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Multiregional input-output model for China's farm land and water use

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Key words: China; multiregional input-output model; farm land and water use

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Abstract

Land and water are the two main drivers of agricultural production. Pressure on farm land and water resources is increasing in China due to rising food demand. Domestic trade affects China's regional farm land and water use by distributing resources associated with the production of goods and services. This study constructs a multiregional input-output model to simultaneously analyze China's farm land and water uses embodied in consumption and interregional trade. Results show an imbalance between the origin of farm land and water resources, and final consumption destinations. Shandong, Henan, Guangdong and Yunnan are the most important drivers of farm land and water consumption in China, even though they have relatively few natural resource endowments. Significant net transfers of embodied farm land and water flows are identified from the central and western areas to the eastern area via interregional trade. Heilongjiang is the largest farm land and water supplier in contrast to Shanghai as the largest receiver. The results help policy makers to comprehensively understand embodied farm land and water flows in a complex economy network. Improving resource utilization efficiency and reshaping the embodied resource trade nexus should be addressed by considering the transfer of regional responsibilities.

1. INTRODUCTION

The two basic elements of land and water have the most significant impact on worldwide agricultural production activities.[1, 2] Agricultural production is currently exerting great pressure on farm land and water use in China due to rising food demands, which is caused by population growth, changes in dietary habit, and enhanced biofuel production.[3] Per capita farm land in China is only about 0.08 hectares, while per capita freshwater availability is less than 2000 m^3/year.[4] Due to this unfavorable situation, studies concerning China's land and water resources have proliferated.[5-9] However, there have been no studies focusing on the mismatch of farm land and water resources in China with the aim of developing sustainable agriculture production and minimizing environmental risks. And, although blue water resources have been comprehensively studied, green water resources have received little attention despite their importance.[10] To fill this gap in the literature, this paper simultaneously analyses China's farm land as well as green and blue water uses.

The geographic distribution of China's farm land and water resources are unbalanced.[7] Meanwhile, the ever-closer economic relationship among various industries in different regions through interregional trade exacerbates the pressure on resource displacement. The farm land and water-intensive commodities/services are generally consumed in economically developed regions, but produced in resource-rich regions. The issue of resource pressure transfer and responsibility allocation, as well as the total direct and indirect resource consumption in the whole supply chain, i.e. the embodied resource utilization, have attracted much attention in the environmental accounting field.[11-13] Input-output analysis (IOA) is a useful tool to comprehensively clarify the interweaving economic linkages among industries, which facilitates the tracking of resources to their origin or to where they are utilized through a complex economic network.[14-16] To take account of regional characteristics as well as industrial impacts, multiregional input-output analysis (MRIO) has been used to present the interactions among various industries within several associated economic regions.[17] Many studies have applied MRIO to analyze onefold resource endowment or pollution emissions.[7, 18-23] However, the environmental indicators usually interact and complement each other. To monitor different aspects of human impact on the ecosystem, some researchers accessed different kinds of resource endowments simultaneously using an extended MRIO model. The definition of the "footprint family" was first provided by Galli[24] as a suite of indicators to track human impact on the planet from different aspects. Kjartan et al.[25] identified three interconnected and mutually influenced environmental pressures, including carbon emissions, appropriation of productive land, and freshwater use, caused by consumption in the

European Union based on an MRIO model. Ewing et al.[25] harmonized the ecological footprint and water footprint using an environmentally extended MRIO model. Galli et al.[26] developed an environmentally-extended MRIO model to group the footprint family under a common framework and combine the indicators in the family with European economic accounts and trade statistics. Fang et al.[27] evaluated the performance of the footprint family, including ecological, energy, carbon, and water footprints.

This study establishes a MRIO model to simultaneously access the farm land and water uses in China based on recent available data with regional and sectoral details (30 sectors within 30 regions). A set of indicators are also proposed to reveal the regional and sectoral farm land and water use efficiency, as well as the impacts of consumption and trade on regional farm land and water use. In addition to responsibility allocation under the land/water-demand requirements, agricultural policies can also be formulated to improve resource end-use efficiency and optimize industrial structure and regional trade structure.

2. DATA AND METHODOLOGY

2.1 Data

2.1.1 Environmental data

The farm land use data for 30 regions in China is obtained from China Land and Resources Statistical Yearbook 2008.[28] The official statistics show that land resources can be categorized as farm land, construction land, and unused land. Farm land denotes the land used for agricultural production, including cropland, garden land, forest land, pasture land and other agricultural land. Despite being a relatively small proportion of total available land, farm land is the main focus of research due to its important role in food production and thereby in survival of the human species.[29, 30]

Crops can only directly use soil water, which is composed of blue water, i.e. the surface water and ground water used for farm land irrigation, and green water, i.e. the rainwater stored in the soil supplied to crops.[31] These are the two forms of water either diverted or withdrawn. However, water use in this study refers to water consumption, meaning that the withdrawn water is incorporated by the crops. Therefore, the total farm water use in this study is defined as the total water consumption of blue and green water for crop production. To collect the required blue and green water data, China Environmental Statistical Yearbook 2008,[32] the Yearbook of China Water Resources 2008,[33] China's Water Resources Bulletin 2007[34], and China's Agricultural Water Use Report 1998-2007[35] are referenced. The detailed database of direct blue and green water used for farm land in 30 regions across mainland China is obtained from China's Agricultural Water Use Report 1998-2007.[35] The water resources statistics in China can be classified as agricultural water, industrial water, household and service water, and eco-environment water. Agricultural water use accounted for 61.86% of China's total water use in 2007,[32] while 90~95% of agricultural water was used for farm land irrigation.[35] These proportions provide a basis for blue water estimation, while green water use is based on regional precipitation in farm land areas and the water seepage into groundwater.[35] Although the estimation procedures are crude, they provide the most detailed temporal and spatial farm water resource data that distinguishes between blue and green water.

China's farm land and water resources are extremely scarce compared to the world average. China Ecological Footprint Report shows that China's ecological footprint per person in 2008 was 2.1 global hectares (gha), lower than the global average of 2.7 gha.[36] Although China has 6% of the world's total water resources, the available water per capital is only 25% of the world average.[37] Notably, 60%-70% of food produced worldwide is entirely dependent on green water.[10] Another important characteristic of

China's land and water resources is the unbalanced geographic distribution. Less than 14% of land resources in eastern China are used to support nearly 40% of the population, while more than 56% of land resources are in western China with only 23% of the population.[6] In terms of water resources, only 15% of fresh water resources are distributed in northern China with 57% of the land resources, whereas eastern, central and southern China have 43% of water resources with 57% of the population.[7] Taking land and water together, an diametric land-water pattern is shown in China, i.e., relatively abundant water resources but scare land resources in southern China, and abundant land resources but scare water resources in northwest China.

Unbalanced economic development is a key element in the resource supply and demand imbalance. The unbalanced distribution of farm land and water resources has raised many debates on the sustainability of China's agricultural production and resources utilization. There therefore needs to be a discussion on how China could better allocate farm land and water resources to meet unbalanced food demands and satisfy regional economic growth needs.

2.1.2 Economic data

The MRIO model was first put forward by Isard in 1951 to illustrate the inter-industrial technical relationship and the supply-demand balance.[38] Chenery,[39] Moses,[40] Polenske,[41] and Miller[42] have made a great contribution to the model's development and application. Studies concerning China's input-output applications have been conducted extensively, but those related to MRIO are still lacking due to unavailable interregional trade data. China's State Information Center[43] compiled China's first MRIO table with 8 regions and 30 sectors in 1997, which was followed by MRIO tables for more regions and sectors in 1987, 1997, 2002, and 2007.[44-46] Global MRIO tables, such as the Global Trade Analysis Project, are readily accessible due to detailed interregional trade data. However, domestic trade data in China is unavailable and many mathematical models, such as the gravity model and the maximum entropy model, have been established and applied to estimate the interregional trade flows.[7, 47, 48] This study adopted the most recent MRIO table in China, which was compiled by researchers from the Chinese Academy of Science and China's National Bureau of Statistics.[48] This MRIO table includes 30 provinces with 30 sectors and is based on 30 single regional input-output (SIRO) tables and the calculated interregional trade matrixes using the gravity model.[20, 48] Much more detailed sectoral and regional classifications compared with previous studies, enabled this study to conduct a comprehensive analysis of embodied farm land and water flows.

2.2 Methodology

As a popular environmental accounting methodology from a macro-economic top-down perspective, the system IO model quantitatively represents the sectoral embodied ecological flows accompanied by economic flows. IO-based studies can be categorized as either SRIO or MRIO analysis, determined by the scope of the study area. Compared with SRIO, MRIO not only presents the interactions among industrial sectors within an economy, but also provides the spatial linkages of multi-sector and multi-region economies.[20] It is therefore possible to estimate the interlinked regional resource distributions and the influence of interregional trade on resources use and environmental emissions. In recent years, MRIO has been a popular method for energy, water, land and carbon accounting in relation to climate change, water crisis and land degradation.[17, 21, 49-51] However, few studies have focused on the influence of China's enormous interregional trade flow on regional farm land and water requirements. This study therefore clarifies the relationship between spatial distribution of embodied farm land/water and interprovincial trade.

To analyze the resource endowments associated with China's interregional trade network, an MRIO simulation is used. To achieve this, the study compiled a revised MRIO table by integrating regional resource flows into economic flows. Table S2 is the MRIO table of 30 provinces with 30 sectors in China, which is divided into an intra-regional and inter-regional sectoral economic part, and a farm land and water resource endowments part. As shown in the table: z_{ij}^{fr} represents the monetary value of goods/services sold by sector i in region f as intermediate use to sector j in region r, where f/r=1, 2, 3,⋯, 30 loops over the regions, i/j=1, 2, 3,⋯, 30 loops over the sectors; f_{it}^{fr} is the monetary value of goods/services from sector i in region r as final use supplied by region f, where t stands for the consumption categories; including rural household consumption, urban household consumption, government consumption, fixed capital formation, growing inventories and export; x_i^f is the monetary value of total output of sector i in region f; l_i^f represents the value of direct farm land use of sector i in region f; and w_i^f describes the value of direct farm water use of sector i in region f.

Based on this MRIO table, the basic balance of economic flows of sector i in region f can be formulated as:

$$\sum_{r=1}^{30}\sum_{j=1}^{30} z_{ij}^{fr} + \sum_{r=1}^{30}\sum_{t=1}^{6} f_{it}^{fr} = x_i^f . \quad (1)$$

Combined with the farm land and water flows, the total ecological balance of sector i in region f can be expressed as:

$$r_i^f + \sum_{r=1}^{30}\sum_{j=1}^{30} \varepsilon_j^r z_{ji}^{fr} = \varepsilon_i^f x_i^f , \quad (2)$$

where ε_i^f denote the embodied resource intensity of sector i in region f, r_i^f is direct resource consumption of sector i in region f.

For the whole economic system with 900 entries (30 sectors × 30 regions), the aggregate matrix form of Eq. (2) can be deduced as:

$$R + \varepsilon Z = \varepsilon \hat{X} \tag{3}$$

in which the embodied intensity matrix ε =[ε_1^1, ε_2^1, ⋯, ε_{30}^1; ⋯⋯; ε_1^{30}, ε_2^{30}, ⋯, ε_{30}^{30}]^T, the direct resource consumption matrix R=[r_1^1, r_2^1, ⋯, r_{30}^1; ⋯⋯; r_1^{30}, r_2^{30}, ⋯, r_{30}^{30}]^T, $\hat{X}$ is diagonal matrix $\hat{X}$

...

x_1^{30}

... ...

x_{30}^1

...

Finally, the embodied resource intensity matrix ε can be calculated as:

$$\varepsilon = R(\hat{X} - Z)^{-1}. \tag{4}$$

2.3 Indicators

To assess regional resource use efficiency and interregional resource transfer, the farm land and water use indices in this study are provided as below.

