Journal of Cleaner Production xxx (2015) 1–7

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Factor analysis of energy-related carbon emissions: a case study of Beijing

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A R T I C L E I N F O

Article history:
Received 12 May 2015
Received in revised form
15 July 2015
Accepted 16 July 2015
Available online xxx

Keywords:
Carbon emissions
Beijing
Generalized Fisher index
Factor decomposition
Policy suggestions

A B S T R A C T

Carbon emissions in China have attracted increasing world attention with rapid urbanization of this country. It is critical for the government to identify the key factors causing these emissions and take controlling measures. Consistent results have not been achieved yet although some research has been conducted on the factors leading to emissions. Meanwhile, there is still considerable room to improve the methods of previous research. Index decomposition analysis (IDA) is the main method for quantifying the impact of different factors on carbon emissions. At present, the widely used forms of IDA are primarily the Laspeyres and the Divisia index methods. Compared with the Laspeyres and the majority of the Divisia index methods, the generalized Fisher index (GFI) decomposition method can eliminate the residuals and has better factor decomposition characteristics. This paper chooses Beijing as a typical example and analyzes the factors causing carbon emissions. Based on the extended Kaya identity, we built a multivariate generalized Fisher index decomposition model to measure the impacts of economic growth, population size, energy intensity and energy structure on energy-related carbon emissions from 1995 to 2012 in Beijing. The results show that the sustained growth of economic output in Beijing was the leading factor in carbon emissions. Population size had a stimulating effect on the growth of carbon emissions during this period; the pulling effect increased after 2003 and then decreased slightly after 2011 with a cumulative effect of 165.4%. Energy intensity was the primary factor restraining carbon emissions, and the inhibition effect increased yearly. The continuous optimization of the energy structure had no obvious inhibitory effect on carbon emissions. To control carbon emissions, Beijing should continue to adjust the mode of economic development and appropriately control the population size while improving energy efficiency.

1. Introduction

With the rapid development of China's economy, energy consumption based on fossil fuel continues to increase. Air pollution, greenhouse effect and other environmental problems have become increasingly prominent, seriously restricting the sustainable development of China's economy. As China's capital and its political and cultural center, Beijing should play a leading role in mitigating and adapting to climate change. Since entering the 21st century, Beijing's economy has maintained rapid growth, with an average gross domestic product (GDP) annual growth rate of 11.17%; energy intensity has fallen sharply, whereas the energy consumption structure and consumption pattern have improved. However, although Beijing has made remarkable achievements, economic growth continues to depend on energy. Energy consumption grew at an average annual rate of 4.16% from 1995 to 2012. Correspondingly, carbon emissions also increased significantly. Faced with a lack of resources, energy restrictions have gradually become a bottleneck in restricting the Beijing's economic and social development and remain a challenge for energy conservation. For better implementation of emission reduction targets, the contribution of factors influencing carbon emissions from energy consumption in Beijing should be explored and relevant policies and effective measures must be formulated to control and reduce carbon emissions according to the influencing factors. These tasks are urgently needed to achieve the goal of building a "green Beijing", which has positive practical significance for the successful operation of the Chinese low-carbon economy at the provincial level.

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http://dx.doi.org/10.1016/j.jclepro.2015.07.094

2. Literature review

Accurate analysis of the reasons for the increase in carbon emissions is critical to finding a path to carbon reduction. Index decomposition analysis (IDA) as an analytical framework to study the characteristics and mechanisms of change first expanded from the field of energy consumption to energy-related carbon dioxide (CO_2) emissions in 1991, and has gradually become the main research method for analyzing changes to carbon emissions (Xu and Ang, 2013). At present, the most commonly used IDA are the Laspeyres and the Divisia index methods. Complete decomposition analysis was used by Das and Paul (2014) to identify the causes of changes in CO_2 emissions from household consumption between 1993–94 and 2006–07 in India. The results indicate that activity, structure and population effects are the main causes of the increase in CO_2 emissions from household fuel consumption. Diakoulaki et al. (2006) split the period 1990–2002 into two equal intervals and relied on the refined Laspeyres model starting from the major energy consuming sectors and aggregating the obtained effects for estimating their relative impacts on CO_2 emissions in Greece. Ang and Pandiyan (1997) and Lee et al. (2001) used the Divisia decomposition method and adaptive weighting Divisia decomposition method, respectively, to analyze the factors affecting carbon emissions in the manufacturing sectors of different countries.

