Journal of Cleaner Production 145 (2017) 209–220

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Analysis of regional contributions to the national carbon intensity in China in different Five-Year Plan periods

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ARTICLE INFO

Article history:
Received 29 September 2016
Received in revised form
23 December 2016
Accepted 9 January 2017
Available online 11 January 2017

Keywords:
Regional contribution
Carbon intensity
Carbon emissions
Energy consumption
LMDI method

ABSTRACT

Using the logarithmic mean Divisia index (LMDI) method, we decomposed factors affecting the national carbon intensity (NCI) in China at a multi-regional level. A comparative analysis of regional contributions in different Five-Year Plan (5YP) periods revealed that the energy structure had inhibitory effects on NCI during the 9th and 10th 5YP periods, but had promoting effects during the 11th and start of the 12th 5YP periods. The energy structure had a strong inhibitory impact in eastern, north-eastern, and northern regions of China, but only a slight impact in central, northern, south-western, and north-western regions. Energy intensity is a major factor and had a strong inhibitory effect on NCI except during the 10th 5YP period. Energy intensity had a strong inhibitory effect in eastern and northern regions, but only a slight impact in north-western and southern regions, especially in Hainan, Ningxia, Xinjiang, and Qinghai provinces. Overall, proportional output in China had a promoting effect on NCI, which indicates regional economic development was not coordinated. The combined effects of regional carbon intensity (RCI) and proportional output determined changes in NCI, and RCI had a strong effect on NCI. Regions with high proportional output and large carbon emissions had a great impact on NCI. The total effect in developed areas such as eastern, northern, and north-eastern regions was strongly inhibitory, while the impact was slight in relatively less developed areas such as northwestern and southern regions. Some policy implications arising from our study results are discussed.

1. Introduction

As the largest carbon emitter, China has attached great importance to energy consumption and carbon emissions, and issued *The National Plan on Climate Change* (2014–2020) in September 2014, which states that CO_2 per unit GDP (carbon intensity) will decline by 40–45% by 2020 compared with the 2005 level. The *Sino-US Joint Statement on Climate Change* describes plans to achieve peak CO_2 emissions in China around 2030 and clarifies the strategic direction for dealing with climate change and low-carbon development. According to the 13th Five-Year Plan (5YP) for 2016–2020, initiatives will be undertaken to control carbon emissions, achieve emission reduction commitments, comply with global climate governance, and make contributions to minimize global climate change. In addition, China's air pollution has reached the hazardous level since 2000s and air pollution is one of the most predominant challenges (Sun et al., 2016a, 2016b). Thus, strategies to reduce emissions in China are an urgent issue. To meet reduction targets for the national carbon intensity (NCI), the targets must be decomposed to a regional level and even to provincial and municipality level. Therefore, it is necessary to study the contributions of different regions to NCI in relation to economic growth to identify mechanisms for reducing carbon intensity from a regional perspective.

Recent studies have included simulation, econometric, and decomposition analyses of carbon intensity, mainly at national, sectoral, and regional levels. In simulation analyses of carbon intensity, previous studies investigated whether carbon intensity reduction targets could be realized under different scenarios (Stern and Jotzo, 2010; Yi et al., 2011; Li et al., 2012; Long et al., 2015). Zhang and Zheng (2014) simulated carbon intensity constraints

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http://dx.doi.org/10.1016/j.jclepro.2017.01.044
0959-6526/

according to economic growth and structure. Chang and Chang (2016) investigated allocation of increments in CO_2 emissions quotas and carbon intensity reduction targets. Yuan et al. (2012) examined the 2020 carbon intensity target and its interdependence on overarching national economic and social development goals, while Yu et al. (2015b) estimated the potential for carbon intensity abatement.

Previous econometric studies explored the relationship between carbon intensity and economic development, fossil fuel intensity, energy intensity, economic structure, investment, technological expenditure, and energy efficiency (Roberts and Grimes, 1997; Zhang, 2003; Moutinho et al., 2014; Zhang and Wang, 2014; Wang et al., 2014b; Yu et al., 2015a; Tian et al., 2016). There have been investigations into the factors driving carbon intensity (Wang et al., 2012a; Cao and Karplus, 2014; Wise et al., 2015; Wang et al., 2016; Yang et al., 2016), the contributions of weather and fuel mix to declines in carbon intensity (Davis et al., 2003), the influence of policies such as energy taxation and emissions trading systems on carbon intensity (Jeffrey and Perkins, 2015), and the main approaches for reducing carbon intensity (Zhou et al., 2014).

Decomposition methods are widely used to analyze carbon emissions and energy consumption. These methods are currently divided into structural decomposition analysis (SDA) and index decomposition analysis (IDA). For example, Ebohon and Ikeme (2006) applied an SDA method to decompose carbon intensity for oil-producing and non-oil-producing sub-Saharan African countries. Zhang (2009) used an SDA method to analyze historical changes in energy-related carbon intensity in China between 1992 and 2006. Shrestha and Timilsina (1996) used an IDA method to analyze the evolution of carbon intensity in the electricity sector in 12 selected Asian countries during 1980–1990. Su and Ang (2012) performed a comparative analysis of SDA and IDA, and found that IDA has been applied to study a wider range of problems within the broad area of energy and the environment. IDA methods contains adaptive weighting Divisia index (AWDI), logarithmic mean Divisia index (LMDI), and so on. Greening et al. (1998, 1999) used an AWDI method to decompose aggregate carbon intensity for the manufacturing and freight sectors in 10 OECD countries. Greening et al. (2001, 2004) used the same method to compare the effects of changes in residential end use and behavior on aggregate carbon intensity and effects of human behavior on aggregate carbon intensity of personal transportation from 10 OECD countries. Fan et al. (2013) examined driving factors of aggregate residential carbon intensity from an end-use perspective using the AWDI method. The logarithmic mean Divisia index (LMDI) is a preferred method in IDA because it can be used for the decomposition of incomplete data sets and benefits from the lack of an unexplainable residual in the results (Jeong and Kim, 2013). Therefore, many literature used the LMDI method to examine carbon emissions for various countries, such as the UK, Brazil, Greece, Turkey, and South Korea (Hammond and Norman, 2011; Hatzigeorgiou et al., 2008; Freitas and Kaneko, 2011; Akbostanci et al., 2011; Oh et al., 2010), make comparative analyses between nations (Lee and Oh, 2006; Fernández González et al., 2014), and study carbon emissions at a national level (Wei et al., 2008; Li et al., 2015), sectoral level (Liu et al., 2007; Lin and Moubarak, 2013; Xu et al., 2014b; Shao et al., 2016) and regional level (Zhao et al., 2010; Wang et al., 2013; Kang et al., 2014; Xu et al., 2014a; Wang and Yang, 2015).

To analyze carbon intensity in China using the LMDI method, Fan et al. (2007) quantified the driving force behind China's primary energy-related carbon intensity and measured the material production sectors' final energy-related carbon intensity. Tan et al. (2011) examined the role of activities related to the electric power industry in reducing China's carbon intensity between 1998 and 2008. Liu et al. (2015) examined changes in carbon intensity in the Chinese industrial sector. Su and Ang (2015) introduced four different models to calculate the aggregate carbon intensity for a country using an input–output framework and decomposition of aggregate carbon intensity changes.

The studies mentioned above mainly analyzed factors related to carbon intensity between nations, and at a national or sectoral level. Some studies have examined carbon intensity at a regional level, but there are still some gaps in this research area. First, the LMDI method is typically used to decompose factors influencing carbon intensity with respect to different energy types and sectors. It can be applied to decompose these factors for a specific nation or region into energy structure, energy intensity, and economic structure effects. However, in this decomposition, it is difficult to explore the differences in these effects among different regions, and the effects of regional proportional output and regional carbon intensity (RCI) on NCI cannot be examined for different regions, so it is necessary to extend the LMDI decomposition method in order to investigate the regional differences in the factors affecting NCI. Second, from a regional perspective, factors influencing carbon intensity were mainly examined for a specific region (Yi et al., 2011; Zhou et al., 2014; Yang et al., 2016; Wang et al., 2016). There have been few comparative analyses of different regional contributions to carbon intensity, especially for different periods and influencing factors. Because the regional energy structure, energy intensity, and proportional output affect NCI, it is necessary to investigate NCI at a multi-regional level to elucidate regional differences in factors influencing NCI. Third, there were different economic development policies for China in different 5YP periods, so regional factors influencing NCI differed greatly. Thus, the contributions of the driving factors in different regions to NCI considering different 5YP periods in China should be investigated, with decomposition in each of the periods using time series data. Therefore, we extended the LMDI method to decompose factors influencing NCI with respect to eight energy types and 29 provinces and municipalities of China to investigate the energy structure, energy intensity, proportional output, and RCI effects in different regions. Compared with the previous LMDI decomposition method, our decomposition method can decompose factors affecting NCI at a multi-regional level, and some important effects on NCI can be effectively examined for different regions, so in this study we choose this decomposition through LMDI method to investigate the regional contributions to the national carbon intensity. Thus, our study may provide novel insights in this research field.

The remainder of the paper is organized as follows. Section 2 presents the methodology. Section 3 describes the data. In Section 4, we present our empirical analysis. Section 5 discusses the main results, while Section 6 gives our conclusions and policy implications.

2. Methodology

In previous studies, the LMDI method is mainly used to decompose factors on carbon emissions into energy structure, energy intensity, economic structure, and economic scale effects, with respect to different energy types and sectors in a specific nation or region. In this paper, the LMDI method was used to decompose factors affecting NCI at a multi-regional level so as to discuss the contributions of factors among different regions to NCI, and some effects such as regional proportional output and RCI effects on NCI can be examined for different regions. At the multi-regional level, the LMDI method was extended to decompose the factors affecting NCI with respect to different regions and energy types. NCI can be decomposed at a multi-regional level and expressed as Eqs (1) and (2) according to different regions and energy types: