Energy 97 (2016) 296–305

Contents lists available at ScienceDirect

Energy

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

Decomposition analysis of energy consumption for an freeway during its operation period: A case study for Guangdong, China

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A R T I C L E I N F O

Article history:
Received 6 April 2015
Received in revised form
27 December 2015
Accepted 31 December 2015
Available online xxx

Keywords:
Energy consumption
Decomposition analysis
Operation period
Freeway management

A B S T R A C T

Freeways have become the main subject of energy conservation reviews in China because of their large energy consumption. Decomposition analysis has been widely applied in energy consumption studies. However, most studies have only analyzed the driving forces of energy consumption on the national level, and seldom at smaller levels, e.g. for departments like toll stations and maintenance centers. Based on the characteristics of the freeway operation period, this paper serves as a preliminary attempt at applying the logarithm mean Divisia index method I on the department level to analyze the energy consumption of freeways during the operation period. To elucidate the evolution of energy consumption during the operational period, the logarithm mean Divisia index analysis was performed to disentangle the energy consumption based on a real case in Guangdong from 2005 to 2013. The analyses establish that the traffic volume influences energy consumption. The results show that some departments can influence the total energy consumption. For example, the tunnels and toll stations are key factors that influence the total energy consumption of the whole road. The decomposition in the departments revealed that energy efficiency improvements caused by the use of alternate materials and energy-saving technologies mainly contributed to energy conservation.

1. Introduction

The transportation sector is an industry that consumes resources and energy. According to relevant statistical data, the energy consumption related to the transport, storage, and postal industries in China was 7.47% of the country's total consumption in 2005, which increased to 8.2% by 2011 [1]. With increased infrastructure development and traffic volumes, the transportation sector has emerged as the second largest energy consumer in China. Data from the Chinese statistical yearbook [1] (Fig. 1) shows that the constructed mileage of freeways has increased greatly since 1988, when freeway construction began. In addition, since freeways are a type of independent toll-road in China, many facilities and huge manpower input are required for the daily maintenance of freeways to ensure vehicular safety. For one of the freeways in China, Ting and Wei reported that the total energy required for operating the lighting system in 9 tunnels was 395.3×10^4 kWh/year [2]. Moreover, Shang et al. reported that the energy required per kilometer for maintenance of a four-lane freeway with a PCC (Portland cement concrete) pavement during its operation is 7.119×10^6 kcal/t [3]. Compared with the construction and recycling periods, the operation period is characterized by long-term, variable, and heavy consumption, which makes it very important in the study of freeway energy consumption. Therefore, evaluating the energy consumption related to transportation, especially that related to the daily operation and management of freeways, has become necessary.

However, due to a lack of standardized energy consumption indexes and computation methods, evaluating energy consumption by freeway management is difficult. Therefore, the characteristics of energy consumption must be urgently studied and appropriate computation and evaluation methods must be selected to support both the evaluation of freeway management energy consumption and work related to censoring for energy conservation.

For controlling and mitigating energy consumption, an effective analysis of the factors influencing consumption, including traffic volume, maintenance strategy, and technological changes, is required. Nowadays, decomposition analysis is widely applied in

Abbreviations: IDA, index decomposition analysis; SDA, structural decomposition analysis; LMDI, logarithm mean Divisia index; AC, asphalt concrete; PCC, Portland cement concrete; CRCP, continuously reinforced concrete pavement; CIP, cold in-place; LED, light-emitting diode.

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http://dx.doi.org/10.1016/j.energy.2015.12.141

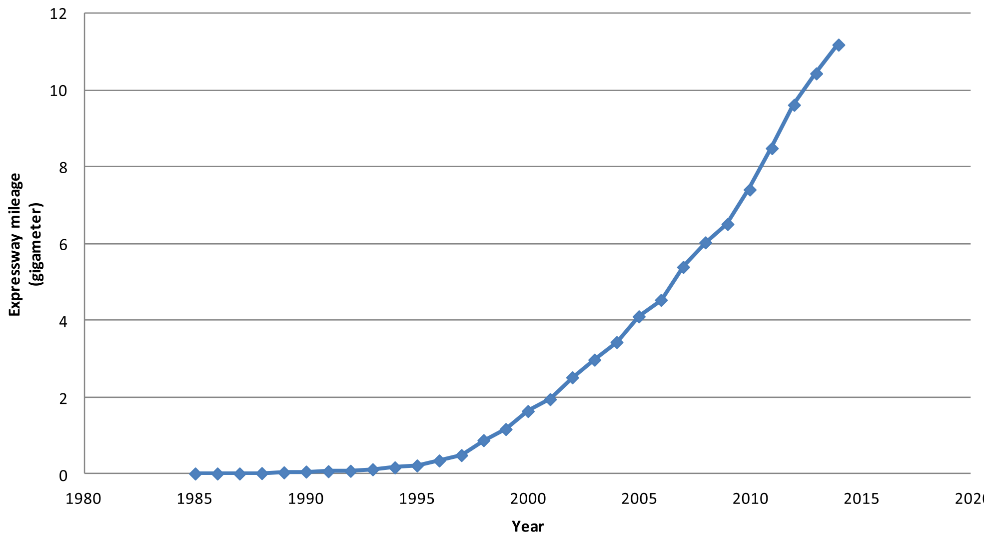

Fig. 1. Constructed mileage of freeways in China by year.

