Journal of Cleaner Production 167 (2017) 110–119

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Accounting carbon emission changes under regional industrial transfer in an urban agglomeration in China's Pearl River Delta

Lei Chen, Linyu Xu*, Zhifeng Yang

State Key Laboratory of Water Environment Simulation, School of Environment, Beijing Normal University, Beijing 100875, China

A R T I C L E I N F O

Article history:
Received 15 September 2016
Received in revised form
13 June 2017
Accepted 5 August 2017
Available online 13 August 2017

Handling Editor: Yutao Wang

Keywords:
Carbon emissions
Industrial transfer
LMDI
Urban agglomeration
Spatial analysis
Pearl River Delta

A B S T R A C T

Industrial sectors account for a large part of urban carbon emissions. To address this, regional industrial transfer has recently been proposed in China, especially for areas consisting of urban agglomerations. In this manuscript, by applying LMDI method to the industrial transfer theory, driving forces of carbon emission changes from manufacturing industries were evaluated in the Pearl River Delta (PRD) of China. Firstly, the theories of industrial transfer were thoroughly analyzed to systematically study the pattern and trend. Then, a multi-region LMDI model was made to simulate the effect of the driving forces of regional transfer on carbon emissions, considering the production element flows of capital, labor, and technology under the background of industrial transfer through the cities. Finally, using the integrated model with spatial analysis, the temporal and spatial characteristics of carbon emission changes were quantified. The results revealed that the economic growth triggered the high speed of carbon increases, while industrial structure effect especially for labor-intensive industries and technology-intensive industries, help to prevent the carbon emissions from ever increasing. The developed cities effectively reduce high energy consuming industries, mainly the capital-intensive industries, by transferring to the developing places, causing the inequality distribution of carbon emissions of manufacturing industries in the PRD. The results may implied the adjustments of coordinated development to reduce the carbon disparities.

1. Introduction

Carbon dioxide (CO_2) emissions from urban industrial fossil fuels have been gradually recognized as a non-ignorable contributor to global climate changes (Marland and Rotty, 1984; Yue et al., 2016), especially in China, one of the largest energy consumers in the world (Deng et al., 2012). In response, activities of energy conservation and low-carbon economic development are becoming the focus sustainable development approaches (Andreoni and Galmarini, 2012; Lee and van de Meene, 2013; Yu et al., 2015). Meanwhile, urban agglomeration has gradually become the most dynamic and potential regional units in China, which takes on an irreplaceably important task in guiding the upgrading of industrial structures and further development of the regional economy (Li et al., 2009). The resulting urban agglomeration will also suffer even greater pressure to reduce emissions (Dhakal, 2009) due to its enormous energy use. With the increase in urban productivity, industrial transfer, especially in the manufactory industries, which reflects production flows from relatively developed countries (regions) to the relatively less developed countries (regions), becomes an essential economic phenomenon between countries or regions. Thus, it is necessary to take spatial effects into account when studying the issue of carbon emissions under the industrial transfer in an urban agglomeration.

Research on the spatial economic and energy connections of urban agglomerations helps understand the inner space of urban agglomerations and industrial structures, and finally provides an essential theoretical basis and evidence for decision-making (Grimm et al., 2008; Parshall et al., 2010). Cities in urban agglomerations may have different economic factors influencing economic development, urbanization and industrial structures, and the presence of regional differences (Camagni et al., 1998). While regional differences will lead to the various carbon reduction responsibilities, each city is dedicated to achieve its carbon emission goals individually instead of together, leading to wasting resources, not able to maximize the sense of overall welfare economics (Poumanyvong and Kaneko, 2010; Zhang and Xu, 2015). The

* Corresponding author.
E-mail address: xly@bnu.edu.cn (L. Xu).

http://dx.doi.org/10.1016/j.jclepro.2017.08.041
0959-6526/

economic essence of industrial transfer is to seek maximum benefits of the comparative advantages from a relatively high region to the low region (Lewis, 1954).

