embodied pasture land use in China during the period of 2000–2015, has several limitations. First, it intends to analyze embodied pasture land use in China by sector. However, pasture land is directly aggregated into only the agriculture sector and is not divided into various sectors according to different types of agricultural activities due to limited data. Derived from the same sector, the embodied pasture land intensities for various agricultural products are equal. However, for effective formulation and implementation of policies on pasture land protection in China, an indepth understanding of pasture land use for different agricultural and animal husbandry products is necessary. Second, with regard to conventional IO studies, imported commodities are assumed to have the same embodied pasture land use intensities as those of domestic commodities because of data restriction. However, imported commodities can exhibit great differences from domestic commodities (Weber et al., 2008). To increase the reliability of results, the multi-scale input-output model will be used in future studies combining more available international trading databases. Third, the total land area is fixed and various land use types compete for the same land. Thus the competition relationship between pasture land and other land use types should be discussed. However, the nexus of various land use categories is of significance because of their close relations. The limited studies and materials concerning attributes of various land use categories become the major limiting factors of exploring the linkages among various land use categories. Forth, further studies will take a systematic consideration of synergistic programs for ensuring sustainable land and water management practices, which are more effective than the single-objective program in this study. This will suggest international cooperation on various ecosystem service initiatives to explore global sustainable development.

5. Conclusions and policy implications

5.1. *Conclusions*

In the context of urbanization, globalization, and industrialization, China is experiencing substantial land use changes that are correlated with its economic network (He et al., 2012; Wu et al., 2017b). Approximately 28% of the total land area of China, which covers nearly 4 million km^2, is used as pasture land (Ni, 2002). Pasture land is of great importance in livestock production, and water and soil conservation. However, pasture land degradation is aggravated and has become a serious issue in China (Zhang et al., 2007). Rapid urbanization during the recent twenty years in China has led to significant changes in tastes, lifestyles, and food markets, which may lead to a large increase in pasture land requirements in the future (Popkin and Du, 2003).

Studies on how China's pasture land is utilized sustainably under the background of globalization are necessary, given that they acknowledge the importance of pasture lands in China and their associated major problems. To fill the research gap, this study analyzes embodied pasture land use in China in terms of domestic consumption and international trade in view of IOA in order to provide insights on sustainable pasture land use. In particular, a comprehensive time series analysis of embodied pasture land use in China during the period of 2000–2015 and a detailed industrial analysis for 2015 are conducted. This study can facilitate the Chinese government to identify the real factors that influence sustainable pasture land use in China in the context of globalization. Further studies will assess the related policy implications considering the international trade. The specific results are as follows.

(1) Time series analysis of embodied pasture land use in China.

China's embodied pasture land intensities in 2000–2015 display a downswing, decreasing from 22.53 to 2.24 hectares/thousand Yuan. China is a net exporter of pasture land in 2000–2015. Embodied pasture land in trade balance varies substantially during the study period, and the largest value (17.24 million hectares) is obtained in 2007. The fluctuation is closely related to the evolution associated with international agricultural trade structure in China. The change in consumptionbased embodied land use is not highly significant during the study period. The consumption-based embodied pasture land varies between 202.81 and 262.15 million hectares.

(2) Sectoral analysis of embodied pasture land use in China.

Sector 1 (Agriculture) has the largest intensity, and the other sectors with high intensities, including Sectors 6 (Food Processing), 7 (Textile Industry), and 31 (Hotels, Catering Service), are closely associated with the necessities of daily living. In the three agricultural land use categories, Sector 1 (Agriculture) is China's highest net importer of embodied pasture land, with the value of 13.54 million hectares, and Sector 8 (Garments) is China's largest net exporter of embodied pasture land, with the value of 6.79 million hectares respectively. Although there is a structural similarity of the embodied pasture land in trade across sectors, considerable differences in magnitude still exist. From an industrial perspective, the basic necessities, especially dairy and meat products, consume a large amount of pasture land resources. Specifically, Sectors 1 (Agriculture), 6 (Food Processing), and 28 (Construction) embody the largest volumes of pasture land at 59.88, 59.37 and 29.30 million hectares, respectively.

5.2. *Policy implications*

Pasture land is used for grazing to raise livestock for meat, dairy, and other animal products. Livestock grazing is the major driver of the serious degradation and deterioration of grasslands in China during the past three decades (Yu et al., 2011). Intensive grazing has a detrimental effect on soil physical quality, and may further destroy the ecological balance.

The Chinese government has implemented a large number of pasture land protection policies from different perspectives. China has set the "red line" of ecological protection to achieve its total control for national pasture land since 2012. In October 2018, Ministry of Ecology and Environment of the People's Republic of China promised that China's ecological protection areas will reach 25% of the total national areas by 2020. To achieve this objective, a series of detailed measures for the land resources registration and statistics have been established to help statistically accounting of land resources. Besides, the central government has established ecological protection grants and incentives for pasture land since 2011. Pasture land ecological protection was taken into account when evaluating the government performance, which provided an effective incentive for local governments. All these public policies show the Chinese government's determination and efforts in improving the ecological situation of pasture lands.

To achieve these government objectives, specific measures are proposed and suggested from the production perspective, such as planting technology. The use of appropriate plants and grazing systems based on the local climatic and soil conditions is encouraged as direct ecological protection strategies. However, this study finds that direct pasture land protection strategies are insufficiently effective for protecting pasture land in China, since the regional displacement of pasture land use takes place along with the economic globalization. Domestic and international trade will redistribute the ecological impacts of local government policies. To avoid the leakage of local policy effects on pasture land, industrial and trade structure adjustments are considerably more effective for establishing systematic protection strategies for pasture lands in China under the background of globalization. Many scholars explore the effect of globalization on land use change, which shows that globalization has become the main driver to achieve sustainable land use (Lambin and Meyfroidt, 2011).

Appendix A

See Table A1, A2, A3, A4.

Table A1

Year	2000	2002	2005	2007	2010	2012	2015
GDP deflator	100.00	102.73	117.18	131.15	151.24	167.48	172.71

GDP deflators in 2000–2015 (calculated from CSY (2016)).

Actually, the Chinese government has demonstrated the relevant policy directions. As the executive body of China's highest organ, the State Council's advice on "strengthening ecological environmental protection and pollution prevention" (short for "advise") indicated that the industrial structure, mode of production, and lifestyle should be changed to be more sustainable, which is the key point to make a fundamental turn for China's ecological environment until 2035. This study provides a theoretical basis, data supporting system, and specific policy approaches to implement this "advice". Several policy directions and suggestions are listed below.

(1) This study provides a scientific foundation for the Chinese government to achieve sustainable development from a macro perspective by adjusting its international cooperation strategies and foreign trade policies. According to our calculated results shown in Figs. 1 and 3, China has paid a high cost in pasture land resources to fulfill consumption beyond its territory, although the decreasing trend of embodied pasture land use intensities during the selected 15-year period confirms the effort of the country in improving pasture land use efficiency through various institutional and technical approaches. This proves that the spatial spillover of local policy effects will occur to alleviate the country's efforts. Therefore, international or regional cooperation should be emphasized to avoid the cross-border transfer of embodied pasture land. In fact, this initiative is implied in the global sustainable development goal (SDG), which was put forward in Rio+20 in 2012.

(2) The detailed industrial analysis in this study provides the orientation of industrial structure adjustment. As China's largest net exporter of embodied pasture land, Sector 8 (Garments) should be paid close attention: The policy decision-making should be involved from both the production and consumption views, like performing cooperate social responsibility (CSR) on the sustainability of garment enterprises and guiding the sustainable household clothing consumption pattern. Export restrictions on industries that require the intensive use of pasture lands and export incentive policies on high-tech and eco-friendly industries are recommended based on the results of this study. The pasture land use intensities

of 42 sectors have been displayed in Fig. 7, which could be used to recognize the industries with intensive pasture land use.

All in all, this study established a historical pasture land database of China through an effective land use accounting mechanism, which is important in sustainable policymaking. A fundamental understanding of the historical embodied pasture land use trend of China in a globalized network for policymakers is a significant issue in national food safety, ecological safety, and sustainable land use, particularly under the background of globalization.

Acknowledgments

This study has been supported by the “Integrated Support for Worldclass Universities and First-class Disciplines Construction Fund” established by the Renmin University of China and the “Support for Oversea Talent Scientific Research Funding” established by the Renmin University of China.

Table A2

Sectors for China’s economic input-output table 2015.

