Energy 85 (2015) 366–378

Contents lists available at ScienceDirect

Energy

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

Logarithmic mean Divisia index (LMDI) decomposition of coal consumption in China based on the energy allocation diagram of coal flows

ChinHao Chong, Linwei Ma*, Zheng Li, Weidou Ni, Shizhong Song

State Key Laboratory of Power Systems, Department of Thermal Engineering, Tsinghua-BP Clean Energy Centre, Tsinghua University, Beijing 100084, China

ARTICLE INFO

Article history:
Received 22 December 2014
Received in revised form
17 March 2015
Accepted 20 March 2015
Available online 2 May 2015

Keywords:
Coal consumption
LMDI
Sankey diagram
Coal flow
Influencing factor

ABSTRACT

This manuscript attempted to analyze the influencing factors of coal consumption growth in China using the logarithmic mean Divisia index (LMDI) decomposition method developed based on the physical processes of coal utilization from raw coal to the end-use sectors. By mapping the energy allocation diagram of coal flows, we built a method to balance the energy allocation of coal flows and derived several technical influencing factors. These factors were used to develop an LMDI decomposition method suitable for analyzing the coal consumption growth of complex coal-use systems, such as that of China. The method is subsequently applied to analyze the influencing factors of China's coal consumption growth from 2001 to 2011. The results indicate the rapid growth of GDP (gross domestic production) per capita, which heavily relied on the expansion of heavy industry as the dominant factor driving coal consumption growth. Improvement in the energy efficiency of coal power generation and coal end-use combustion were the primary factors reducing coal consumption.

1. Introduction

China now is the largest coal producer and coal consumer in the world, accounting for 46.6% of the global coal production and 50.3% of the global coal consumption in 2013 [1]. Faced with challenges of global climate change and domestic environment protection, controlling the rapidly increasing coal consumption in China has become an important issue, not only for China but also for the world [2–4]. Referring to IEA and BP, policy choices in China, which has outlined plans to cap the share of coal regarding total energy use, will be particularly important as China now consumes as much coal as the rest of the world combined [5]. In addition, the trends of global coal growth before 2035 will be greatly influenced by China's profile [6]. However, most of the discussions presented in previous studies have focused on the coal needs and targets for controlling the total coal consumption [7–9]. Quantitative analyses on the influencing factors of coal consumption growth that consider the rapid and dynamical development of energy systems in China are lacking, which are essential for developing effective policies to control coal consumption and deserve further study.

The index decomposition analysis (IDA) method has been widely applied to analyze the influencing factors of energy consumption growth, including those based on the Laspeyres index and the Divisia index [10]. Ang et al. [11–13] presented a review of the development and applications of IDA methods and recommended the logarithmic mean Divisia index I (LMDI) method because it is robust and convenient for many applications. Many studies have utilized the LMDI method to decompose the total energy consumption growth of various regions and countries [14–16], and the commonly considered factors are population growth, GDP (gross domestic production), economic structure, energy intensity and energy mix. However, to apply the LMDI method to coal consumption growth in China, for which research is lacking, the factors that are considered need to be expanded because coal is only one part of the energy system. In addition, China consumes a huge amount of coal, and the uses of coal have been diversified for various sectors, including power and heat generation, coking and end-use combustion, etc. Therefore, the structural changes through energy use systems, including the stages of primary energy sources, energy conversion and energy end-use, in addition to technically detailed factors such as energy conversion efficiency and energy end-use efficiency, should be carefully considered to further develop the LMDI method to decompose the technical details of coal consumption growth.

* Corresponding author.
E-mail addresses: malinwei@tsinghua.edu.cn, malinwei@gmail.com (L. Ma).