(1) Resource use efficiency

Resource use efficiency depicts the total (direct and indirect) resource cost per unit monetary value of a particular good or service, which can be termed the embodied resource intensity.[52] It is deemed to be the most basic indicator for the IOA of various resource endowments.

(2) Resource embodied in regional consumption

IOA is a useful method for resource accounting from the perspective of consumption.[53] Therefore, resource embodied in regional consumption (REC) is regarded as a representative indicator to reveal the consumption-based resource occupations in a targeted region, which can be expressed as the total resource consumption regardless of their origins (inside or outside of the system boundary):

$$EEC^{r} = \sum_{f} \varepsilon^{f} F^{fr}, \tag{5}$$

where F represents the final consumption activities.

(3) Resource embodied in interregional trade

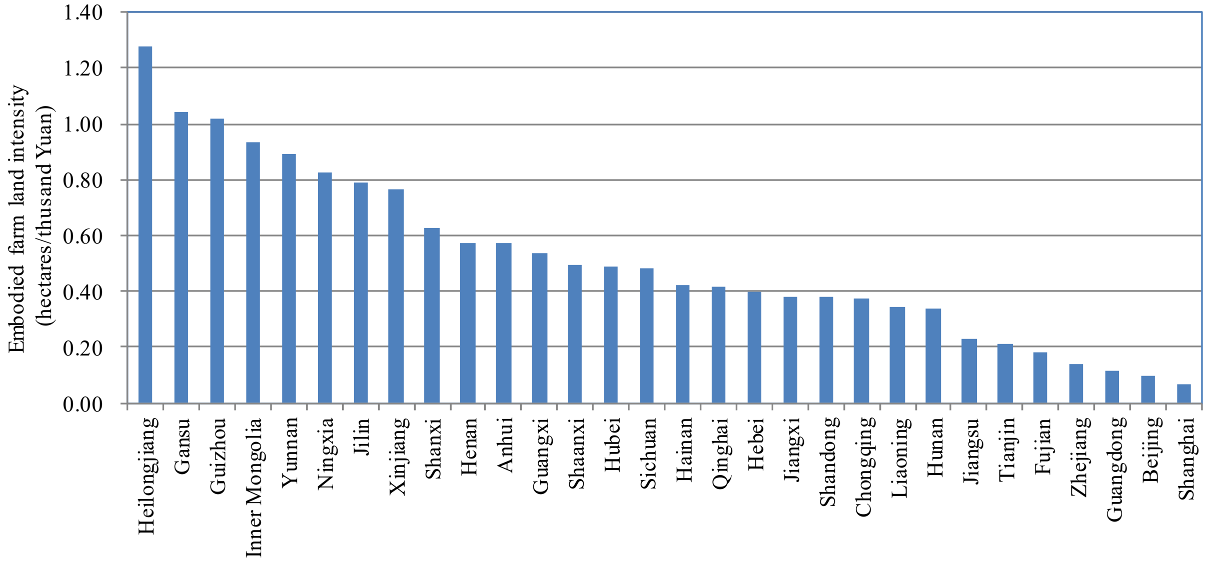
Interregional trade will greatly reshape the regional industrial structure and further affect resource allocation.[54] Resource embodied in interregional trade (RET) is a relevant indicator that reveals intrinsic linkages between resource consumption and production by tracking back to where the resource impacts really occur. This indicator comprises three parts: resources embodied in interregional import (REI), resources embodied in interregional export (REE), and resources embodied in interregional trade balance (REB), which can be formulated as:

$$REI^{r} = \sum_{f} \varepsilon^{f} T^{fr}, \quad REE^{r} = \sum_{f} \varepsilon^{r} T^{rf}, \; REB^{r} = REE^{r} - REI^{r}, \tag{6}$$

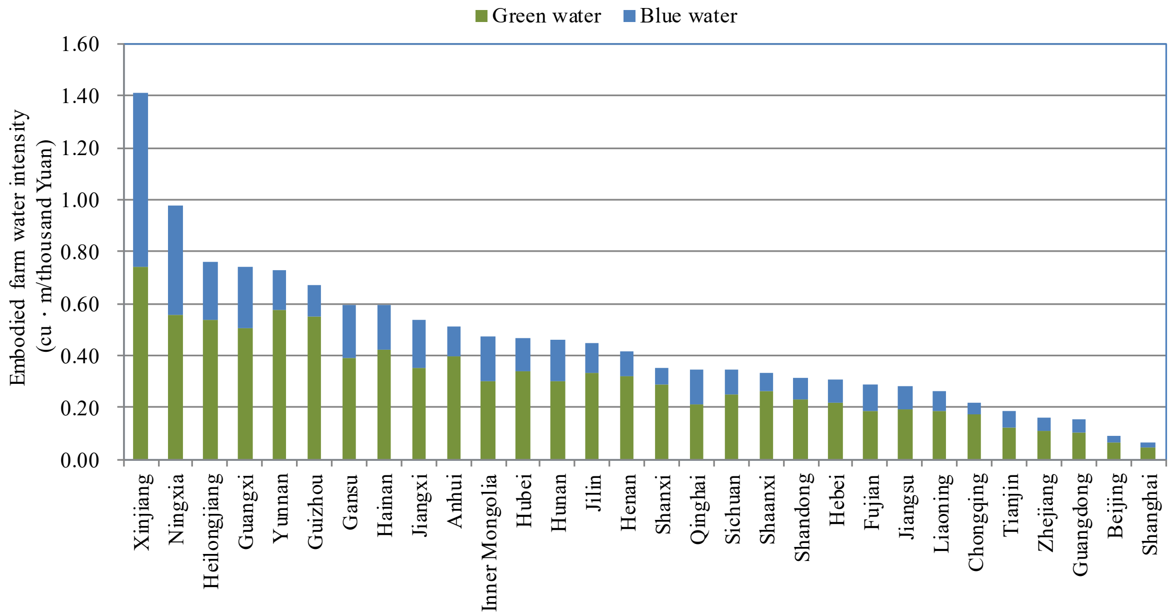
in which T^{fr} denotes the monetary value of goods/services sold from region f to region r and T^{rf} is the monetary value of goods/services sold from region r to region f.

