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Energy-water-carbon nexus in transnational agricultural trade

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ABSTRACT

Agricultural trade works as an important node in transnational trade. As various resources and emissions inextricably interrelate and interact with each other, exploring the flow becomes rather complicated. This article integrates multi-regional input-output (MRIO) and the nexus intensity to investigate the energy-water-carbon nexus correlated with agricultural products at the transnational level through the entire supply and demand chain. The combination is aimed at bettering bilateral policy formulation and optimal resource allocation in the context of ambiguity in the flow of resources and emissions correlated with agriculture. Consequently, this article takes RCEP as a case study and the results show that:(1) China is consistently the largest producer and demander of energy-water-carbon flows correlated with agricultural products. (2) When it comes to the external dependence on resources correlated with agriculture, the majority of countries in RCEP rely on a higher degree of energy and carbon than water. On average, Singapore shows the highest external dependence while Indonesia displays the lowest. (3) The self-sufficiency, production, and consumption of agricultural trade-related resources and emissions among RCEP countries present different nexus intensities due to discrepant policies and natural endowments.

Keywords: RCEP, Multi-Regional Input-Output Analysis, Energy-Water-Carbon, Nexus intensity

NONMENCLATURE

Abbreviations	
MRIO	multi-regional input-output
Symbols	
E	final energy demand
W	final water demand
C	final carbon demand

1. INTRODUCTION

With the accelerated globalization in recent years, the pressure of population growth and economic development inevitably leads to the mounting consumption of energy and water in agriculture, accompanied by more carbon emissions release [1]. This variation has posed a threat to human survival and challenged the sustainable development goals of regional economies (SDGs) [2].

Nexus is progressively used to handle resource relationships. Experts nowadays are mainly dedicated to creating feasible arrows between conceptual interpretations [3-5] and practical applications [6-9]. Nevertheless, carbon is usually neglected by the traditional combination of energy, water and land involved in the analysis of agriculture, paying more attention to the impact of resource consumption exerted on the climate environment in the process of agricultural trade is imperative. Furthermore, Globalization has increased the separation between consumers and producers. But the inseparable economic link between consumption and production implies the role of issues such as the expansion of producer responsibility in the negative global impact [12]. The multi-regional input-output (MRIO) analysis is available covering all traded products and relevant supply chains explicitly [10-11].

Therefore, targeting RCEP, this paper constructs an energy-water-carbon nexus system based on agriculture in order to ascertain the resource flows and emissions through the agricultural trade process, hoping to propel a green development of both economy and resources worldwide eventually.

2. METHODOLOGY

The methodology is mainly based on MRIO analysis, using the nexus intensity indicator to reflect the magnitude and balance of resource consumption.

2.1 Multi-regional Input-output Analysis

A data matrix of resource flows correlated to agriculture for RCEP countries can be constructed by referring to the basic structure of the MRIO table. The MRIO model is anchored in the matrix of Input-output (IO) analysis, and the total output per sector of the latter can be expressed as Eqs. (1).

$$X_i = \sum_{j=1}^{N} Z_{ij} + y_i \quad (1)$$

where X_i represents the output of sector i, Z_{ij} indicates the amount of resource flow from sector i to sector j, N represents the number of economies, and y_i means the aggregate demand of sector i.

Thus the equilibrium equation of MRIO can be expressed as Eqs. (2):

$$\begin{pmatrix} x^1 \\ \vdots \\ x^m \end{pmatrix} = \begin{pmatrix} A^{11} & \cdots & A^{1m} \\ \vdots & \ddots & \vdots \\ A^{m1} & \cdots & A^{mm} \end{pmatrix} \begin{pmatrix} x^1 \\ \vdots \\ x^m \end{pmatrix} + \begin{pmatrix} \sum_s y^{1s} \\ \vdots \\ \sum_s y^{ms} \end{pmatrix} \quad (2)$$

where the A matrix represents the matrix of intermediate inputs between different countries and sectors, and the x-column matrix represents the total output of each sector in each country.

