ARTICLE IN PRESS

Applied Energy xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Growth in embodied energy transfers via China's domestic trade: Evidence from multi-regional input–output analysis

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HIGHLIGHTS

- China had significant growth of embodied energy transfers via domestic trade.
- Interregional trade of total embodied energy uses tripled between 2002 and 2007.
- The temporal and spatial changes of regional energy use inventories were revealed.
- Increasing complexities of China's domestic supply chains were identified.

ARTICLE INFO

Article history:
Received 22 June 2015
Received in revised form 9 September 2015
Accepted 10 September 2015
Available online xxxx

Keywords:
Embodied energy transfer
Domestic trade
Multi-regional input–output analysis
Regional China

ABSTRACT

This paper investigates the temporal and spatial changes of embodied energy transfers via China's domestic trade over 2002–2007 based on the multi-regional input–output models. Interregional trade of total embodied energy uses approximately tripled between 2002 and 2007, and the total trade volumes in it were equivalent to 38.2% of the national total direct primary energy input in 2002 and 62.9% of that in 2007, respectively. Among all the eight regions, *Northwest*, *Central*, *Northeast* and *Southwest* were the interregional net exporters and deficit receivers of embodied energy in contrast to *East Coast*, *South Coast*, *North Coast* and *Beijing–Tianjin* as interregional net importers and surplus receivers. Significant growth of net embodied energy transfers can be identified from central and western inland regions to eastern coastal regions, and the *Central* region partly served as a "transmission channel". By considering the interregional embodied energy transfers, regional energy use inventories changed largely, and the spatial and temporal differences between 2002 and 2007 were expanding. Industrial positions in domestic and global supply chains and inherent economic driving factors such as increasing regional consumption level, accelerated investment in fixed assets and rapidly expanding export were the major driving forces for the embodied energy transfers among regions. To form a set of useful tool for controlling energy consumption and achieving the goals for energy saving and emission reduction, China's governors at all levels deserve to understand the relationships between energy producers and users from the view of demand-driven energy requirements.

1. Introduction

As the world's top primary energy consumer, China's demands for energy resources continue to increase along with its rapid economic development. Although traditional energy policy schemes in China aimed at alleviating energy resource shortage focus on the development of domestic energy supply over the energy safety [1], the governments at various levels have a greater pressure to control vastly growing energy consumption and deal with negative environmental effects such as air pollution [2,3] and greenhouse gas emissions [3–5]. In 2011, the Chinese government assigned the energy intensity reduction goal of 16% in the 12th Five-Year Plan (2011–2015) to respond to the challenge of ensuring continuous growth of GDP at a high speed and

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http://dx.doi.org/10.1016/j.apenergy.2015.09.076

achieving the reduction of energy consumption. Meanwhile, the reduction targets of CO_2 emission intensity and major pollutant emissions such as SO_2 were also assigned in this Plan. In 2013, the State Council announced that China will keep the total energy consumption below 4 billion tce in 2015. Recently, the State Council set forth a new target in the Energy Development Strategy Action Plan (2014–2020) that China will cap primary energy consumption at 4.8 billion tce by 2020 [6].

As a vast country, the national targets of China generally will be allocated down to 31 provincial authorities by requiring the regional targets correspondingly [7], considering the fact that substantial regional variations exist in physical geography, economic development, infrastructure, population scale and density, resident income level and lifestyle, and environmental resource condition across regions within China [8,9]. Since there are fewer barriers to trade between the regions than to trade between countries [10], the regions with high urbanization and industrialization level have tended to purchase much more final goods or services rather than produce them locally. In other words, China's interregional goods trades are always associated with energy in domestic supply chains. Large interregional trade transfers of direct or indirect energy uses not only can help to distribute uneven endowments of energy resources among different regions, but also lead to great gaps between regions in terms of energy production and consumption. The implementation of regional end-reduction oriented energy policies may accelerate interregional direct or indirect energy transfers [11] and exacerbate related environmental problems such as carbon leakage [10,12,13], along with the rapid expansion of domestic trade in China.

The concept of embodied energy originates from the theory of systems ecology [14,15]. Embodied energy use or demand-driven energy requirement is defined as the total primary energy input to satisfy final demand, i.e., the direct plus indirect energy resources input through the production processes to produce the goods used for final demand [16,17]. When direct primary energy input indicates the physical energy resource supply for production, embodied energy use reflects the direct and indirect energy requirements throughout the whole supply chain to satisfy different final demand categories [11,18]. Based on the input–output analysis methods [19], scholars have carried out a large number of input–output analyses regarding energy embodiments in the global, national and regional economic activities by considering the inter-industry linkages between energy producers and energy users [16–18,20–24].

