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Embodied energy, export policy adjustment and China's sustainable development: A multi-regional input-output analysis

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ABSTRACT

China has surpassed the United States to be the world's largest energy consumer, but a lot of energy was used to produce products for exporting to other countries. Presently, China faces a great challenge in energy security and environmental protection. This paper focuses on the energy embodied in China's foreign trade with a multi-regional input–output approach. Three versions of the GTAP (Global Trade Analysis Project) database were used to capture the trend and distribution of the embodied energy flows for China during 2001–2007. The results indicate that the energy embodied in the global trade is increasing rapidly, growing faster than the total direct energy exported in the same period. China is shown as an energy exporter in terms of embodied energy, and the embodied energy trade surplus increased from 156 million tons of oil equivalents (Mtoe) in 2001 to 514 Mtoe in 2007, with a proportion of domestic energy consumption increased from 14% to 23%. This paper also studies the effects of the energy-intensive industry restrictive export policy of China, and we find that this policy could reduce the national energy consumption and promote industrial structure upgrades effectively. However, the expansion of energy-intensive industries in other countries may reduce China's efforts for global energy saving and global warming alleviation. Our simulation shows that carbon leakage is about 50%.

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1. Introduction

China has become the world's second largest economy next to the United States [24]. With the economic growth, the national energy consumption and environmental pollutant emissions are also growing rapidly. In 2013, nearly 22% of global primary energy consumption occurred in China [3]. Consequently, China has surpassed the United States to be the world's largest energy consumer, the largest source of CO_2 emissions and the largest emitter of SO_2 [3,61]. As China is still in the process of industrialization and urbanization, energy consumption and pollutant emissions will increase in the near future [36]. How to maintain the energy supply and address environmental protection effectively while achieving economic and social sustainable development is an important issue for policy makers.

Imports and exports play an important role in the economic growth of China. China has become the world's largest exporter and the second largest importer [48]. According to statistics released by the National Bureau of Statistics of China, national exports increased from $266 billion in 2001 to $2049 billion in 2012; meanwhile imports increased from $244 billion to $1818 billion, and the trade surplus increased from $221 billion to $230 billion [35]. The rapid increase in exports has positively affected China's economic, but it has also caused an overexploitation of resources and expanded the exportation of energy embodied in goods during their production [32]. In recent years, the Chinese government has frequently adjusted its foreign trade policy (for example, export restrictions on energy-intensive industries) and policy makers want to achieve sound development in the whole economy by guiding the rational development of export industries [57,49].

Embodied energy refers to total energy consumed in all activities necessary to support a process, including upstream processes [55]. It is an accounting method that aims to find the total of the energy necessary for an entire product life-cycle [53]. As the same to that of carbon footprints and water footprints, embodied energy also belongs to the life cycle analysis that captures the resource requirements throughout the whole life cycle of products [19,42]. Embodied energy reveals the direct and the indirect energy use for producing one unit of final demand. It is particular useful for the policy makers to design appropriate energy policies and industrial

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policies. For example, through the calculation of the embodied energy for a special industry, we could not only observe its positive effect on the national economy, but also the potential energy outflow when it exports to other regions. Consequently, the industries that have small share in export-value but large share in embodied energy exports will be given special attention, and taking export restriction measures on this kind of industries may effectively reduce energy outflow and pollution generation with low economic cost.

Based on a multi-regional input–output approach, this paper focuses the energy embodied in the international trade of China with three versions of GTAP (Global Trade Analysis Project) databases. We not only study the trend and distribution of the national embodied energy flows during 2001–2007, but also evaluate the energy-intensive industry restrictive export policy of China. Our findings can be useful for policy makers to design reasonable energy policies in China. The rest of the paper is organized as follows: Section 2 is literature review; Section 3 introduces the multi-regional input–output model and data sources; Section 4 details the empirical results of the energy embodied in the international trade of China; Section 5 provides a quantitative evaluation of China's export restrictions on energy-intensive industries; The conclusions and policy recommendations are presented in Section 6.

2. Literature review

With the increasing situation in energy shortage and global environment pollution, embodied energy has attracted widespread attention in recent years. The studies on this topic mainly focus on the calculation of energy embodied in the international trade of specific countries or regions, and these studies are mostly based on an input–output approach [2,12,14,22,29–31,48]. For example, in Ref. [33] adopt an input–output approach to the Brazilian economy to evaluate the impact of international trade on its energy use. The results indicate that the total energy embodied in the exports is larger than that embodied in the imports. Ref. [39] discuss the household energy requirements in the Republic of Korea, and they find that more than 60% of a household's energy requirement is indirect. Ref. [47] focus on the energy embodied in the international trade of the UK, and they find that the embodied energy in imports have exceeded embodied energy in exports every year since 1997.

With the increase of the trade surplus, the energy embodied in the international trade of China has also been evaluated. Most of these studies adopt the SRIO (single regional input–output approach), which assumes that imports are produced using the same or similar technologies as are used for domestic production, thus imported goods and domestic products have the same energy intensities [41]. More specifically, Ref. [25] adopt the national input–output table to analyse linkages between China's exports and domestic energy consumption, and they find that exports are the largest source of energy demand growth. Ref. [32] use the SRIO approach to evaluate China's embodied energy during 1992–2005, and they adopt a structural decomposition analysis to investigate its drivers. The results indicate that China is a net energy exporter, and the energy embodied in exports tends to increase over time. Ref. [49] calculate oil embodied in the international trade of China, and they find that the net oil exports embodied in China's foreign trade is nearly 87 million tonnes (1747 thousand barrels daily) in 2007, which is almost half of the net oil imports (nearly 178 million tonnes) in that year.

Additionally, some scholars focus on energy uses embodied in the interregional trade of China. For example, in Ref. [29] divide China into eight regions and establish a multi-regional input–output model for energy use and carbon emissions, the results indicate that the improvement in energy end-use efficiency could generate intra-regional energy savings. Ref. [62] discuss how domestic trade impacts on the regional energy consumption, and they find that significant net embodied energy is transferred from the central and western areas to the eastern area via interregional trade.

On the whole, although the embodied energy (or carbon emissions) of the international trade of China has attracted widespread attention and several studies have been undertaken both at home and abroad, this issue is not going away due to the flawed methodology or the databases. From a methodological perspective, the most used single regional input–output approach may be biased for the estimation of the energy embodied in imports, as it is assumed that imported goods and services are being produced with the same technology as the domestic technology in the same sector, thus the single regional analysis does not allow for a distinction between domestic and foreign production technology [58,59]. In reality, however, imports to one country come from numerous different trading partners with different production structures and energy inputs and therefore emission and resource intensities [59]. The assumption that imports are produced using the same or similar technologies as domestic production seems unreasonable [11]. The MRIO (multi-regional input–output) approach could address this shortcoming by using a global economic database, in which countries are distinguished, bilateral trade flows are described and imported and domestically produced intermediate inputs are tracked [41]. However, the MRIO approach also has a disadvantage in terms of its extensive data requirements.

The model from the GTAP (Global Trade Analysis Project), which was developed by the Center for Global Trade Analysis at Purdue University, is a static multi-region and multi-sector CGE (computable general equilibrium) model. In GTAP, the economic system for each country is modelled first, and then the subsystems are linked to a global system through bilateral trade flows and global investment mechanisms. The quantitative analysis of the economic policy of the GTAP model has reached the frontier of international trade and economic theory, and this model has been widely used to discuss trade-related issues [27,34,43,56]. The GTAP model is famous for its databases and, up till now, several versions of the database (e.g. GTAP 6.0, GTAP 7.1 and GTAP 8.0) have been released (These databases are subjected to restricted access, and it is charged for all users except for the data contributors). The GTAP database is a global energy and economic database, with a detailed sectoral and regional description. These databases not only describe the interdependencies between different branches of a national economy, but also detail the energy trade in physical terms among different economies [21,40]. The GTAP databases build heavily on the national input–output tables, as well as research and data contribution from some national and international agencies (such as the past bilateral services trade estimated by the International Monetary Fund [38]). The GTAP database is particular useful for estimating the embodied energy in the international trade of China when using the MRIO approach.

3. Methodology and data

3.1. Multi-regional input–output method for embodied energy

In this paper, the embodied energy in the international trade of China will be discussed with a MRIO approach. The input–output model, which was first proposed by Ref. [28], has been widely used in ecological footprint analysis. For example, many scholars have adopted this method to study the carbon embodied in the international trade for specific countries or regions [13,16–18,45,46,50].

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