3. RESULTS

3.1 Farm land and water use efficiency



(a) Farm land



(b) Farm water

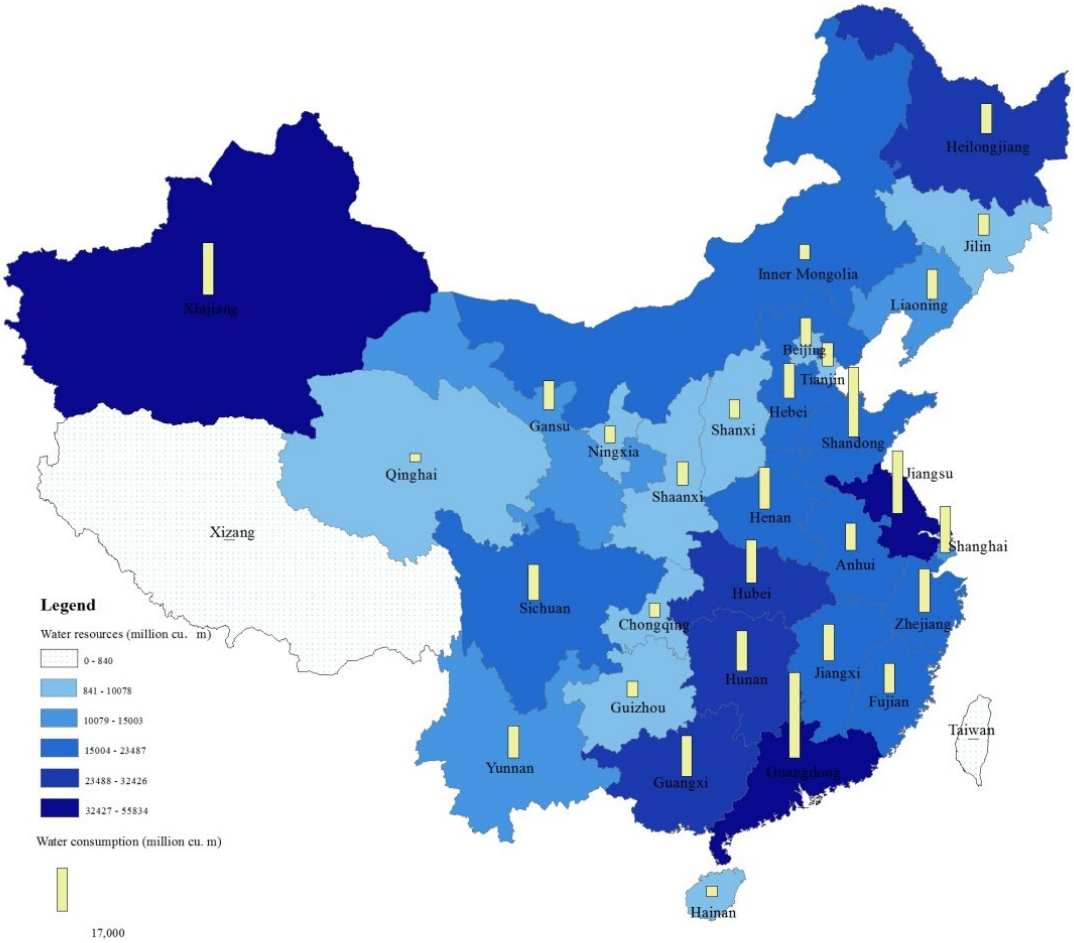
Figure 1. Farm land and water use efficiency. Regional embodied farm land intensity (a), and regional embodied farm blue and green water intensities (b).

Comparing the regional resource use efficiency in China as shown in Figure 1, the following can be observed: there is a remarkable spatial distribution discrepancy among the 30 provinces; the resource use efficiency is negatively correlated with the economic level; most undeveloped western provinces have higher farm land and water use efficiency compared to the relatively developed central and eastern provinces; the top 5 regions with the highest farm land use efficiency are Heilongjiang, Gansu, Guizhou, Inner Mongolia and Yunnan with values of 1.28, 1.04, 1.02, 0.93 and 0.89 hectares/thousand Yuan respectively, most of which are undeveloped western provinces; the developed eastern coastal provinces of Fujian, Zhejiang, Guangdong, Beijing and Shanghai, have the lowest farm land use efficiency with values of 0.18, 0.14, 0.11, 0.10 and 0.07 hectares/thousand Yuan respectively; Xinjiang, Ningxia, Heilongjiang, Guangxi and Yunnan are the top five in water use efficiency with values of 1.41, 0.98, 0.76, 0.74 and 0.73 m^3/Yuan respectively, while Tianjin, Zhejiang, Guangdong, Beijing and Shanghai have much lower water use efficiencies ranging from 0.19 to 0.07 m^3/Yuan.

The average China's farm land and water use efficiency is 0.36 hectares/thousand Yuan and 0.32 m^3/Yuan, respectively. As for the blue and green water, the average green water use efficiency in China is 0.22 m^3/Yuan, which is higher than the blue water of 0.10 m^3/Yuan. This shows the important role that green water plays in maintaining agricultural sustainable development.

3.2 Farm land and water use embodied in regional consumption

(a) Farm land



(b) Farm water

Figure 2. Farm land and water use embodied in final consumption. The relationship of actual vs. embodied farm land/water use is also revealed. The graduated colors represent the actual farm land/water use and the bars show the embodied farm land/water use.