Consequently, the consumption of energy, water and carbon can be signified in Eqs. (3):

$$\begin{cases} \mathrm{E} = S_e(I-A)^{-1}Y \\ \mathrm{W} = \mathrm{S}_w(I-A)^{-1}Y \\ \mathrm{C} = S_c(I-A)^{-1}Y \end{cases} \quad (3)$$

where E, W, and C represent the final energy, water, and carbon demand matrices for the economic system composed of the 15 countries in RCEP. S_e, S_w, and Sc indicate the pressure coefficients for energy, water, and carbon consumption, respectively. $l=(I-A)^{-1}$ is the Leontief inverse matrix. The diagonal element of Y which is a diagonal matrix represents the final demand for the product of sector j.

2.2 External Dependence

The article holds the view that external dependence could reflect the self-sufficiency of a country's resources or self-digestion of the emissions correlated to agricultural products. In other words, the high numerical value of external dependence means that the country satisfies its basic agricultural needs by importing relative resources which manifest in the products. The equation of external dependence FTD is shown as Eqs.(4).

$$\mathrm{FTD} = 1 - \frac{O}{C+P-O} \quad (4)$$

Where O, C, and P represent the resource self-sufficiency, consumption, and production of each country respectively.

2.3 The nexus intensity

Due to the order of magnitude differences in the data from MRIO calculations, the analysis results are not characterized distinctively when comparing the quantity of production and consumption in different resource and emission types correlated with agricultural products. As a result, this article poses an indicator named nexus intensity to deal with ambiguity. The normalized equations are displayed in Eqs. (5)-(6):

$$c_i^{e(w,c)} = \frac{d_i}{average(d_i)} \quad (5)$$

$$\mathrm{N} = \alpha_e c_i^e + \alpha_w c_i^w + \alpha_c c_i^c \quad (6)$$

$$cp_i^{e(w,c)} = \frac{c_i^{e(w,c)}}{c_i} \quad (7)$$

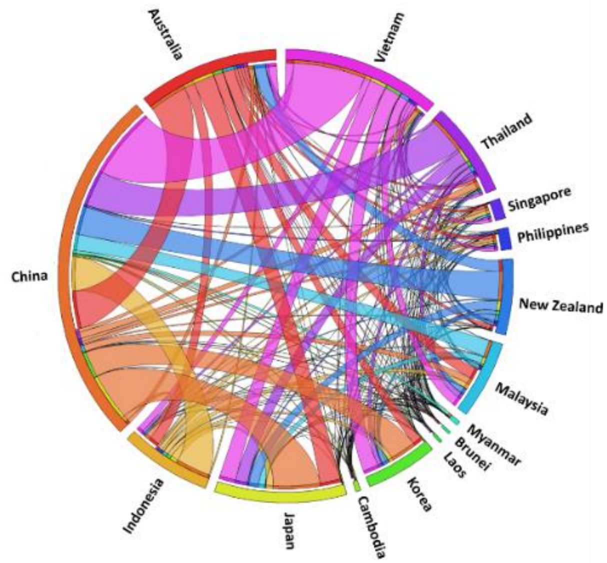
where $c_i^{e(w,c)}$ is the standardized resource utilization index of energy, water and carbon respectively. d_i is the corresponding demand of a country. $average(d_i)$ is the average demand of RCEP countries. N is the standardized total utilization index (nexus intensity). $cp_i^{e(w/c)}$ is the country's energy, water and carbon resource usage (production, consumption or the percentage of self-sufficiency), the sum of which should be 100%.

3. RESULTS AND DISCUSSION

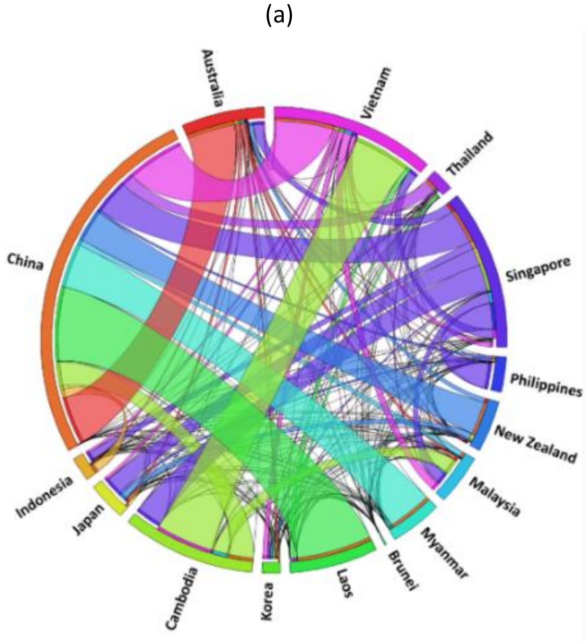
3.1 resources and emissions correlated to transnational agricultural trade

This section shows the energy, water and carbon flows associated with transnational agricultural trade. The circles stand for the RCEP economic system. Resources owned by and flowing out of each country are colored the same, while those colors different are exports of resources from other countries. The flow chart mirrors the current state of production and consumption of resources in terms of bilateral transnational trade.

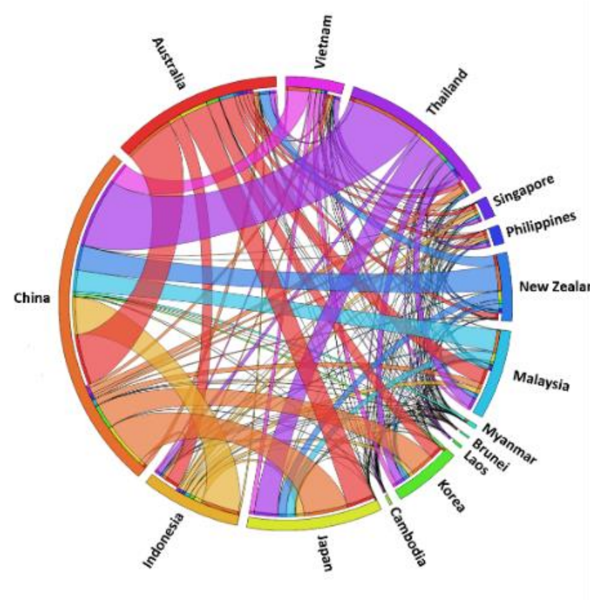
From the perspective of agricultural production and consumption, China is the largest provider and consumer of energy, providing 29,507.5 TJ of energy, accounting for nearly 65% of the total amount among all countries. Trade between countries is rather active as can be seen in figure 1. The largest single flow is Vietnam's export of 537.3 TJ of energy to China, while Australia, Thailand, New Zealand, Malaysia and Indonesia all exported larger amounts of energy correlated to agricultural products to China. In addition to China, Australia, Thailand, and Japan provide more than 1,000 TJ of energy to foreign countries. Despite its large energy production, China is still the top energy importer, importing a total of 946.4 TJ of energy to other countries for agriculture. Australia is the largest exporter instead. The largest net import to China came from Australia at 256.9 TJ and Thailand at 223.6 TJ, indicating that these two countries are important partners in China's energy trade correlated to agricultural products.



(a)



(b)



(C)

Fig. 1. Resource flows correlated to transnational agricultural trade (a. energy,b. water,c. carbon)

Laos supplied 596.8Mm³ of water to China, the largest flow in one-way trade. China, Malaysia, Vietnam and Korea are all large producers of water trade correlated to agricultural products, whose total account takes up for about 50%. Malaysia and Vietnam are both urgent demanders, with 13.4% and 11.5% shares respectively. When comparing countries' net imports or exports of water correlated to agriculture, China is the largest exporter, implying that 2,775.4 Mm³ of water is exported to other countries through the agricultural trade. On the contrary, Singapore is the largest importer, obtaining 1070.6Mm³ of embodied water from the purchase of agricultural products from other countries.

3.2 External dependence of resources and emissions correlated to transnational agricultural trade

Overall, most countries' external dependence on resources and emissions correlated to agricultural products is dominated by energy and carbon, while water is more inclined to be provided indigenously. This indicates that these countries hope to alleviate the pressure on local resources and the environment by import with products which are more likely to bring about pollution. Among them, Indonesia has a low external resource dependence in general, while Singapore is extremely dependent on agricultural related resources from other countries. Laos, Cambodia, Brunei, Korea, and Japan show discrepant external dependence on energy, water, and carbon. For instance, Brunei's external dependence on water is only 0.26%, but on energy and carbon are 21.73% and 94.14%. Furthermore, China is unique in that its external dependence on water is much higher than that on energy and carbon, with external dependence of 39.0%, 8.8%, and 8.4% respectively. The reason can be ascribed to China's self-sufficiency in agricultural products and its probability of having produced more energy-consumed and carbon-emitted products locally to sustain demand. Focusing on all the countries' external dependence on simple resources correlated to agricultural products, the fluctuating trend in the share positions of energy is similar to that of carbon. This indicates that the country has a clearer attitude toward energy and carbon correlated to agricultural products because they would like to avoid excessive resource consumption and emission natively.

