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Embodied energy consumption of the construction industry and its international trade using multi-regional input–output analysis

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ABSTRACT

International trade supplies a great number of new opportunities for the development of the construction industry in relation to globalisation. Many construction industry studies relevant to international trade have focused on the evaluation of national trade performance in energy from the viewpoint of the whole economy or of a specific product. Intermediate demand and input, as significant components of the input–output table, indicate the interrelationships between economic sectors, as well as the economic structure in relation to aspects of production and consumption. The purpose of this paper is to analyse the international trade in construction products and services with a focus on their embodied energy consumed at the intermediate level. A multi-regional input–output method is adopted to assess the transfer of embodied energy that accompanies the international trade of the global construction industries. The net embodied energy in the construction industry of each world region has been identified based on its exports and imports. The results indicate that the average embodied energy consumption in intermediate demand over 1999–2009 accounted for approximately 90% in the world construction industries. International construction industries were dominated by activities of intermediate production which aimed to satisfy the embodied energy consumption in the intermediate and final requirements. The USA, China, Japan, Spain and India were the top five in the scale of the intermediate consumption of embodied energy. The production of intermediate goods and services in some world regions decreased its dependence on embodied energy imports from the international construction industries. This study highlights the influence of the international trade in embodied energy on the development of the construction industry at the intermediate level. The outcomes provide considerable resources and references for policy adjustment and strategy design in the management of international trade for the construction sector.

1. Introduction

Global trade consists of international trade and domestic trade, and international trade comprises a significant part of the world economy. Compared to domestic trade, international trade supplies opportunities to exchange goods and services between countries, and the participants in international trade now come from all over the world with the internationalisation of the construction industry. According to a report of the International Energy Agency, the world's total primary energy supply is approximately 13.7 billion tonnes of oil equivalent in 2015 [15], while the construction industry accounts for about 40% of primary energy consumption at the global level [28]. As the use of primary energy in international trade in the construction industry has displayed high growth due to globalisation, there is no doubt that the construction industry has become the dominant energy consumer in many sectors. Embodied energy is the total energy spending on the whole processing of production [37], so the embodied energy of international trade indicates the transfer of energy embodied in goods and services among the construction industries around the world that is induced by intermediate and final requirements. Primary energy refers to the natural energy that is a direct input into production processes, such as crude oil, coal, natural gas and electricity. For the construction industry, fully understanding the process of embodied energy flow provides positive benefits in relation to satisfying the production requirements in upstream and downstream sectors. Hence, it is important to evaluate the embodied energy applied to the production of commodities and service activities so as to improve production sustainability.

According to the research of O'Brien and Leichenko [29], the level of international trade, the investment originating from foreign

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Nomenclature

Acronyms

GDP	gross domestic product
MJ	million Joule
MRIO	multi-regional input–output
RoW	rest of the world
TJ	trillion Joule
UK	United Kingdom
USA	United States of America
USD	United States Dollar
WIOD	world Input–Output Database

Symbols

u_{ij}^{rk}	intermediate use of sector j in region k from sector i in region r
U_j^k	total intermediate input for sector j in region k
U_i^r	total intermediate output for sector i in region r
V_j^k	total value added for sector j in region k
T_j^k	total input for sector j in region k
T_i^r	total output provided by sector i in region r
q_j^k	direct energy input of sector i in region r
c_i^{rk}	final consumption in region k provided by sector i in region r
d_i^{rk}	final investment in region k provided by sector i in region r
F_i^r	total final demand provided by sector i in region r
E	embodied energy intensity matrix
Q	direct energy input matrix
T	diagonal matrix of total output
U	intermediate input matrix
IEE_i^r	embodied energy consumption of intermediate demand for sector i in region r
IEE_j^k	embodied energy consumption of intermediate input for sector j in region k
e_i^r	embodied energy intensity of sector i in country r
IM_{ji}^{kr}	embodied energy imports of sector j region k from sector i in region r
IM_j^k	total embodied energy imports of sector j in region k from the same sector of all the regions in intermediate demand
EX_{ij}^{rk}	embodied energy exports of sector i in region r to sector j in region k
EX_i^r	total embodied energy exports of sector i in region r to the same sector of all the regions in intermediate demand
NET_i^r	net embodied energy between exports and imports for sector i in region r

countries and the number of multinational firms are all growing, as illustrations of economic globalisation. The construction industry has become a significant part of the world economy, along with the domestic construction industry becoming more globalised. The ratio of the economic contribution of the construction industry to gross domestic product (GDP) is more than 5–10% in most countries [27]. In the context of this tendency towards globalisation, domestic construction industries face many challenges, such as overcompetitiveness and environmental deterioration. These disadvantages limit their development and contribute to the internationalisation of the construction industry. The input of natural resources to the construction industry is largely limited by the total reserves in a single country. Since national requirements for products can be satisfied by foreign countries through international trade, the increasing total volume of international trade is attributable to the effects of globalisation. This increased demand consumes more natural resources, which come from the environment, but then the environment deteriorates due to the rapid expansion in resource consumption. So the domestic construction industries are restricted due to the limitations on sectoral input with respect to resources. However, for the construction sector itself, the international market offers a great number of opportunities in the form of requirements derived from the upstream and downstream sectors in foreign territories. Lee et al. [18] reported that the development of the international construction industry has created many new opportunities for construction contractors in the expanding international market. For instance, based on statistics from the WIOD, the Chinese construction sector achieved a trade value of 780 million USD in 1995 from its foreign market, while this foreign trade value increased to 5564 million USD in 2009. International trade supplies a large market for the construction sector from domestic to foreign markets, so international trade can be seen as the original driving force in the development of the construction industry.

International trade enlarges embodied energy requirements and speeds up consumption in the construction sector. The economic factors which influence the performance of the construction industry have been considered in previous studies [22–24]. International trade supplies a channel for the transaction of goods and services, while the energy embodied in these goods is transferred via the global trade network. Global supply chains have also been extended in the process of transferring energy resources due to increasing numbers of participants in the global trade network. Construction-related energy problems have attracted worldwide attention due to the negative impacts on the environment. Based on a report of the Intergovernmental Panel on Climate Change, the share of energy-related emissions in global greenhouse gases is approximately one-third, and about one-fifth of global emissions are due to the construction industry [34]. Carbon dioxide dominates the greenhouse gas emissions derived from energy consumption in the construction industry [25]. Moreover, the goods in international trade supply a great quantity of embodied energy to meet the consumption demand in the construction industry. Due to this sectoral requirement for embodied energy, both the direct energy input and the embodied energy of intermediate goods are increasing rapidly.

The purpose of this paper is to analyse the embodied energy consumption and its international trade at the intermediate level of the construction industry in the context of globalisation. Intermediate demand indicates products that need further processing. Intermediate input means the consumption of raw materials and services in production processes. The intermediate level represents both the production activities in relation to intermediate demand and the consumption activities in relation to intermediate input. This study focuses on the transmission of embodied energy by products in international trade between the construction sectors in different countries. The data for international trade can be extracted from the intermediate demand area of an economic input–output table. At the intermediate level, embodied energy transfer within and between sectors is measured by indicators of embodied energy intensity and quantity. This paper combines multi-regional input–output (MRIO) analysis with economic and environmental energy data derived from the World Input–Output Database (WIOD) in order to explore the interaction between sectors. The multiple-sector trade pattern illustrates the reallocation of different production processes and the expansion of intermediate markets at the global level.

Thus, a focus on intermediate demand and intermediate input is beneficial in understanding the interaction between sectors in different regions. For the construction sector, the embodied energy consumption levels induced by intermediate demand for 41 world