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Factors that influence carbon emissions due to energy consumption in China: Decomposition analysis using LMDI

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HIGHLIGHTS

- We developed a model to decompose carbon emissions into five factors.
- We estimated the directions and magnitudes of the influences of five factors.
- We find the sources of carbon emissions from sectors and regions.
- We discussed some strategies for China's emissions abatement.

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ABSTRACT

This study analyzes factors that influence carbon emissions due to fossil energy consumption in China to identify key factors for policies promoting carbon emission reductions. Carbon emissions for energy consumption are decomposed into energy structure, energy intensity, industry structure, economic output, and population scale effects. The major driver of carbon emissions is the economic output effect, followed by population scale and energy structure effects. The energy intensity effect is a main inhibitory factor. The factors influencing carbon emissions in China were investigated for different industries, sectors and regions. The results show that carbon emissions mostly arise from industry, while the other sectors generally exhibit good performance in reducing emissions. In industry, the main contributors to carbon emissions are electricity production, petroleum processing and coking, metal smelting and rolling, chemical manufacture, and non-metal mineral products. Regional analysis revealed differences in economic output, energy intensity, and industrial structure among three regions of China. Policy implications in terms of industrial structure and energy consumption are highlighted.

1. Introduction

Rapid economic growth in China has led to a series of problems associated with resources and the environment, particularly high carbon emissions. Economic growth causes increased energy consumption and CO_2 emissions [1]. Because of the rapid growth of carbon emissions, research by academic and other policy-analysis institutions is important within a climate and energy-policy framework. How to identify sensitive variables for reducing carbon emissions via energy saving and emission reduction systems is a hot topic in academic research [2]. In this study we analyze factors that influence carbon emissions due to fossil energy consumption in China to identify key factors for policies promoting carbon emission reductions. China is undergoing widespread industrialization, with huge energy consumption dominated by fossil fuels. The carbon emission coefficient is very high for fossil energy, reflecting environmental damage due to energy utilization. According World Resources Institute (WRI) data, China exceeded the USA and became the world's largest carbon emitter in 2009, with rapid growth in CO_2 emissions because of increasing economic development and energy consumption. Before the Copenhagen Climate Conference in 2009, China announced that the carbon emissions intensity per unit of GDP would decrease by 40–45% of the 2005 level by 2020, and effective measures would be taken to reduce carbon emissions. However, on August 3, 2010, the National Bureau of Statistics, the National Development and Reform Commission and the National Energy Bureau pointed out that Chinese

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energy consumption per unit of GDP was showing an increasing trend, putting more pressure on carbon emissions. Furthermore, according to a research report published by global carbon project organization, economic development in China continued to be dynamic, resulting in historical records for CO_2 emissions. Thus, China is facing an urgent huge challenge to reduce carbon emissions. For coordinated economic development in China, it is necessary to study the factors influencing carbon emissions due to fossil energy consumption, explore the key factors, and identify policy implications to promote reductions in carbon emissions. This is a significant step in achieving the carbon emissions reduction target for 2020 and coordinated economic development in terms of resources and the environment in China.

Two main methods are used for decomposition of carbon emission factors: structural decomposition analysis (SDA) and index decomposition analysis (IDA) [3–5]. SDA is based on input–output data, whereas IDA uses departmental aggregate data. Because SDA requires input–output data, which are normally issued every 5 years in China, it is not suitable for in-depth studies; IDA uses only departmental aggregate data, so it is applicable for time series modeling. The log mean Divisia index (LMDI) can be used for decomposition of multiple factors with zero residual errors and of parts of incomplete data sets. This method can be used to quantitatively decompose carbon emissions into several 'effects' [6–11] and is therefore widely used in environmental economics. Because the method has relatively low data requirements, it is easy to perform comparative analyses both within time series and among countries [12]. For these reasons, we use the LMDI method to explore factors that influence carbon emissions due to energy consumption in China.