Figure 2(a) shows the geographical distribution of China's farm land use embodied in consumption (LEC) with a total LEC of 101.24 million hectares. Shandong, Henan, Guangdong, Yunnan and Sichuan have the largest LEC of 8.09, 6.02, 5.18, 4.78 and

4.69 million hectares respectively. Together these five provinces account for 28.41% of China's total LEC. The populous provinces of Shandong, Henan, Guangdong and Sichuan all have higher household consumption. Due to lower farm land use efficiency, Yunnan also makes a great contribution to embodied cultivated land consumption. In contrast, Fujian, Xinjiang, Ningxia, Qinghai and Hainan have the smallest LEC at 1.70, 1.62, 0.89, 0.65 and 0.64 million hectares respectively. The undeveloped regions of western China, including Xinjiang, Ningxia, Qinghai and Hainan, have some similar characteristics, such as low level of household consumption and undeveloped economic status. Although Fujian is located on the eastern coast, it consumes less embodied farm land resources owing to its higher farm land use efficiency. Figure 2(a) also reveals the relationship of actual vs. embodied farm land use. As a multifactorial indicator, LEC is influenced by the actual farm land resources and the regional economic development status (including consumption level and trade structure), therefore it has no significant correlation with the actual farm land area.

Presented in Figure 2(b) is the spatial distribution of farm water use embodied in consumption (WEC) and the total value of WEC in China (623.69 billion m^3). There is great similarity between the distribution of LEC and WEC, since both of them are deeply influenced by China's economic structure. Shandong, Guangdong, Jiangsu, Henan and Yunnan are the leading WEC regions with values of 47.54, 42.96, 33.64, 33.47 and 30.79 billion m^3 respectively. While Chongqing, Inner Mongolia, Hainan, Ningxia and Qinghai are the regions with the minimum WEC values of 11.90, 75.37, 63.30, 59.67 and 34.19 billion m^3 respectively. The results show that WEC is positively correlated to the economic development level, which can be measured by GDP. Figure 2(b) also clarifies the relationship between WEC and actual farm water resources. Similar to farm land resources, the distribution of WEC in not consistent with the actual farm water use, which leads to an unbalanced resource demand-supply situation.

Taking both blue and green water into consideration, Figure S1 displays the difference between these two kinds of water use. In terms of China's total WEC, the green water takes the prominent proportion of 57.43%, while blue water accounts for 42.57%. For most provinces, green water is the primary source for demand-driven farm water use, especially Guizhou, Shanxi and Yunnan, whose composition ratios of green water are up to 75.15%, 75.04% and 71.64% respectively. While the western arid regions of Xinjiang, Ningxia and Qinghai, only consume 16.97%, 27.81% and 38.03% green water resources respectively.

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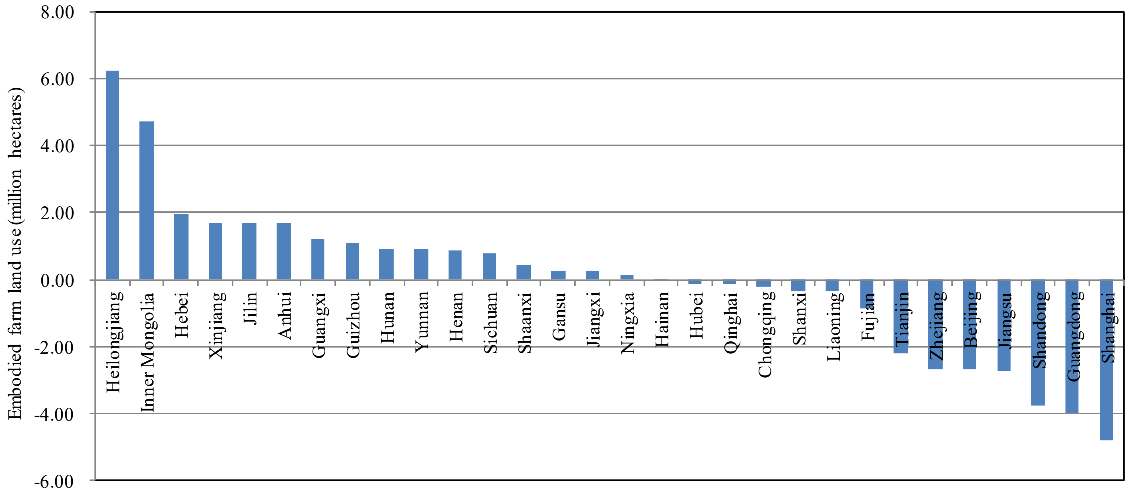
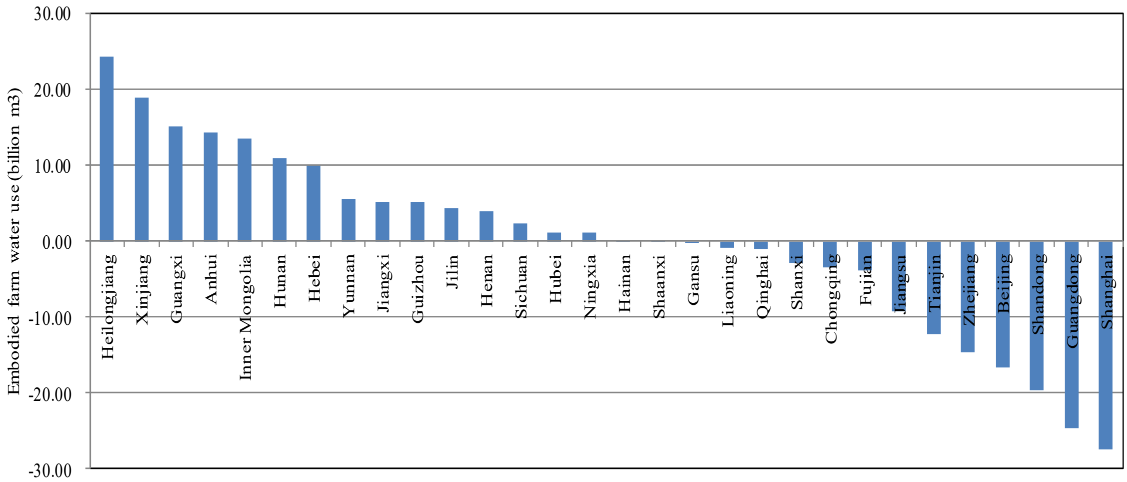
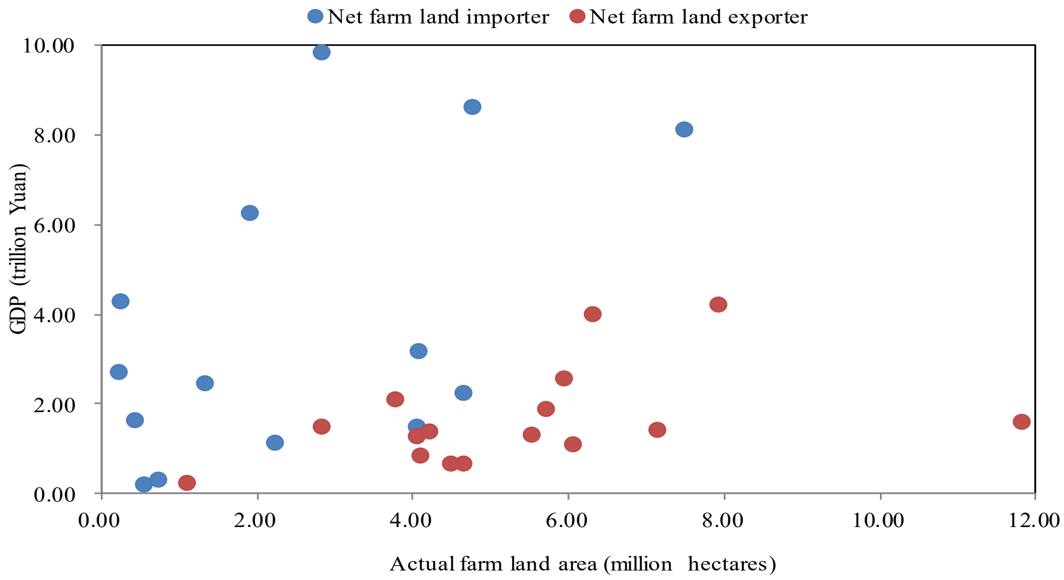
3.3 Farm land and water use embodied in interregional trade