http://dx.doi.org/10.1016/j.energy.2015.03.100
0360-5442/

Abbreviations

Subscript i	ith industry involved
Subscript j	jth energy involved
Subscript k	kth influencing factors involved
IDA	index decomposition analysis
LMDI	logarithmic mean Divisia index
SQ	standard quantity
PEQ	primary energy quantity
CBPEQ	coal-based primary energy quantity
$E_{SQ,j}$	jth energy expressed in SQ
$E_{SQ,ij}$	jth energy expressed in SQ in the ith industry
$E_{PEQ,j}$	jth energy expressed in PEQ
$E_{CBPEQ,j}$	jth energy expressed in CBPEQ
C	total raw coal consumption
C^0	total raw coal consumption at time 0
C^T	total raw coal consumption at time T
P	population
GDP	gross domestic production
GDP_i	value added of the ith sector
Q	GDP per capita
S_i	proportion of the ith industry
I_i	energy intensity of the ith industry
M_{ij}	proportion of the jth fuel in the ith industry
$K_{combustion,j}$	end-use combustion factor of energy j
$K_{PEQ,j}$	primary energy quantity converted factor of energy j
$K_{coal,j}$	coal component factor of energy j
$K_{fossil,j}$	fossil fuel component factor of energy j
ΔC_{pop}	increment of raw coal consumption caused by change of P
ΔC_{aff}	increment of raw coal consumption caused by change of Q
ΔC_{str}	increment of raw coal consumption caused by changes of S_i
ΔC_{int}	increment of raw coal consumption caused by changes of I_i
ΔC_{mix}	increment of raw coal consumption caused by changes of M_{ij}
ΔC_{com}	increment of raw coal consumption caused by changes of $K_{combustion,j}$
ΔC_{peq}	increment of raw coal consumption caused by changes of $K_{PEQ,j}$
ΔC_{coal}	increment of raw coal consumption caused by changes of $K_{coal,j}$
ΔC_{fos}	increment of raw coal consumption caused by changes of $K_{fossil,j}$
F_k^0	value of the kth influencing factor at time 0
F_k^T	value of the kth influencing factor at time T
ΔC_{F_k}	increment of raw coal consumption caused by the kth influencing factor
λ_k	elastic efficiency of the kth influencing factor

This study aims to develop an LMDI method suitable for analyzing the coal consumption growth of countries with complex coal use systems, such as in China, and to apply the method to analyze the influencing factors of coal consumption growth in China. First, by mapping China's coal flows to Sankey diagrams, we studied the physical processes of coal use from the raw coal supply to the end-uses as electricity, heat and coke, and thus derive key influencing factors that need to be further considered. Then, using these key influencing factors, we develop an LMDI method suitable for analyzing such coal use systems and apply it the coal consumption growth in China from 2001 to 2011, during which China's coal consumption increased by an average growth ratio of 12.5%.

The contents of this paper are organized as follows: an introduction of the methodology and data input are described in Section 2, the results and discussion are given in Section 3, and conclusions and suggestions are summarized in Section 4.

2. Methodology and data input

2.1. Sankey diagram and technical influencing factors

Sankey diagrams are popular in energy system analyses [17–19] and coal system analyses [20–22]. In this work, an energy allocation Sankey diagram, which presents the energy balance from raw coal supplies to the final end-uses, is used as a tool to understand the physical process of coal systems and to derive the key influencing factors of coal consumption growth.

2.1.1. Diagram structure and energy balance

In this study, the energy allocation Sankey diagram of coal was divided into three stages: 1.) raw coal supply 2.) coal transformation and 3.) end-use sector. The diagram was mapped according to the first law of thermodynamics. The width of the flow signified the quantity of the energy, and the colour of the flow signified the type of energy.

No energy loss is reflected in energy allocation Sankey diagrams. Therefore, we trace the energy of raw coal as it is exploited. After production and importation, the raw coal is processed and converted into secondary energy sources, such as coke, heat and electricity, in transformation sector and finally consumed at the end-use sectors. By compensating for all of the energy losses that occur during energy processing and transformation, we can express the secondary energy consumption as a coal-based primary energy quantity (CBPEQ), which indicates the amount of raw coal consumption required to produce a secondary energy source.

2.1.2. Original data – energy balance table

The Energy Balance of China and the Final Energy Consumption by Industrial Sector, are two statistical tables in the China Energy Statistical Yearbook, are used as the original data sources for mapping the Sankey diagram. The data in the Energy Balance of China is vertically divided into 6 parts: A) primary energy supply, B) input (−) and output (+) of the transformation, C) loss, D) final consumption, E) statistical difference, and F) total energy consumption, and horizontally divided into 30 types of energy, including raw coal, various coal products, crude oil, various oil products, natural gas, electricity, heat and recovery energy. The details of the final energy consumption of industrial sectors are further presented in another table named Final Energy Consumption by Industrial Sector, which includes more than 40 subsectors. To illustrate the structure of the final consumption of the industrial sectors in the diagram, we re-categorized the subsectors in the industrial sector, as shown in Table 1. Because the coal preparation ratio according to the Energy Balance of China is much lower than the actual data, we adjusted the ratio according to another study [23] in the mapping. However, it became too complex to apply this adjusted ratio because we are unable to obtain more accurate information to estimate the losses in the coal preparation process after the revision. Hence, the original ratio is kept in the LMDI decomposition.