Code	Sector	Short Name	Industrial Classification

Farming, Forestry, Animal Husbandry, Fishery and Water Conservancy	Agriculture	Primary Industry
Coal Mining and Dressing	Coal Mining	Secondary Industry
Petroleum and Natural Gas Extraction	Petroleum Extraction	
Ferrous and Nonferrous Metals Mining and Dressing	Metals Mining and Dressing	
Nonmetal and Other Minerals Mining and Dressing	Minerals Mining and Dressing	
Food Processing, Food Production, Beverage Production, Tobacco Processing	Food Processing	
Textile Industry	Textile Industry	
Garments and Other Fiber Products, Leather, Furs, Down and Related Products	Garments	
Timber Processing, Bamboo, Cane, Palm and Straw Products, Furniture Manufacturing	Timber Processing	
Papermaking and Paper Products, Printing and Record Medium Reproduction, Cultural, Educational and Sports Articles	Paper Products	Tertiary Industry
Petroleum Processing and Coking, Gas Production and Supply	Petroleum Processing	
Raw Chemical Materials and Chemical Products, Medical and Pharmaceutical Products, Chemical Fiber, Rubber Products, Plastic Products	Chemical Products	
Nonmetal Mineral Products	Nonmetal Mineral Products	
Smelting and Pressing of Ferrous and Nonferrous Metals	Smelting and Pressing of metal	
Metal Products	Metal Products	

23	Ordinary Machinery	Ordinary Machinery
24	Equipment for Special	Special Equipment
25	Purpose Transportation	Transportation
26	Equipment	Equipment
27	Electric Equipment and Machinery	Electric Equipment
28	Electronic and Telecommunications Equipment	Telecommunications
29	Instruments, Meters Cultural and Office Machinery	Equipment
30	Other Manufacture Products	Instruments, Meters
31	Waste	Others
32	Manufacture of Artwork and Other Manufactures	Waste
33	Electric Power/Steam and Hot Water Production and Supply	Manufacture of
34	Gas Production and Supply Industry	Artwork Electric
35	Water Production and Supply Industry	Power
36	Construction Industry	Gas Production and
37	Wholesale, Retail Trade	Supply
38	Transport, Storage and Post	Water Production
39	Hotels, Catering Service	and Supply
40	Information Transmission, Computer services and Software	Construction
41	Financial Industry	Wholesale, Retail
42	Real Estate	Trade
	Leasing and Commercial Services	Transport and
	Research and Experimental Development	Storage

Water conservancy, Environment and Public Facilities Management	Hotels, Catering Service
Service to Households and Other Service	Information
Education	Financial Industry
Health, Social Security and	Real Estate
Social Welfare Culture,	Leasing
Sports and Entertainment	Research
Public Management and Social Organization	Environment
	Service to Households
	Education
	Health
	Culture
	Public Management

Table A3

Embodied pasture land use intensity, embodied pasture land use in consumption and trade.

Year	Embodied pasture land intensity (hectares/10^3 Yuan)	Production-based pasture land use (million hectares)	Consumption-based pasture land use (million hectares)	Net export of pasture land (million hectares)
2000	22.53	263.85	244.27	11.50
2002	17.79	263.52	243.00	10.02
2005	10.98	262.14	262.15	10.41

2007	6.99	261.86	221.66	17.24
2010	3.77	219.67	202.81	2.05
2012	2.49	219.57	215.99	−0.38
2015	2.24	219.42	222.85	−1.57

Table A4

Net export of China's pork, beef, and mutton (calculated from China Agriculture Yearbook).

Year	pork (kt)	beef (kt)	mutton (kt)
2001	8.94	17.48	−22.50
2002	17.04	0.65	−29.88
2003	64.37	0.73	−21.58
2004	220.74	12.16	−9.01
2005	219.47	17.96	−11.32
2006	245.04	26.29	−3.47
2007	47.78	24.70	−24.43
2008	−291.14	18.50	−40.87
2009	−47.58	−0.76	−56.94
2010	−91.21	−1.50	−43.49
2011	−387.02	1.82	−75.03
2012	−455.97	−49.19	−118.90
2013	−510.09	−277.53	−255.51
2014	−472.82	−288.62	−278.45

2015	−706.01	−462.44	−219.17

References

Bai, Y., Han, X., Wu, J., Chen, Z., Li, L., 2004. Ecosystem stability and compensatory effects in the Inner Mongolia grassland. Nature 431, 181–184.

Cadarso, M.-Á., López, L.-A., Gómez, N., Tobarra, M.-Á., 2012. International trade and shared environmental responsibility by sector. An application to the Spanish economy. Ecol. Econ. 83, 221–235.

CAY, 2018. China Agriculture Yearbook 2017. China Agriculture Press, Beijing [in Chinese].

Chaudhary, A., Kastner, T., 2016. Land use biodiversity impacts embodied in international food trade. Glob. Environ. Chang. Part A 38, 195–204.

Chen, G., Chen, Z., 2011. Greenhouse gas emissions and natural resources use by the world economy: ecological input–output modeling. Ecol. Modell. 222, 2362–2376.

Chen, G.Q., Han, M.Y., 2015. Global supply chain of arable land use: production-based and consumption-based trade imbalance. Land Use Policy 49, 118–130.