The Laspeyres and the majority of the Divisia index methods cannot handle the residuals existing in the decomposition process, which renders the model unable to explain all of the changes in carbon emissions. Ang and Choi (1997) put forward an improved method called logarithmic mean Divisia index (LMDI), which has been widely applied in practical research. Fernández et al. (2014) applied the LMDI method to quantify the driving forces behind changes in CO_2 emissions in the EU-27 in 2001–2008 and noted in general terms that the increased efficiency in CO_2 emissions by European countries had been sufficient to override the joint pressure of population and economic growth on CO_2 emissions. Liu et al. (2007) and Deng et al. (2014) also used the LMDI decomposition method to explore the reasons and regulations of the Chinese industrial sector and the changes in carbon emissions in different regions of China.

As observed in the above literature, the Laspeyres and the Divisia index methods are chosen more often in the decomposition of carbon emissions. As noted above, these methods have their defects; although LMDI can eliminate the residuals, its formulae contain logarithmic terms that cannot accommodate negative values (Ang et al., 2004). The generalized Fisher index (GFI) has better decomposition characteristics because it can overcome the shortcomings of the Laspeyres index and the Divisia index and the traditional two-factor analysis of the Fisher index well. Ang et al. (2004) compared the GFI method with five widely known IDA methods. In the comparison, factor-reversal, time-reversal, proportionality, aggregation, zero-value robust and negative-value robust tests had been done. The GFI method failed only the aggregate test and passed the remaining tests, achieving complete factor decomposition, which provide a powerful basis for reasonable selection of the GFI for factor decomposition.

Some scholars have analyzed the factors in carbon emissions from energy consumption in Beijing. Wang et al. (2012) and Zhu and Zhang (2012) adopted STIRPAT to examine the relationship between carbon emissions produced in the process of economic development in Beijing and different driving factors, with different results. Wang et al. (2012) noted that CO_2 emissions were positively influenced by urbanization level, economic level and industry proportion and negatively influenced by the proportion of tertiary industry, energy intensity and R&D output. Zhu and Zhang (2012) confirmed the contribution of the level of urbanization and population to carbon emissions but noted that per capita GDP and energy intensity had less effect than urbanization and population. The proportion of secondary industry was negatively correlated with CO_2. Based on input–output structural decomposition analysis, Wang et al. (2013) analyzed the driving forces of the increase in CO_2 emissions in Beijing from both production and final demand perspectives during 1997–2010. According to the results, the growth in CO_2 emissions in Beijing was driven mainly by changes in production structure and population growth, partly offset by a reduction in the intensity of CO_2 emissions and a decline in per capita final demand volume during the study period. Change in final demand structure had a limited effect on the change in CO_2 emissions in Beijing. From the final demand perspective, urban trade, urban residential consumption, government consumption and fixed capital formation were mainly responsible for the boom in emissions. Tian et al. (2013) conducted a structural decomposition analysis to quantify the contributions of technological and socio-economic factors to Beijing's rapid growth in CO_2 emissions from 1995 to 2007. The results showed that the final demand for export and investment led to variations in CO_2 emissions in Beijing for the same period by 56% and 21%, respectively; the change in production structure jointly contributed 455% of the total increase in CO_2 emissions; and improved energy intensity was Beijing's primary source of decarbonizing its economic development in 1995–2007. Zhang and Xie (2013) introduced the same method and analyzed the driving factors of carbon emissions in Beijing at the levels of the overall situation, different industries and different industrial sectors in 1997–2007. The results proved the pulling effect of economic growth and the inhibitory effect of energy intensity on carbon emissions and noted that domestic exports and consumption override exports and investment were major contributors to the increased emissions in the size expansion effect. In the studies using the LMDI decomposition technique to decompose the changes in Beijing's carbon emissions in different periods, Liu et al. (2010), Liu and Chen (2013), Li (2011), and Wu et al. (2014) produced results consistent with those of previous research on the role of economic growth and energy intensity in carbon emissions. As for the impact of energy structure and industrial structure, the researchers' opinions differ. Wu et al. (2014) expressed the view that energy structure and industry structure have greatly contributed to carbon emission reduction. Liu et al. (2010) and Liu and Chen (2013) noted that energy structure has played a positive role in reducing carbon emissions but that the effect is small. Li (2011) further noted that the contribution of energy structure to carbon emission reduction in Beijing is not large, showing a further weakening trend after 2006.

As observed, the factors influencing carbon emissions have been analyzed with different methods by current scholars; however, the GFI model is used by few scholars, and the conclusions have not been the same. The GFI model, as the best choice for factor decomposition, is seldom used in the empirical analysis of carbon emissions in China and is used even less at the regional level. Tian and Zhang (2011) and Li and Wang (2008) respectively constructed decomposition models of per capita carbon emissions and regional energy-related carbon emissions in China. However, when calculating the contributions of the influencing factors, they violated the multiplication form of the GFI and adopted the proportion form for calculation and analysis; thus, the conclusions are not accurate. From the above analysis, this paper selects the GFI method to explore the driving forces of carbon emissions in Beijing.