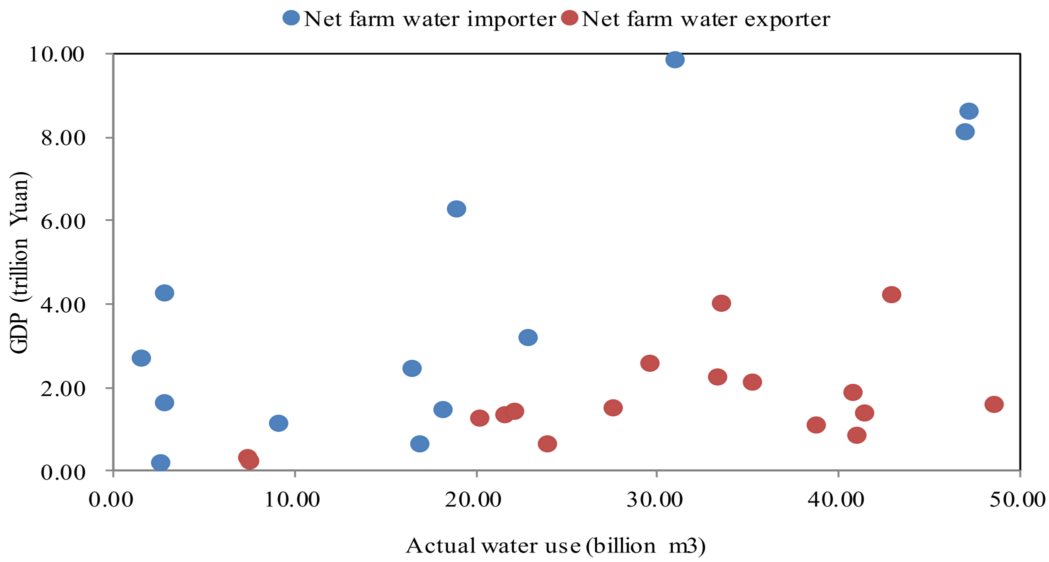
(a) Farm land



(b) Farm water



(c) Farm land



(d) Farm water

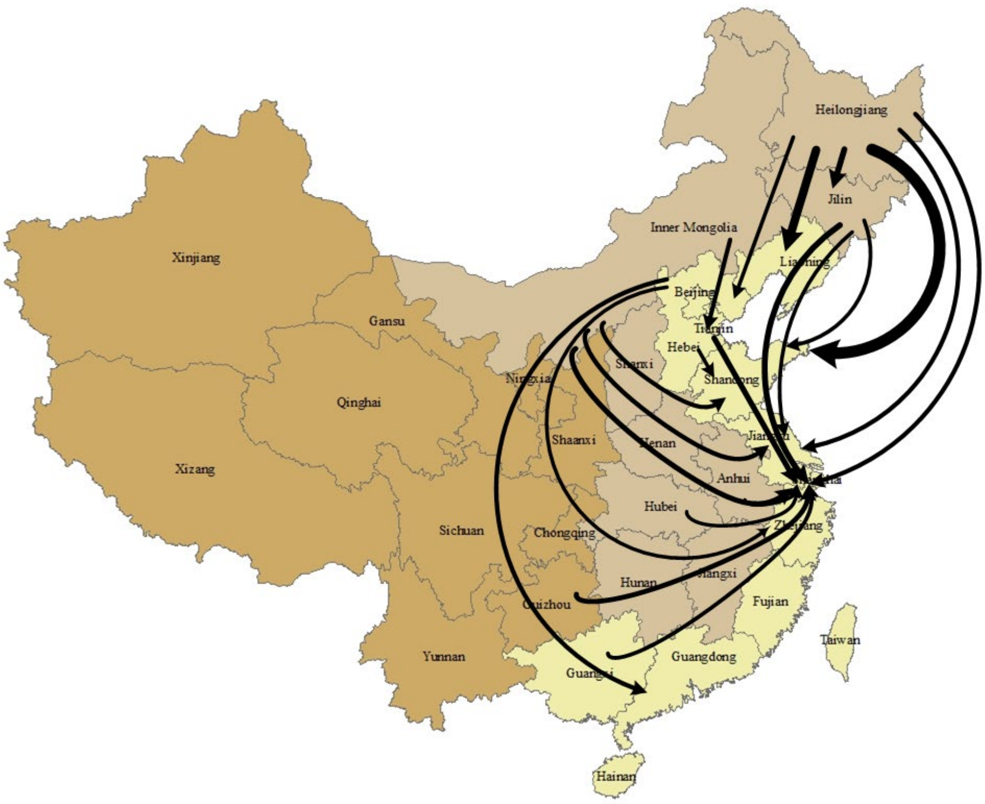
Figure 3. Farm land embodied in trade balance (a), farm water embodied in trade balance (b), relationships between actual farm land use, GDP and farm land trade balance (c), relationships between actual farm water use, GDP and farm water trade balance (d).

The distribution of embodied farm land and water in the trade balance is shown in Figure 3(a) and 3(b). The 30 provinces can be categorized into two groups, i.e. the regions with positive values of resources embodied in trade balance (REB) are net resource exporters, and regions with negative values are net resource importers. In terms of LEB, there are 14 regions as exporters and 16 regions as importers. The top five largest net exporters of LEB are Heilongjiang, Inner Mongolia, Hebei, Xinjiang and Jilin with embodied farm land overshoots of 6.25, 4.72, 1.94, 1.71 and 1.71 million hectares respectively. By contrast, Shanghai, Guangdong, Shandong, Jiangsu and Beijing are the top five importers of LEB, with the embodied farm land deficits of 4.82, 3.99, 3.78, 2.72 and 2.70 million hectares respectively. The spatial distribution of farm water embodied in trade balance is very similar to the spatial distribution of farm land. Thirteen regions are embodied farm water exporters and seventeen regions are embodied importers. The largest exporter of WEB is Heilongjiang with embodied farm water overshoots of 24.33 billion m^3, followed by Xinjiang (18.96 billion m^3) Guangxi (15.10 billion m^3), Anhui (14.29 billion m^3) and Inner Mongolia (13.47 billion m^3). While for the importers of WEB, Shanghai is the largest with embodied farm water deficits of 27.37 billion m^3, followed by Guangdong (24.54 billion m^3), Shandong (19.53 billion m^3), Beijing (16.67 billion m^3) and Zhejiang (14.61 billion m^3).

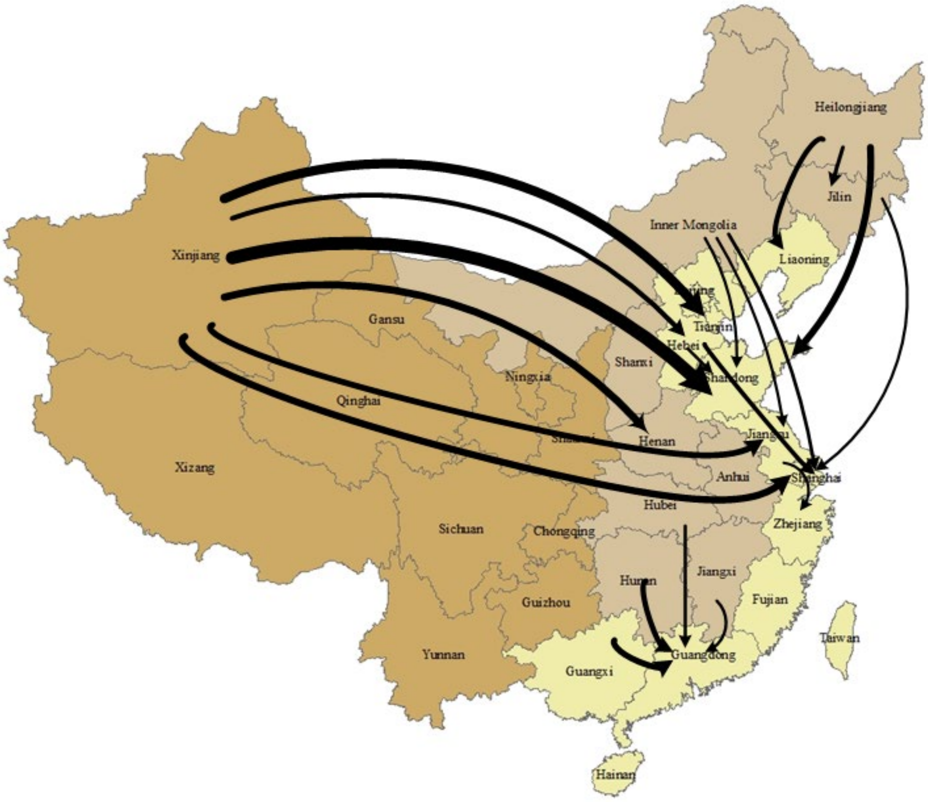
The driving forces of the embodied resource trade balance include the physical resource occupation and economic flows (which can be measured by GDP). Figure 3(c) and 3(d) reveals the casual relationships between actual resource usage, GDP and embodied resource trade volumes. It can be concluded that the net resources exporters are generally the resource-rich or undeveloped regions, and the net resource importers are mostly the resource-poor or developed regions. For example, the main net farm land and water importers, Heilongjiang and Xinjiang, who rank among the top five largest importers of both farm land and water resources, all have abundant farm land and water resources but a relatively low economic level. By contrast, several of the largest exporters of both farm land and water, Shanghai, Beijing, Zhejiang, Tianjin and Fujian, are all developed coastal eastern areas but with relatively less farm land and water resources.

However, regions with more resource endowments or less-developed economies are not necessarily net resource exporters, and vice versa. Two provinces located in the northern China plains, Shandong and Hebei, have a rapid economic development rate with abundant farm land and water resources. The net imports of embodied farm land and water in Shandong province are 3.78 million hectares and 19.53 billion m^3 respectively, which indicates that Shandong's economic development depends highly on external resources. However, Hebei is a net farm land and water resource exporter with values of 1.94 million hectares and 9.86 billion m^3, which suggests that Hebei has satisfied its own resource needs and can also support other regions.

