Extended Abstract

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Paper/Poster Title	Quantification of the water-carbon nexus in food systems: A provincial-level perspective in China

Abstract prepared for presentation at the 97th Annual Conference of the Agricultural Economics Society, The University of Warwick, United Kingdom

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Abstract	***200 words max***
Studying the water-carbon nexus is becoming crucial for the sustainability of agricultural economic systems. As the physical flows of water and carbon are hidden in trade, it makes sense to apply the concepts of "virtual water" and "embodied carbon" to explore the water and carbon flows in agricultural economic systems from a more holistic perspective. This study developed an agriculture-oriented multi-regional input-output (MRIO) model based on the IElab technology and the RAS method, which disaggregates the agricultural sector into 12 sub-sectors. The water consumption and carbon emissions generated by the food systems were allocated to the entire supply chain based on the input-output method, and then virtual water flow and embodied carbon emissions were calculated to identify the key nodes and routes of water-carbon nexus in China for 2017. This study has also calculated the carbon/water productivity of various agricultural products, and analysed their productivity levels and spatial distribution characteristics. Our results demonstrate that thein China food sector is a high-intensive node of carbon-water nexus, with nearly 60% of embodied carbon and 75% of virtual water concentrated in downstream sectors of the production supply chain. The highest carbon-water productivity is found in Northeast and Central regions.	

Keywords	Water, Carbon, Nexus, Food system, Multi-regional input-output model, Provincial-level
JEL Code	D57, Q17, Q51 see: www.aeaweb.org/jel/guide/jel.php?class=Q)

Introduction	***100 – 250 words***
As the global population continues to grow and food consumption escalates driven by rapid urbanization, total global and per capita food demand are growing in tandem, which puts stress on the environment. Limited availability of water resources, as well as carbon emission constraints, are major bottlenecks to the development of a sustainable agricultural economy. The United Nations predicts that global water supply will exceed the Earth's water capacity in 2050. Consequently, approximately 4 billion people (or about 40% of world population) will suffer from severe water restrictions. Almost 70% of global freshwater is consumed by agriculture, yet "Agricultural water use" as a statistical indicator cannot fully reflect water consumption. Meanwhile, food systems are responsible for one third of global anthropogenic GHG emissions. The investigation of water-carbon nexus is becoming crucial for the sustainability of agricultural economic systems. As the physical flows of water and carbon are hidden in trade, it makes sense to apply the concepts of "virtual water" and "embodied carbon"	

to explore the water and carbon flows in agricultural economic system from a holistic perspective. Input-Output (IO) model is an effective tool to evaluate the direct and indirect environmental effect. Nexus is an interdisciplinary approach that acknowledges the inherent synergies and trade-offs involved in managing water, food and energy. The investigation of water-carbon nexus has also lately received attention from a policy perspective for the design of national strategies regarding the governance of natural resources of different economic sectors, including agriculture.

Methodology	***100 – 250 words***

(1) Environmental inventory calculation

The accounting approach and emission factors for agriculture carbon emission(CE) are based on the IPCC and Chinese Guidelines, multiplying the activity data (AD) with emission factors (EF). The CE of the other 41 sectors, except for agriculture, are based on the data provided by the CEAD database. The water consumption inventory for food sectors use the "Water Footprint (WF)" concept, where the WF of food production is obtained by multiplying the amount of food production and the virtual water content coefficient per unit of product. Regarding the water consumption for the other 41 sectors, we first determined the total water consumption of industrial and service sectors, and then allocated them proportionally to each sub-sector.

(2) The updated MRIO table based on RAS method

The modified MRIO table based on IELab technology was used to fill the data gaps in the agricultural sectors. However, the MRIO table for China is currently available only for2011.. By targeting gross output, final demand and primary inputs' import, RAS generated a new matrix X for 2017 from the IO table for 2011. The results were calculated using R Studio based on the "ioanalysis" and "lpSolve" packages.

(3) Multi-regional input-output (MRIO) approach

The MRIO approach integrated the complex material/service exchange among regions and sectors, and captured the cumulated water use and emission among the supply chains. The environmental impact (Q) is calculated by the following formula,

$$\mathrm{Q} = \widehat{W}(I-A)^{-1}\mathrm{F} = \widehat{W}\tilde{B}F$$

$\widehat{W}$ represents Resource Input Coefficient;$(I-A)^{-1}$ is the Leontief inverse matrix, F represents final demand.

Results	***100 – 250 words***

The RAS model yields a great approximation of the actual 2017 MRIO table with an R^2 of 0.9921, a median APE of 8.01% and a STEP of 8.7%.

From the production side, CEs are mainly concentrated in the northern coastal, central and western regions, while WFs are mainly concentrated in central and south coast regions. The food sectors have a small share of CEs (9.23%), however, they have a significant share of WFs, with the blue WFs accounting for 69% of the entire economic system and 90%, if the impact of precipitation (green WFs) is taken into account. For the food sectors, CEs and WFs are concentrated in the main grain-producing areas, accounting for 63.5% and 63.9%, respectively. From the consumption side, the CEs and WFs caused by consumption activities are concentrated in coastal and central regions, with the food sectors accounting for only 3.71% and 20.64%, respectively. In terms of the inter-regional transmission of embodied carbon-water footprints, 60% of embodied CEs and 75% of virtual water are exported to other regions or sectors, with the manufacturing and electric power/heat power sectors being the main carbon-water input sectors.

The industrial sector has the lowest carbon productivity, while the agricultural sector has the lowest water productivity. The food sectors in the northeast and central regions have a higher carbon-water productivity than other regions, and the spatial distribution of carbon-water productivity is positively correlated (R^2=0.57), meaning that regions with high carbon productivity also have high water productivity.

Discussion and Conclusion

100 – 250 words

This study developed a modified agriculture oriented carbon-water MRIO model based on the RAS method that disaggregates the agricultural sector into 12 subsectors and updates the MRIO table from 2011 to 2017. The CEs and WFs characteristics of 53 sectors in 31 provinces were analysed from production side, inter-regional trade and consumption side by using the input-output method. Then, based on the consumption side, the carbon-water productivity was calculated, and the carbon-water nexus of 53 sectors in 31 provinces was initially explored.

(1) On the production side, there are obvious regional differences in provincial CEs and water resource utilization, due to natural conditions and the level of industrial technology. The electricity sector is the direct carbon-water nexus node, while the food sector has a weak carbon-water nexus.

(2) For carbon-water flow embodied in trade, economically developed or coastal areas, such as Beijing, Shanghai, Jiangsu, and Guangdong, are the main importers of carbon-water footprints, transferring local environmental pressure through trade imports. For all these provinces, the food sector is a high-intensive embodied node of carbon-water nexus. Nearly 60% of embodied carbon and 75% of virtual water are focused in downstream sectors of the production supply chain.

(3) On the consumption side, the economically developed and densely populated coastal areas have the highest carbon-water footprint, followed by the central region, while the western region has a lower carbon-water footprint.