Renewable and Sustainable Energy Reviews 73 (2017) 85–94

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

An Overview of the driving forces behind energy demand in China's construction industry: Evidence from 1990 to 2012

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ARTICLE INFO

Keywords:
Construction industry
Structural decomposition analysis
Driving forces
Energy consumption

ABSTRACT

The rapid urbanization in China has produced a large demand for energy in the past decades. It is therefore urgent to have an understanding of the driving forces behind the energy increase in the construction industry. This study applies structural decomposition analysis (SDA) to quantify the effects of driving factors from insight into consumption and production. The results show that the energy consumption trajectory of China's construction industry is the result of competition between the effect of increasing final demand and improvement in energy efficiency. Although the effect of consistent efforts in structure optimization by the central government was significant from 2007 to 2012, the potential to save much energy still lies in structure optimization in energy, production, and final demand. According to the projection, structural upgrades in economy would be the most important factor for energy reduction in 2020. Scenario analysis further indicated that the percentage change of energy increments in 2020 can be reduced at 22% of 2010 level under the optimistic scenario. Sector aggregation analysis revealed that more aggregates would increase uncertainty to some extent and result in a misinterpretation of the importance of the underlying factors. According to the quantitative analysis in this study, the percentage change of total embodied energy consumption in the construction industry should be limited below 25% of 2010 level at the end of the 13th Five-Year Plan.

1. Introduction

China is on path to rapid urbanization and industrialization. As the result of such intensive construction, the growth rate of energy consumption in buildings is more than 10% in the past decades [1]. Being the primary energy consumer in the society, the construction industry accounted for 16% of total economy's energy consumption in China in 2007 [2] and projected to be 20% in 2015 by Chang and Wang [3]. Therefore, considering the requirement for sustainable development in China, it is urgent to understand the driving forces behind the energy increase in the construction industry. The aim of this study is to provide an overview of the driving forces and energy use trajectory of the construction industry by utilizing both economy analytical methods and time-series input-output tables. Such investigation could not only facilitate specific policy decisions on energy and environmental issues in relation to the building sector but also switch the urbanization process towards more sustainable development.

An effective method to comprehensively understand the relative contribution and mechanism of different driving forces is decomposition analysis, which breaks down the total changes into sub-effects induced by a number of factors. This method quantifies these effects on total energy demand individually at the industrial or national level [4–7].

In general, many different methods based on decomposition theory have been proposed by different researchers [8–12]. Index decomposition analysis (IDA) and structural decomposition analysis (SDA) are two of the most popular approaches in previous studies. Of these, IDA is the most time-efficient and has the advantage of lower requirements for specific economic data to explore the driving factors hidden behind the economic system. However, without the use of an input-output table, IDA fails to provide detailed information on the economic structure and supply chain. This implies that only direct effects from the changes of factor can be assessed by index decomposition [5,13,14].

These theoretical deficiencies have been addressed by employing the SDA model, which is designed to quantify the effects of driving factors based on the input–output analysis in the entire economy. SDA enables decomposition analysis to understand the hidden linkage and

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http://dx.doi.org/10.1016/j.rser.2017.01.021
Received 26 October 2015; Received in revised form 12 July 2016; Accepted 7 January 2017
1364-0321/

indirect interactions at the sectoral level and to reflect the structural changes from insight regarding consumption and production [15,16]. The contributions from different factors have been assessed quantitatively and separately with the decomposition of all directly related factors. Although the SDA model has been restricted to the availability of economic data and can only be represented additively due to the use of input-output table, it has been widely employed to examine the driving forces leading to Chinese environmental loading issues [17–21]. SDA has also been applied on the industrial and city scale in China with the results playing a significant policy role [13,22,23]. Therefore, given the data specificity and information completeness, this study used SDA as the basic model to conduct decomposition analysis.

However, very few studies have applied the SDA model to China's construction industry, which currently has large energy demands because of the booming property market. Lu et al. [24] used Logarithmic Mean Divisia Index decomposition method to quantify incremental carbon emissions of China's construction industry from 1994 to 2012. The findings indicated that the change of energy structure and intensity comprised the major leading factors for emission mitigation in the construction industry. Hatayama and Tahara [25] utilized decomposition analysis to predict metal consumption (e.g. steel, aluminum, copper, and zinc) in the building stock. Hong et al. [26] decomposed energy interactions of the construction sector to identify critical energy-intensive paths in the upstream supply chain. Liu et al.[27] made a structural analysis of China's construction industry based on the Panzar-Rosse model. In fact, China's construction industry is an ideal subject to investigate energy consumption trajectory because it not only generates significant environmental impact but is also characterized by its extensive and sizable construction projects. Thus, exploring the driving forces behind the increase in energy consumption is not only fundamental to provide comprehensive analyses and projections for future energy consumption but also critical to enhance sustainable development of energy application in the construction industry. This study seeks reasoned explanations and policy implications regarding the characteristics of the construction industry from 1990 to 2012. The contribution of this paper consists of the following two aspects. First, a national level investigation of the trajectory of the energy use embodied in China's construction industry will provide an indication of potential barriers and possible means of improving the development of sustainable construction in China. Second, a systematic analysis of the driving forces behind the energy demand will provide a holistic understanding of leading driving factors. This can not only facilitate decision makers to determine the direction of further improvement but also promote the development of relevant policies at both national and industrial levels.