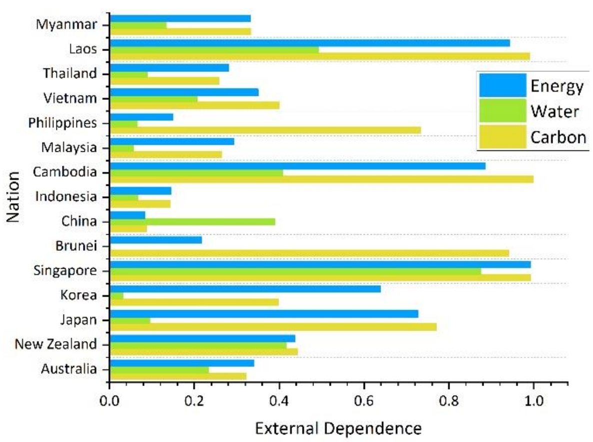


Fig. 2. RCEP External dependence of resources and emissions correlated to transnational agricultural trade

3.3 Nexus Intensity of energy-water-carbon correlated to transnational agricultural trade

The self-sufficiency, production and consumption of resources and emissions correlated to agricultural trade have no obvious difference from each other. They mainly cluster in two areas which are named high water and balance. China has the largest gross resource utilization, with both energy and carbon consumption close to 50% and lower water consumption. Indonesia, New Zealand, and Australia again form a triangle of stable resource utilization within the balance region, where an increase in water utilization is accompanied by a decrease in carbon consumption, irrelevant with energy consumption. Thailand's self-sufficient consumption of resources and emissions varies little, but its carbon production related to agriculture exceeds 50%. The self-sufficiency and production correlated to agricultural products in Japan are both high in energy and water, but the consumption process has lower demand for these two resources and higher carbon emissions, implying Japan's carbon-limiting policy. Another country that is noteworthy is Singapore, which has extremely low carbon emissions from the output end of agricultural products and over 25% of the carbon emissions in reality, reflecting the country's great efforts in environmental protection. Brunei, Cambodia, Laos, and Myanmar all exhibit rather high water consumption nearly 95% or even higher at the arbitrary end of the agricultural trade.

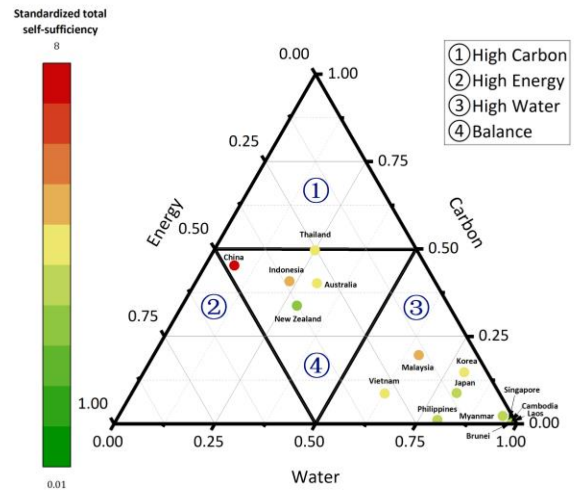


Fig. 3. Nexus intensity of resources and emissions self-efficiency correlated to agricultural products

4. CONCLUSIONS

In summary, China plays a critical role in the transnational agricultural trade of RCEP countries. The embodied carbon emissions and energy consumption of China's agricultural imports reflect the inferior position of China in the trade chain. Thus, the position needs to be improved through technological innovations and trade agreements that could help lead to a more balanced or lower energy consumption and carbon emissions of agricultural products. The contexts of other countries in regards of external dependence and resource nexus intensity also hint at potential risks that some countries may have. For example, Singapore's external dependence is too high, Japan and Korea need to import large amounts of carbon-rich agricultural products to meet domestic demand, etc.

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