When both the environmental and economic conditions are satisfied, the embodied resource trade balance is relatively stable, which means that consumption activities determine the resource demand and the physical resource usage indicates the degree of resource self-sufficiency. If developed regions, such as Shanghai, Beijing and Tianjin, lack resources they will import a large amount of resources from other places to support their demand. On the other hand, undeveloped regions that are resource rich, such as Xinjiang, Guizhou and Guangxi, will export their resources in return for economic growth.



(a) Farm land



(b) Farm water

Figure 4. Major embodied farm land and water flows in interregional trade. The direction of arrow represents the embodied resource flow direction and the width of arrow shows the size of the embodied resource flow.

Figure 4 shows the major embodied farm land and water flows in interregional trade, with the amounts exceeding a million hectares and a million m^3 respectively. The overall flow trends of embodied land and water are from western and central regions to the eastern coastal regions and from the northern to the southern part in

China. Specific to regions, Heilongjiang and Inner Mongolia have a considerably high land supply. The counterparts to these land surpluses are the deficits in Shandong, Jiangsu and Shanghai. The largest interregional farm water trading flow is from Heilongjiang to Shandong with a value of 1.36 million hectares. Xinjiang, Heilongjiang and Inner Mongolia also contribute a massive amount of farm water resources through interregional trade flows; Guangdong and Shanghai are two of the recipients of these water surpluses. The embodied farm water flux from Xinjiang to Shandong has a maximum flow of 3.92 billion m^3. It is worth noting that the Yangtze River Delta and Pearl River Delta attract huge resource flows as the main hubs of China's economic development, which depend highly on the country's farm land and water resources.

The South-to-North Water Diversion Project aims to transfer the water in Yangtze River in South China to the more arid and industrialized north. From the perspective of embodiment of water resources, although the north borrows a massive amount of physical water from the south, the farm water is eventually re-transferred to the south in the shape of embodied water flows through commodity trading.[7] That it, water consumption in southern China is partly responsible for the demand for water from northern China.

4. DISCUSSION

4.1 Comparison with previous studies

The concept of an "ecological footprint" (EF) proposed by Rees and Wackernagel in the 1990s, was defined by them as "the total area of productive land and water area required continuously to produce all the resources consumed and to assimilate all the wastes produced, by a defined population, wherever on earth that land is located".[55-57] A decade later, an analogous concept termed "water footprint" (WF) was introduced by Hoekstra and Hung[58] to measure the occupation of freshwater resources. These two popular concepts are now widely used to measure land and water requirements on a global, national and regional scale.[59-63] Due to the fact that EF and WF do not reveal causal relationships that would allow researchers to trace back to the places where the ecological impacts really occur,[64] the combination of IOA with EF and WF is a big step forward in ecological resource accounting research. A plethora of studies concerning EF and WF based on the IOA have been conducted and widely applied at the global, national, regional (sub-national, cities and provinces) and river basins levels.[65-69] These studies are considered as significant guides to the implementation of environmental policies. They also make a great contribution to land and water resources accounting.

This study measures the underlying land and water appropriation in the whole lifecycle production process of goods and services. By comparing China's embodied land and water use, we find that the physical land and water resources distribution is unbalanced, and that despite resource endowments flowing into the same economic structure, the embodied land and water flows embodied in interregional trade has obvious differences. Embodied land and water flows associated with real commodity trade show a shift of the uneven resource pressures related to agricultural production. For example, Hunan exports 17.51 million m^3 of embodied farm water to Gansu, in contrast, Gansu exports 4.23 thousand hectares of embodied farm land to Hunan. It is therefore not appropriate to evaluate the embodiment of resource transfer based on certain kinds of resources. Thanks to the differences among various resource endowments, farm land and farm water can be regarded as complementary to each other in the sustainability of agricultural production.[70]

4.2 Application of results

This study quantifies the regional embodied farm land and water use in China based on a MRIO model. Having taken into consideration both land and water, the results will be helpful to those making integrated agricultural policy decisions to fulfill China's increasing food demand. Embodied land and water can be regarded as the complement of the indicators to track the main resource pressures on agricultural development. It is very helpful to be able to understand the diversity of natural resource pressures on agricultural production and the nature of the links between economic activities and natural endowments.

As a populous country, China faces a great challenge to meet the food requirements of its people. Farm land and water are the two key elements essential for agricultural activities. Whether a region is appropriate for large-scale agricultural production activities should be decided by its own resource endowments. In order to establish a development model for complementary interregional industrial structures, economic compensation systems for the ecological benefit of farm land and water has to be understood. For example, Heilongjiang, rich in farm land and water resources, has an obvious advantage when it comes to agricultural development. To protect its resource-related industrial advantage, corresponding compensation policies should extend to Heilongjiang province. In contrast, resource-poor Shanghai should pay for its large share of embodied land and water use derived from other regions.

Regions play the role of either receiver or supplier. Receivers of farm land and water resources should take the greatest share of consumer responsibility, since most are regions with highly developed economies who have the capacity to significantly contribute to farm land and water protection. However, regional farm land and water use efficiency could also be enhanced by compensating suppliers for sharing their farm land and water resources with other regions. It can be concluded that appropriate allocation of regional farm land and water production and consumption can best be achieved through a series of economic measures, such as tax adjustments and optimization of regional trade structures.[20]

ASSOCIATED CONTENT

Supporting Information

Section S1: The mismatch between direct regional farm land and water use (Table S1); Section S2: The MRIO table for farm land and water use in China (Table S2); Section S3: Farm green and blue water use embodied in final consumption (Figure S1); Section S4: Comparison with the existing general findings (Table S4). This information is available free of charge via the Internet at http://pubs.acs.org/.

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Notes

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ABBREVIATIONS

IOA input-output analysis

MRIO multiregional input-output

SIRO single regional input-output

REC resource embodied in regional consumption

LEC farm land use embodied in consumption

WEC farm water use embodied in consumption

RET resource embodied in interregional trade

REB resources embodied in trade balance

EF ecological footprint

WF water footprint

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