Given the multi-regional input–output (MRIO) model can present the interactions among industrial sectors within an economy and the spatial linkage of industries between any two regions in the system, MRIO analysis has been widely used in analyzing the embodiments of resource uses and environmental emissions in certain economic activities [25–29]. Some studies have applied China's MRIO models to reflect the impacts of international and interregional trade on regional ecological footprint [30,31], water footprint and virtual water uses [32–36], embodied energy uses [11,37], and consumption-based emissions of air pollutants [38–40] and greenhouse gases [10,12,13,41–51]. For instance, Meng et al. [13] explained the relationship between China's interregional spillover of energy-related CO_2 emissions and domestic supply chains in 2002–2007. Zhang et al. [46] showed the trends and disparities of consumption-based CO_2 emissions from China's provincial regions over 2002–2007. Tian et al. [44] also used the MRIO analysis method to study China's carbon footprint over 1997–2007. Prior studies have contributed to support the provincial-level policy-making processes such as the allocation of national emission reduction targets to the various provinces. Since the MRIO model can identify how much of a region's primary energy inputs are created by its partner region's final demands, Zhang et al. [11] have conducted a MRIO study on the impact of domestic trade on China's regional energy uses for the year 2007. However, systematic analyses of the temporal and spatial variations of the energy uses embodied in China's domestic trade have not been conducted.

The aim of this paper is to present a MRIO analysis of China's interregional embodied energy transfers via domestic trade in 2002 and 2007 by using the recently available MRIO tables. The MRIO modeling can not only explain how primary energy inputs are created and distributed across regions, but also reveal the trends and disparities of regional energy use inventories considering interregional embodied energy transfers. Such analyses can identify regional energy use features and corresponding driving factors of embodied energy transfers to reflect the position and participation degree of different regions in domestic supply chains, and provide new insights for allocating regional responsibility for China's energy demands in consideration of regional socioeconomic diversity and complexity.

This paper is organized as follows. The next section introduces the methodology for MRIO analysis employed in the study and the data used. Section 3 presents the results of MRIO modeling for China's interregional embodied energy transfers in 2002–2007. Section 4 examines the relationships between China's regional embodied energy uses and the increasing complexity of domestic supply chains in connection with the impacts of interregional trade, and discusses several key policy implications from our analysis. Main conclusions will be drawn in the ending section.

2. Material and methods

2.1. Introduction for the MRIO tables

Following the methodological, data and institutional development, several MRIO tables for China have been published in recent years. China State Information Center of China [52] compiled a MRIO table for the year 1997 in China, which is classified into 8 regions and 30 industries. Ichimura and Wang [53] estimated a MRIO table with 7 regions and 9 sectors for the year 1987 in China. Shi and Zhang [54] compiled a MRIO table for the year 2002 in China, which is a competitive MRIO model with 30 provinces and 21 sectors covered. Liu and his fellows [55] finished a MRIO table for the year 2007 in China, which is classified into 30 province s and 30 industries.

For the time-series research, Zhang and Qi [56] provided the 2002 and 2007 MRIO tables for China, which are the most recently available MRIO tables in China covering two different years. In this study, the two MRIO tables are adopted directly. It should be noted that, in these MRIO tables, the 30 provinces of Mainland China (Tibet is not included for lack of data) were integrated into 8 regions, i.e., *Northeast*, *Beijing–Tianjin*, *North*, *Central*, *East Coast*, *South Coast*, *Northwest* and *Southwest* (also see Fig. 1). The eight-region classification can relatively reflect the similarity of economic structure and spatial location of different provinces. Given the original MRIO tables have differentiated domestically produced goods from imported ones in the model to present the interregional trade dependency within China, the international imports item has been removed to focus on the domestic interregional connection. The format of revised MRIO table is shown in Table 1, with the economic sector classifications of 17 sectors. Detailed sectoral and regional information in the two MRIO tables are listed in Tables A1 and A2.

2.2. Mathematic forms of MRIO model and energy embodiment

For the revised MRIO table (see Table 1), the basic row balance can be expressed as