Resources, Conservation & Recycling xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

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

Full length article

Inter-provincial trade driving energy consumption in China

Nan Zhao[a], Lixiao Xu[a], Arunima Malik[b], Xuguang Song[a,*], Yafei Wang[a,*]

[a] School of Statistics, Beijing Normal University, Beijing 100875, People's Republic of China
[b] Centre for Integrated Sustainability Analysis, School of physics, The University of Sydney, New South Wales 2006, Australia

ARTICLE INFO

Keywords:
Structural decomposition analysis
Subnational multi-regional input-output table
Spatial decomposition
Energy consumption

ABSTRACT

China's energy saving at the provincial level has important policy implications for the mitigation of the greenhouse gas emissions in the world. Therefore, this study uncovers the driving forces of the changes of the provincial energy consumption by distinguishing the domestic and interregional trade based on the MRIO-based SDA technique for the period of 1997–2011. We find that (1) final demand per capita was the top determinant of the increments in provincial energy consumption, while both energy intensity and production structure offset the provincial energy changes; (2) most of 30 provinces were outsourcers due to the close interprovincial linkages; (3) product flows from utility and raw materials of upstream resource-dependent provinces were supplied to the coastal provinces, which are the manufacturing hubs. This implies policy making for the reduction of provincial energy in China should simultaneously implement measures on production-side and consumption-side. This is even more important when considering the embodied energy due to the interprovincial linkages within China.

1. Introduction

The Paris Agreement on Climate Change has entered into force in November 2016 and its goal is to keep global average temperatures from rising well below 2 °C with the aim of working to limit it to 1.5 °C. Nations have agreed to limit greenhouse gas emissions which essentially relates to deal with energy usage measured by the total primary energy supply (TPES) that reflects total energy use both in transformation and final use. Global energy production has been continuously rising since 1971 and reached 13,800 million tonnes of oil equivalent (Mtoe) in 2014 (International Energy Agency, 2016a). The continuous rise induced by nations' energy usage dramatically changed energy proportions among developed and developing economies over the past 40 years. For example, OECD (including Japan and Korea) and the rest of Asia (including China) together steadily accounted for three quarters of the global total for each year. However, OECD's share of global TPES fell from 61% in 1971–38% in 2014 while that of Asia has risen to 35% with more than 5% annually average growth during the past 40 years (International Energy Agency, 2016a). The dramatic changes of energy use proportions among nations is motivated by globalization and international trade because one region supports not only its domestic final demand but also final demand from other regions (Lan et al., 2016). This impact has been confirmed by other key research such as on CO_2 emission (Peters and Hertwich, 2008) and value added (Koopman et al., 2014). Among these nations, China has played an important role in the world's environmental and economic issues.

China was the world's largest energy consumer (23% of global total) and largest energy producer (19% of global total) in 2014 (International Energy Agency, 2016b) and thus the centre of the global energy issues. Thus, its energy transformation will contribute substantially to limit greenhouse gas emission and combat global climate change. Although China is currently the largest developing country and second largest economy in the world, its regional discrepancies between provinces are significant due to policy preferences, industrial foundations, and natural resource distribution (Guo, 2007). The east coastal regions have achieved a developed industrial level, while central and west regions are still in a relatively poor developing stage. This leads to increasing interregional links between provinces for promoting regional development (Wang et al., 2017b). Regional differences and interregional trade provide China key opportunities and challenges ahead for renewable energy, the central pillar of the low-carbon energy transition, as well as the critical role for energy efficiency. *The 11th, 12th, and 13th Five-Year Plans (FYPs) on National Economic and Social Development* have set energy-saving targets for energy efficiency, i.e., energy consumption per unit of GDP, for each five-year period (2006–2010, 2011–2015, and 2016–2020) has to decline 20%, 16%, and 15%, respectively. In order to achieve the energy-saving targets of the FYPs, China's has to allocate its targets to provinces and thus the driving forces that affect energy consumption changes in each province has to be revealed for helping to understand the reduction of global greenhouse gas emissions.