Torvanger was the first to use IDA to study energy-related environmental pollution [13]. Shrestha and Timilsina used a Divisia IDA method to analyze changes in carbon emission intensity for electric power industries in 12 Asian countries including China [14]. Ang et al. [15] and Wang et al. [16] used the LMDI method for factor decomposition and found that economic growth is the main source of carbon emissions and energy intensity is the most important factor in reducing carbon emissions. Ma and Stern used a similar method to decompose the factors in carbon emissions in China during 1971–2003 and included biomass in the energy structure effect. Their results showed that a decrease in the proportion of biomass reduced carbon emissions [17]. Fan et al. applied adaptive Divisia weighting to decompose factors affecting the carbon emission intensity during 1980–2003. They found that energy intensity and energy structure had significant effects on carbon emissions [18]. Liu et al. used the LMDI method to decompose carbon emission factors for 36 Chinese industry sectors during 1998–2005 and observed that energy intensity is the most important factor driving changes in the carbon emissions [19]. Wei et al. [20] and Wu et al. [21] studied the factors that influence energy-related carbon emissions and demonstrated the overall situation for carbon emissions and the underlying driving forces. Using a similar method, Zhang et al. found that economic growth is a main factor for carbon emissions, while energy intensity has an inhibitory effect [22]. However, few studies have used province-level data to characterize regional differences in the factors that influence carbon emissions [23–25]. Both Liu and Zhang stressed regional differences in the characteristics of carbon emissions, but provided little information about regional differences in the underlying driving forces. The same decomposition method has been used for other countries. Paul and Bhattacharya decomposed India carbon emissions factors into the effects of GDP change, industrial structure, energy intensity and emissions from different energy sources [26]. Sun analyzed differences in CO_2 emission intensity between Finland and Sweden [27]. Choi et al. studied energy-related carbon emissions in Korea by index decomposition methods [28]. İpek Tunç et al. decomposed carbon emission factors for Turkey into economic growth, structure, energy efficiency, energy type and carbon emission coefficient effects [29]. Comparisons of selected countries or regions have also focused on the application of index decomposition methods, including a study of the factors that influence carbon emissions in 114 countries [30], and a comparison of oil-producing and non-oil-producing nations in sub-Saharan Africa [31].

The above studies mainly used the IDA method to investigate carbon emission problems. Empirical studies have focused on just a few industries and types of energy, mainly coal, oil and natural gas. The small sample sizes do not reflect the actual situation for carbon emissions in China. In addition, most studies have only presented empirical conclusions without exploring the underlying causes. To address this gap, we use six industrial sectors (agriculture, forestry, animal husbandry and fishery; industry; construction; transport, storage and post; wholesale, retail, accommodation and catering; other sectors) and eight energy types (raw coal; coke; crude oil; gasoline; kerosene; diesel; fuel oil; natural gas) to analyze the factors affecting carbon emissions in China. According to the empirical results, we explore the causes of carbon emission problems in China and highlight the policy implications.

2. Methodology

2.1. Decomposition model

For decomposition of carbon emissions, Yoichi Kaya proposed the Kaya identity

$$C = \frac{C}{E} \cdot \frac{E}{GDP} \cdot \frac{GDP}{P} \cdot P, \tag{1}$$

where C denotes carbon emissions, E is total energy consumption, GDP is gross domestic product and P is population scale. The Kaya identity is only suitable for general analysis of a country or region. To analyze industry sectors and energy types, we rewrite the Kaya identity as

$$C = \sum_i \sum_j \frac{C_{ij}}{E_{ij}} \cdot \frac{E_{ij}}{E_i} \cdot \frac{E_i}{GDP_i} \cdot \frac{GDP_i}{GDP} \cdot \frac{GDP}{P} \cdot P, \tag{2}$$

where C denotes total carbon emissions, C_{ij} is carbon emission from consumption of energy j by industry i (E_{ij}), E_i is total energy consumption by industry i, and GDP_i is the GDP output of industry i. The factors influencing carbon emissions due to energy consumption can be decomposed into carbon emission coefficient ($\Delta C_{C_{ij}/E_{ij}}$), energy structure ($\Delta C_{E_{ij}/E_i}$), energy intensity ($\Delta C_{E_i/GDP_i}$), industrial structure ($\Delta C_{GDP_i/GDP}$), economic output ($\Delta C_{GDP/P}$), and population scale (ΔC_P) effects. Product decomposition and additive decomposition yield the same results. For model (2), C^0 and C^t denote total carbon emissions in the base period and period t, respectively, and ΔC_{tot} is the change in C from the base period to period t. Applying additive decomposition, the carbon emission factors for consumption of energy type j by industry i can be decomposed as follows:

Carbon emissions coefficient effect:

$$\Delta C_{\frac{C_{ij}}{E_{ij}}} = \frac{C_{ij}^t - C_{ij}^0}{\ln C_{ij}^t - \ln C_{ij}^0} \cdot \left[\ln \left(\frac{C_{ij}}{E_{ij}} \right)^t - \ln \left(\frac{C_{ij}}{E_{ij}} \right)^0 \right]. \tag{3}$$

Energy structure effect:

$$\Delta C_{\frac{E_{ij}}{E_i}} = \frac{C_{ij}^t - C_{ij}^0}{\ln C_{ij}^t - \ln C_{ij}^0} \cdot \left[\ln \left(\frac{E_{ij}}{E_i} \right)^t - \ln \left(\frac{E_{ij}}{E_i} \right)^0 \right]. \tag{4}$$