2. Methodology

2.1. Data source and consolidation

Two categories of data are required in this study: time-series input-output tables and year-based energy consumption data. First, all of the input-output tables are collected from the Chinese National Bureau of Statistics. These tables are all edited into the 28-sector format (see Appendix A) because sector classification was different from 1990 to 2012. Moreover, to keep the price consistent among the different tables, the monetary flows are all concerted into 1990 constant prices via price indexes. Second, all the year-based energy consumption data are obtained from Chinese energy statistical yearbook. However, the classification of the economic sector in the yearbooks is not consistent with input-output table. In fact, the I-O table compiled by the National Bureau of Statistics is more specific on the detailed monetary flow data while the direct energy input data are collected at a more aggregate level. Therefore, it is necessary to disaggregate the sectoral energy consumption data and make them specifically match the sector classification of the input-output tables. Such disaggregation is based on the assumption that the sub-sectoral energy consumption data is proportional to its economic output. Four types of energy have been considered—coal, oil, natural gas, and other types of primary energy (e.g. nuclear, solar, wind, biomass energy, etc.). To avoid the problem of double-counting, national energy balance tables have been used to remove the energy consumed in the energy transformation, intermediate consumption, and losses in coal washing and dressing.

2.2. Model development

The input-output analysis was introduced by Leontief and completed in 1970. It has served as a validation method to analyze "externalities" of products or services by quantifying the inter-industrial interdependence relationship in the entire economic system using publicly available data [28]. Such analytical tools are an efficient tool and technique to measure environmental impacts from a top-down perspective for many years [29–32]. In general, the input-output analysis can be expressed as:

$$F = C(I - U)^{-1}D \tag{1}$$

Where C is a 4*28 vector representing the direct energy input from four types of primary energy sources to all sectors, I is the identity matrix, U is the 28*28 matrix representing the intermediate use coefficient matrix in the input-output table, D is a 28*1 vector representing the total final demand of the construction sector since this study applies SDA model on one specific industry/sector rather than a national level. F is the target environmental impact related to the final demand in the vector D for the construction sector.

The form of decomposition is flexible according to various perspectives. In general, the total changes can be decomposed into the effects from three separate factors: the change of industrial energy intensity (ΔC), the change of production structure ($\Delta(I - U)^{-1}$), and the change of final demand (ΔD). However, the total change in energy intensity is the sum of energy intensities of various energy types. This overall effect may be caused by the structural change and energy efficiency improvement. Therefore, to measure each individual effect and distinguish the difference between them, an intermediate variable was used in the study by Chang, Lewis [33]:

$$\mathrm{C}^{t(t-1)} = C_{t-1}\frac{\sum_{i=1}^{\mathrm{n}} \mathrm{C}_{i(t-1)}}{\sum_{i=1}^{\mathrm{n}} \mathrm{C}_{\mathrm{it}}},\ \text{where} i = 4 \text{ types of primary energy sources} \tag{2}$$

Eq. (2) indicates that the energy consumption structure is static at the initial year (t-1), and the total amount of energy is equal to the current year (t). Consequently, we have:

$$\Delta C_v = C^t - C^{t(t-1)} \tag{3}$$

$$\Delta C_s = C^{t(t-1)} - C^t \tag{4}$$

Where ΔC_v describes the change in total energy intensity, and ΔC_s describes the change of energy structure. Similarly, another variable for differentiating structural change and growth effect for final demand can be defined:

$$D^{t(t-1)} = D_{t-1}\frac{\sum_{i=1}^{n} D_{i(t-1)}}{\sum_{i=1}^{n} D_{it}},\ i = \text{categories of final demand} \tag{5}$$

$$\Delta D_v = D^t - D^{t(t-1)} \tag{6}$$

$$\Delta D_s = D^{t(t-1)} - D^t \tag{7}$$

Eq. (5) indicates that the final demand structure is maintained in the initial year (t-1) whereas the total volume of final demand is the same as the current year (t). The ΔD_v represents the change of final demand volume, and ΔD_s represents the structural change of final demand. Consequently, the total change in environmental loading F from base year 0 to later year t can be expressed as: