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Tracking Multilayer Energy Flows Embodied in China's Interregional Trade: An Input-Output Network Analysis

Cuixia Gao[a,b], Bin Su[b], Mei Sun[a,*], Zhonghua Zhang[c]

[a] *Institute of Applied System Analysis, Faculty of Science, Jiangsu University, Zhenjiang, Jiangsu 212013, PR China*
[b] *Energy Studies Institute, National University of Singapore, 119620, Singapore*
[c] *School of Management and Economics, Beijing Institute of Technology, Beijing 100081, PR China*

Abstract

While the problems of energy supply-demand security and climate change are being perceived as increasingly urgent, it is important to study embodied energy flows, particularly a large and fast growing developing country like China. To evaluate the energy flows between producer and consumer regions, energy embodied in bilateral trade (EEBT) approach has been adopted to locate the destination of energy bi-directionally. However, in addition to the flow of resources, the topological structure and impact of underlying components are also important for policy making from system science perspective. This study constructs a hybrid regional network model to track multilayer energy flows by integrating EEBT approach and social network analysis (SNA). In particular, the embodied coal, crude oil, natural gas and non-fossil fuels associated with China's 30 provinces/municipalities are quantified at the regional level. By joint analysis of the network-oriented metrics, the hybrid network model elicits the possibility of understanding the dominant regions for different energy flows and the potential impacts of region-specific policy interventions. We explain how unequal distribution of energy resources, economic mechanism, cross-regional industrial transfer and infrastructure construction affect China's regional energy embodiments as well as clustering features. Other findings and some recommendations are also presented.

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Keywords: Multiregional input-output table; Social network analysis; Energy embodied in trade; Community; China

* Corresponding author. Tel.: +8613775366657.
E-mail address: sunm@ujs.edu.cn

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1. Introduction

Between 1971 and 2014, world total primary energy supply (TPES) was multiplied by almost 2.5 times. In 2014, the TPES reached 13700 Mtoe, releasing over 32 $GtCO_2$ [1, 2]. China, as a major contributor, accounted for one-fifth of world TPES and one-fourth of global CO_2 emissions respectively. To address climate change, China committed several actions to peak its carbon emissions by 2030 in the Paris Agreement. Amid China's effort to reduce emissions, the 13th Five-Year Plan provided a clear national strategy and intention. Especially, the adjustment of the relationship between regional energy balance and cross-regional supply was proposed [3].

With the magnitude of potential energy consumption, it is important to study energy or energy-related CO_2 emissions embodied in trade. The measurement using the environmental input-output (EIO) framework has been an actively-researched area [4]. Since the input-output tables capture the exact quantitative economic relationships among industrial sectors, scholars have carried out large numbers of input-output analyses regarding energy consumption or emissions at the national level. See, for example, Su and Ang (2011), Su and Ang (2013), Cui et al. (2015) and Wu et al. [5-8]. However, these studies only considered the energy or environmental impacts from the national perspective while ignoring regional disparities within a country. Only a very few studies have been conducted in the context of regional economy, especially for a large country like China. For example, Su and Ang (2014) [9] combined the HEET approach and SWD-EET analysis to explain how inter-regional trade and international trade affect China's regional domestic emissions. Zhang et al. (2016) [10] investigated the temporal and spatial changes of embodied energy transfers via China's domestic trade over 2002-2007 based on the multi-regional input-output (MRIO) models. Hong et al. (2016) [11] employed a MRIO model to investigate energy use embodied in the consumption and interregional trade of China's construction industry in 2007. Because data limitations are always a challenge in empirical studies at the regional level.

Different from previous studies, the objective of this paper is to construct an energy use inventory framework, following the regional economic input-output tables for China. A comprehensive study of primary energy embodiments is presented. Furthermore, the contribution of each province/municipality is investigated by combing SNA with EEBT which is a systemic analysis. Prominently, the dominant interregional importers/exporters and the significance of regional clustering will be measured and discussed systematically, which will provide references for China's regional and national energy consumption reduction.

2. Hybrid regional network model

On the basis of the concept of embodied energy originating from the theory of systems ecology, the total 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, are termed embodied energy requirement. Then, the indicator of energy intensity $\boldsymbol{E}$ can be calculated by Eq. (1).

$$\boldsymbol{E} = \boldsymbol{D} \times (\boldsymbol{X} - \boldsymbol{Z})^{-1} \tag{1}$$

where $\boldsymbol{E}$ denotes the embodied energy intensity vector; $\boldsymbol{D}$ denotes the direct energy input vector; $\boldsymbol{Z}$ denotes the matrix of intermediate consumption; $\boldsymbol{X}$ denotes the total output which is the sum of intermediate and final consumption.

Thus, the domestic energy demand on domestic production in region r and the energy use embodied in bilateral trade from region r to region s can be calculated using Eqs. (2-3).

$$\boldsymbol{f}^{rr} = diag(\boldsymbol{E}^r) \times (\boldsymbol{I} - \boldsymbol{A}^{rr})^{-1} \times diag(\boldsymbol{y}^{rr}) \tag{2}$$

$$\boldsymbol{f}^{rs} = diag(\boldsymbol{E}^r) \times (\boldsymbol{I} - \boldsymbol{A}^{rr})^{-1} \times diag(\boldsymbol{e}^{rs}) \tag{3}$$

where $\boldsymbol{f}^{rr}$ represents the domestic energy demand on domestic production in region r, $\boldsymbol{f}^{rs}$ represents the embodied energy produced in region r by industry associated with demand of region s, $\boldsymbol{E}^r$ is a diagonalised vector of industry-