energy and environmental studies. Depending on the model type, decomposition analyses can be classified into IDA (index decomposition analysis), SDA (structural decomposition analysis), shift share analysis, growth accounting analysis, etc. [4]. SDA and IDA have been extensively applied to analyze the driving forces of changes in an aggregate indicator. SDA is used primarily by researchers who are familiar with input–output analyses and wish to extend it to the study of changes in energy consumption or emissions. IDA is often used by energy researchers for better understanding the driving forces of energy use and energy-related emissions in a specific energy consumption sector, such as transportation or manufacturing sector [5]. Ang and Zhang provided details on two kinds of IDA methodologies, viz. the Laspeyres index decomposition analysis and Divisia index decomposition analysis [6]. Each IDA can be applied in a period-wise or time-series manner. A period-wise analysis compares indices between the first and the last year of a period, for a given country, region, manufacturing sector, etc. A time-series analysis involves yearly decomposition using time-series data, and its results show how the impact of predefined explanatory factors evolves over time [7].

In 2003, by giving a more complete and up-to-date overview of perfect decomposition techniques and their roles in energy demand and related analysis, Ang et al. concluded that the LMDI (logarithm mean Divisia index) methods, in particular LMDI I, have several advantages over the other perfect decomposition methods, in terms of ease of application and flexibility [8]. In 2004, after an overview of the application and methodology development of decomposition analysis, Ang discussed the properties of the developed methods and concluded by recommending the multiplicative and additive LMDI I methods due to their theoretical foundation, adaptability, ease of use, and result interpretation [9]. Choi and Ang examined the possible link between the ratio measure and the difference measure, including their decomposition techniques and a unique pair of decomposition formulae [10]. Ang and Choi showed that the zero values may be replaced by a small number δ, and that converging results were obtained when δ approaches zero [11]. In the face of arguments about the “zero values” by Wood and Lenzen [12], Ang and Liu compared the two strategies and extend their earlier research by generalizing the analytical limits of LMDI [13].

In recent years, more research has been devoted to applying decomposition analysis to better understand the driving forces of energy consumption and energy-related emissions in transportation. Saidur et al. proposed useful energy and energy analysis models for different modes of transport in Malaysia and compared the result with those obtained from a few other countries [14]. Andreoni and Galmarini used decomposition analysis to investigate the carbon dioxide emission intensity, energy intensity, structural changes, and economic activity growth effects for the water and aviation transport sectors [15]. In China, Zhang et al. identified the relations between transportation energy consumption and its related factors using the LMDI [16]. Li et al. developed a two-phase decomposition model to quantitatively analyze the driving forces behind increases in passenger transport energy consumption in Guangzhou, Beijing, and Shanghai [17]. Zhang et al. used a new decomposition model based on LMDI method to analyze China's passenger transport energy in mega-cities [18]. Chang et al. used the LMDI method to analyze energy consumption related to intercity passenger transport in China [19]. Wang et al. discussed and analyzed the current status of transport-related energy consumption in China, including four different transport sub-sectors: roads, railways, waterways, and civil aviation, and outlined the energy consumption trends in these sub-sectors. They also evaluated the technological status and development direction of energy conservation in these sub-sectors [20]. Kang et al. performed a multisectoral decomposition analysis to disentangle the greenhouse gas emissions in Tianjin from 2001 to 2009 [21].

However, as is evident above, most studies have only analyzed the driving forces of energy consumption at the national level; few studies have focused on energy consumption at the departmental level, such as toll stations and maintenance centers, in the road sub-sector. For department-level management, a more detailed analysis of the sector and sub-sector dimensions is needed. Based on the characteristics of the freeway operation period, this paper discusses a preliminary attempt at applying the LMDI method to analyze freeway energy consumption during operation from 2005 to 2013, to elucidate the factors influencing energy consumption.

The remainder of the paper is organized as follows. Section 2 presents the related factors, and proposes the LMDI model for decomposing the changes in aggregate energy consumption in freeways over time. Section 3 presents the data source. In Section 4, the main results of the decomposition analysis are reported. Section 5 discusses the influence of materials and technology on the