Chen, Z., Chen, G., Chen, B., 2013. Embodied carbon dioxide emission by the globalized economy: a systems ecological input-output simulation. J. Environ. Inform. 21, 35–44.

Chen, G.Q., Zhang, B., 2010. Greenhouse gas emissions in China 2007: inventory and input–output analysis. Energy Policy 38, 6180–6193.

Chuai, X., Huang, X., Wu, C., Li, J., Lu, Q., Qi, X., Zhang, M., Zuo, T., Lu, J., 2016. Land use and ecosystems services value changes and ecological land management in coastal Jiangsu, China. Habitat Int. 57, 164–174.

CSY, 2016. China Statistical Yearbook 2015. China Statistical Publishing House, Beijing [in Chinese].

Delgado, C.L., 2003. Rising consumption of meat and milk in developing countries has created a new food revolution. J. Nutr. 133, 3907S–3910S.

Dorrough, J., Yen, A., Turner, V., Clark, S., Crosthwaite, J., Hirth, J., 2004. Livestock grazing management and biodiversity conservation in Australian temperate grassy landscapes. Aust. J. Agric. Res. 55, 279–295.

Fourcroy, C., Gallouj, F., Decellas, F., 2012. Energy consumption in service industries: challenging the myth of non-materiality. Ecol. Econ. 81, 155–164.

Ge, J., Lei, Y., 2014. Carbon emissions from the service sector: an input-output application to Beijing, China. Clim. Res. 60, 13–24.

Guo, S., Shen, G.Q., 2014. Multiregional input–output model for China's farm land and water use. Environ. Sci. Technol. 49, 403–414.

Guo, S., Shen, G.Q., Chen, Z.-M., Yu, R., 2014. Embodied cultivated land use in China 1987–2007. Ecol. Indic. 47, 198–209.

Han, M., Chen, G., 2018. Global arable land transfers embodied in Mainland China's foreign trade. Land Use Policy 70, 521–534.

He, C., Huang, Z., Wang, W., 2012. Land use changes and economic growth in China. Land Lines 14–19.

Huang, W., Bruemmer, B., Huntsinger, L., 2017. Technical efficiency and the impact of grassland use right leasing on livestock grazing on the Qinghai-Tibetan Plateau. Land Use Policy 64, 342–352.

Infante-Amate, J., Aguilera, E., Palmeri, F., Guzmán, G., Soto, D., García-Ruiz, R., de Molina, M.G., 2018. Land embodied in Spain's biomass trade and consumption (1900–2008): historical changes, drivers and impacts. Land Use Policy 78, 493–502.

Kang, L., Han, X., Zhang, Z., Sun, O.J., 2007. Grassland ecosystems in China: review of current knowledge and research advancement. Philos. Trans. R. Soc. Lond. B Biol. Sci. 362, 997–1008.

Lambin, E.F., Meyfroidt, P., 2011. Global land use change, economic globalization, and the looming land scarcity. Proc. Natl. Acad. Sci. 108, 3465–3472.

Lenzen, M., 2009. Understanding virtual water flows: A multiregion input-output case study of Victoria. Water Resour. Res. 45.

Leontief, W., 1970. Environmental repercussions and the economic structure: an inputoutput approach. Rev. Econ. Stat. 262–271.

Li, H., Wei, Y.D., Zhou, Y., 2017. Spatiotemporal analysis of land development in transitional China. Habitat Int. 67, 79–95.

Lin, G.C., Ho, S.P., 2003. China's land resources and land-use change: insights from the 1996 land survey. Land Use Policy 20, 87–107.

Liu, J., Mooney, H., Hull, V., Davis, S.J., Gaskell, J., Hertel, T., Lubchenco, J., Seto, K.C., Gleick, P., Kremen, C., 2015. Systems integration for global sustainability. Science 347, 1258832.

Meng, J., Liu, J., Yi, K., Yang, H., Guan, D., 2018a. Origin and radiative forcing of black carbon aerosol: production and consumption perspectives. Environ. Sci. Technol. 52, 6380–6389.

Meng, J., Mi, Z., Guan, D., Li, J., Tao, S., Li, Y., Feng, K., Liu, J., Liu, Z., Wang, X., 2018b. The rise of South–South trade and its effect on global CO 2 emissions. Nat. Commun. 9, 1871.

Ni, J., 2002. Carbon storage in grasslands of China. J. Arid Environ. 50, 205–218.

Pingali, P., 2007. Westernization of Asian diets and the transformation of food systems: implications for research and policy. Food Policy 32, 281–298.