Previous studies of socioeconomic drivers for changes of

* Corresponding authors at: School of Statistics, Beijing Normal University, Beijing 100875, People's Republic of China.
E-mail addresses: songxuguang@bnu.edu.cn (X. Song), ywang@bnu.edu.cn (Y. Wang).

http://dx.doi.org/10.1016/j.resconrec.2017.09.009
Received 28 February 2017; Received in revised form 8 September 2017; Accepted 9 September 2017
0921-3449/

environmental indicators have been widely investigated at global (Andreoni and Galmarini, 2016; Lan et al., 2016; Zhao et al., 2016), national (Cansino et al., 2016; Liang et al., 2016; Liu et al., 2016; Nie and Kemp, 2014; Norman, 2017; Wang et al., 2017c; Weber, 2009; Zhang et al., 2016), and regional(Huang et al., 2017; Li et al., 2016; Shang et al., 2017; Zhang and Lahr, 2014) levels and for different indicators such energy (Ang and Wang, 2015; Lan et al., 2016; Nie and Kemp, 2014; Norman, 2017; Weber, 2009; Zhang and Lahr, 2014; Zhang et al., 2016), CO_2 (Andreoni and Galmarini, 2016; Cansino et al., 2016; Feng et al., 2015; Liang et al., 2016; Wang et al., 2013; Zheng et al., 2017), material flows (Huang et al., 2017; Li et al., 2016; Wang et al., 2017), air pollution (De Haan, 2001; Liu and Wang, 2017; Lyu et al., 2016), and water use (Shang et al., 2017; Yang et al., 2016).

Among the drivers' decomposition analysis, Index decomposing analysis (IDA) and structure decomposing analysis (SDA) are two main methods that are used to reveal socioeconomic drivers of environmental indicators (Su and Ang, 2012). The major difference of the two methods is that IDA uses index number methods such as Laspeyres, Paasche, and Divisia indices (Ang and Zhang, 2000), and SDA is based on input-output (IO) model (Hoekstra and van den Bergh, 2003). However, IDA offers highly aggregated sectors and neglects final demand, while IO-based SDA can overcome these technical gaps with the detailed-sector classifications and final-demand information. There are three SDA estimate methods- D & L method (Dietzenbacher and Los, 1998), the logarithmic mean Divisia index (LMDI) method (Ang et al., 2003; Ang et al., 1998), and the mean-rate-of-change index (MRCI) method (Lenzen, 2006). We use D & L method in this study to estimate the SDA results because it is exact, zero-robust and non-parametric (Lenzen, 2006).

Most of the SDA applications have used single-region input-output tables to identify the drivers of environmental variables (Li et al., 2016; Shang et al., 2017; Wang et al., 2013), but they cannot provide explicit transaction information through international or interregional trade and thus couldn't give insightful implications between regions. With multi-regional input-output (MRIO) databases developed in recent years, SDA studies using MRIO tables have been successfully applied to energy consumption (Lan et al., 2016; Wang et al., 2017a; Zhang and Lahr, 2014) and CO_2 emissions (Malik and Lan, 2016; Zhao et al., 2016). Both Lan et al. (2016) and Malik and Lan (2016) use annually continuous MRIO tables from 1990 to 2010 to decompose the increase of the global energy usage and CO_2 emissions into six socioeconomic factors including energy or carbon efficiency, production recipe, final demand composition, final demand destination, affluence, and population. Wang et al. (2017a) and Zhao et al. (2016) only use global MRIO tables to study the drivers of China's footprint or bilateral trade of China and U.S. Zhang and Lahr (2014)'s work is focused on China's grand regions and rough sectors (eight regions and 9 or 17 sectors) rather than detailed provinces and sectors. The four-year MRIO Tables – 1987, 1997, 2002 and 2007 – are constructed by different methods, industrial classifications and thus the comparability of the couple of tables still need to be improved. In addition, Chinese energy transfers through interregional trade have also demonstrated the importance of using MRIO analysis for Chinese meaningful policies of energy saving and emission mitigation at the regional level and via interregional trade (Zheng et al., 2017).

Still some research gaps exist in the current studies. First, most work applying SDA is based on global MRIO tables focusing on nations and international trade. Appropriate MRIO tables for uncovering the drivers at more detailed regional levels are absent/not applied on a wide scale, let alone meaningful policies for significant emissions via interregional trade. Second, present SDA studies do not depend on regionally- and/or sectorally-detailed MRIO tables, which cannot make relevant and useful policies for specific regions or industrial sectors. Additionally, continuous and consistent subnational MRIO tables for Chinese SDA applications are still not available. Therefore, our work is of importance to use a new developed Chinese subnational MRIO database to uncover the energy-consumption drivers at provincial level which distinguishes not only domestic activities but also interprovincial trade.