Plieninger, T., Hartel, T., Martín-López, B., Beaufoy, G., Bergmeier, E., Kirby, K., Montero, M.J., Moreno, G., Oteros-Rozas, E., Van Uytvanck, J., 2015. Wood-pastures of Europe: geographic coverage, social–ecological values, conservation management, and policy implications. Biol. Conserv. 190, 70–79.

Popkin, B.M., 1999. Urbanization, lifestyle changes and the nutrition transition. World Dev. 27, 1905–1916.

Popkin, B.M., Du, S., 2003. Dynamics of the nutrition transition toward the animal foods sector in China and its implications: a worried perspective. J. Nutr. 133, 3898S–3906S.

Rees, W.E., 1992. Ecological footprints and appropriated carrying capacity: what urban economics leaves out. Environ. Urban. 4, 121–130.

Rees, W.E., 1996. Revisiting carrying capacity: area-based indicators of sustainability. Popul. Environ. 17, 195–215.

Röös, E., Patel, M., Spångberg, J., Carlsson, G., Rydhmer, L., 2016. Limiting livestock production to pasture and by-products in a search for sustainable diets. Food Policy 58, 1–13.

Rulli, M.C., Saviori, A., D'Odorico, P., 2013. Global land and water grabbing. Proc. Natl. Acad. Sci. 110, 892–897.

Saikku, L., Mattila, T.J., 2017. Drivers of land use efficiency and trade embodied biomass use of Finland 2000–2010. Ecol. Indic. 77, 348–356.

Sanderson, M., Skinner, R., Barker, D., Edwards, G., Tracy, B., Wedin, D., 2004. Plant species diversity and management of temperate forage and grazing land ecosystems. Crop Sci. 44, 1132–1144.

Satterthwaite, D., McGranahan, G., Tacoli, C., 2010. Urbanization and its implications for food and farming. Philos. Trans. R. Soc. Lond. B Biol. Sci. 365, 2809–2820.

Seto, K.C., Ramankutty, N., 2016. Hidden linkages between urbanization and food systems. Science 352, 943–945.

Smith, A., 2005. From The Wealth of Nations, Readings In The Economics Of The Division Of Labor: The Classical Tradition. World Scientific, pp. 93–123.

Su, B., Ang, B., 2014. Input–output analysis of CO 2 emissions embodied in trade: a multiregion model for China. Appl. Energy 114, 377–384.

Wang, S., Liu, Y., Chen, B., 2018. Multiregional input–output and ecological network analyses for regional energy–water nexus within China. Appl. Energy 227, 353–364.

Weber, C.L., Peters, G.P., Guan, D., Hubacek, K., 2008. The contribution of Chinese exports to climate change. Energy Policy 36, 3572–3577.

Weindl, I., Popp, A., Bodirsky, B.L., Rolinski, S., Lotze-Campen, H., Biewald, A., Humpenöder, F., Dietrich, J.P., Stevanović, M., 2017. Livestock and human use of land: productivity trends and dietary choices as drivers of future land and carbon

dynamics. Glob. Planet. Change.facing 2030: dynamic balance system versus basic farmland zoning. Habitat Int. 69, Wiedmann, T., Lenzen, M., Turner, K., Barrett, J., 2007. Examining the global environ-

126–138.

mental impact of regional consumption activities—part 2: review of input–output Wu, X.D., Guo, J.L., Han, M.Y., Chen, G.Q., 2018. An overview of arable land use for the models for the assessment of environmental impacts embodied in trade. Ecol. Econ. world economy: from source to sink via the global supply chain. Land Use Policy 76,

61, 15–26. 201–214.

Wirsenius, S., Azar, C., Berndes, G., 2010. How much land is needed for global food Würtenberger, L., Koellner, T., Binder, C.R., 2006. Virtual land use and agricultural trade: production under scenarios of dietary changes and livestock productivity increases in estimating environmental and socio-economic impacts. Ecol. Econ. 57, 679–697.

2030? Agric. Syst. 103, 621–638.Yu, Y., Liu, J., Wang, H., Liu, M., 2011. Assess the potential of solar irrigation systems for

Wu, C., Wei, Y.D., Huang, X., Chen, B., 2017a. Economic transition, spatial development sustaining pasture lands in arid regions–a case study in Northwestern China. Appl. and urban land use efficiency in the Yangtze River Delta, China. Habitat Int. 63, Energy 88, 3176–3182.

67–78.Zhang, K., Yu, Z., Li, X., Zhou, W., Zhang, D., 2007. Land use change and land degradation

Wu, Y., Shan, L., Guo, Z., Peng, Y., 2017b. Cultivated land protection policies in China in China from 1991 to 2001. Land Degrad. Dev. 18, 209–219.