The new Chinese subnational MRIO database with annually consistent MRIO tables and environmental satellite accounts has been recently developed (Wang et al., 2017b). This database features high-resolution time series of Chinese subnational MRIO tables from 1997 to 2011. It can provide users' detailed interregional trade information between sectors of 30 provinces and thus is an appropriate tool for underpinning MRIO-based SDA and uncovering driving forces of energy usage increments due to interregional trade. Thereby it helps Chinese provinces to make policies with the aim of saving energy and limiting greenhouse gas emissions at the provincial level.

We aim to unveil the driving forces of the changes of the provincial energy consumption by distinguishing the domestic and interregional trade based on the MRIO-based SDA technique. The novelty of this study is in three aspects: a) it contributes a comprehensive measure of provincial energy changes from temporal and spatial perspectives; b) it is the first study to use a long annual time-series of Chinese MRIO tables containing 30 provinces and 30 sectors from 1997 to 2011 compared to grand regions used in most of the studies; c) it originally distinguishes domestic usage from outsourcing energy and thus provide a possibility to verify the outsourcing of energy-intensive products by coastal provinces to resource-dependent provinces in centre and west China.

The following paper first illustrates how the environmental multi-region input-output model combined with the SDA technique is used in uncovering the drivers of energy consumption changes for Chinese provinces over time. Some key results and insightful discussion are then presented, followed by a conclusion on this topic in the last section.

2. Methods and data

2.1. Environmentally-extended input-output model

Our model starts with Leontief's famous work (Leontief, 1936; Leontief, 1949) and Leontief and Strout (1963). Assume that an economy can be categorized into n sectors. Let $\mathrm{T} = (t_{ij})_{n\times n}$ be an $n \times n$ intermediate transaction matrix with t_{ij} representing the input from the ith sector to the jth sector in the economy, $\mathrm{x} = (x_i)_{n\times 1}$ be an $n \times 1$ vector of the total output with x_i being the ith sectoral total output, $\mathrm{A} = (A_{ij})_{n\times n}$ be an $n \times n$ direct requirement coefficient matrix with a_{ij} showing the direct input from the ith sector to the jth sector to produce one unit of output, $\mathrm{L} = (\mathrm{I} - \mathrm{A})^{-1}$ be the famous *Leontief Inverse Matrix* representing both direct and indirect input in order to produce on unit of output; and $\mathrm{Y} = (y_i)_{n\times m}$ be an $n \times m$ flow matrix including m categories of final demand and with y_i being the ith sectoral final demand. The standard Leontief's demand-driven input-output model can be shown as:

$$\mathrm{x} = \mathrm{L}\mathbf{Y} = (\mathrm{I} - \mathrm{A})^{-1}\mathrm{Y} = (\mathrm{I} - \mathrm{T}\hat{\boldsymbol{x}}^{-1})^{-1}\mathrm{Y} \tag{1}$$

Combining environmental satellite accounts with the above input-output model, we can obtain the environmentally-extended input-output model as:

$$\mathrm{Q} = \mathrm{q}\mathbf{LY} = \mathrm{Q}\hat{\boldsymbol{x}}^{-1}(\mathrm{I} - \mathrm{T}\hat{\boldsymbol{x}}^{-1})^{-1}\mathrm{Y} \tag{2}$$

where $\mathbf{Q}$ indicates the total energy consumption,$\mathrm{q} = (q_j)_{1\times n}$ is a $1 \times n$ vector of the energy intensity with q_j representing the energy usage (physical units, tonne of standard coal equivalent, tce) in the jth sector to produce per unit of monetary output in the corresponding sector.

2.2. Structural decomposition analysis

To enumerate the drivers of an increment in energy consumption over time, the final demand $\mathbf{Y}$ can be further decomposed into four factors:

(1) final demand composition $\mathbf{u} = (u_{id})_{n\times m} = \mathrm{Y}\hat{g}^{-1}$, where