In order to analyze the driving forces of carbon emissions from energy consumption, several decomposition methods were used (Anderson, 1995). Based on different methods, three commonly adopted approaches in carbon decomposition, include structural decomposition analysis (Liang et al., 2016; Mi et al., 2017a), index decomposition analysis (Li et al., 2017), and production theoretical decomposition analysis (Yao et al., 2015). As one of the index decomposition methods, the Logarithmic mean Divisia index (LMDI) method was widely chosen in the industrial field because this method can both eliminate residuals and solve the data of zero value problems using a simple calculation process and intuitive decomposition results (Ang, 2004, 2005; Ang and Liu, 2007). The LMDI method is used widely from the global level (González et al., 2014; Moutinho et al., 2015), national level (Bhattacharyya and Ussanarassamee, 2004; Chen et al., 2013; Liu et al., 2016), urban level (Chen et al., 2016), to the sector level (Ouyang and Lin, 2015; Xu et al., 2012; Yan and Fang, 2015). By combing the research areas as a single object (Geng et al., 2015), spatial relationships needed to be analyzed between the regions in order to find the internal connection and interaction of carbon emissions (Long et al., 2015; Yun et al., 2014).

Spatial relationships should also be a concern when it comes to drawing out the underlying carbon emissions under the industrial transfer (Chuai et al., 2015). According to Tobler's first law of geography, all attribute values on a geographic surface are related to each other, but closer values are more strongly related than are more distant ones (Tobler, 1970). Spatial analysis can reflect the spatial relationships between any focal spatial unit and its neighbors based on spatial weight matrix (Epperson and Allard, 1989), therefore, it can be applied to illustrate the spatial correlative degree of carbon intensity and reveal its spatial distribution patterns (Yang et al., 2013; Cheng et al., 2014). A three-level LMDI method decomposition model to explore the driving forces behind carbon emissions based on provincial aggregated data (Wu et al., 2005) was proposed to identify the spatial-temporal pattern (Chen and Yang, 2014).

Above all, this paper discusses carbon emissions changes in urban agglomerations under the background of industrial transfer. Urban agglomerations connect the close links of populations, resources, technology, and other material flow of production elements between cities, and will have an important impact on the pattern of carbon emissions. Therefore, it is both important and necessary to conduct spatial analysis of the carbon emissions of the urban agglomeration, to conclude the industrial transfers of different types, hence, to develop respective policies related to carbon reduction. Because the industrial transfer mainly happens in manufacturing sectors (Yuan and Shi, 2009), this paper mainly refers to manufacturing sectors when addressing industries. Since energy-related carbon emissions accounts for most parts of the amount, hence the carbon emissions in this paper mainly refers to those from energy consumption.

The structure of this paper is organized as follows. In Section 2, the methodologies with framework and basic methods are illustrated, following the main results in Section 3. Finally, in Section 4, we conclude the study and propose some policy implications.

2. Methodology

2.1. Framework

Industrial transfer is an effective way to optimize the spatial layout of productivity, and form a reasonable industrial division system, it is to promote industrial restructuring, and to accelerate the inevitable requirements of economic development shift. The process of industrial transfer includes not only industries removed from developed areas to undeveloped areas, also elimination of backward industries from both areas. In this paper, carbon emissions from energy consumption under the industrial transfer in the urban agglomeration are studied from three aspects of economic growth, industrial structures, and spatial distribution. Patterns and trends in carbon emissions from different classified industries are discussed, in addition, driving forces of carbon emissions are decomposed using the LMDI method to calculate the carbon emission changes generated by economic growth and industrial structures. On this basis using spatial modeling, the spatial and temporal distribution of carbon changes between cities are illustrated, in combining various industrial types to further analyze effects on regional carbon emissions in urban agglomerations under the industrial transfer.

This paper suggests that the regional industrial transfer is due to policy guidance or market changes. Industries, particularly manufacturing, are transferred through production element flows from economically developed areas to the less developed ones, and therefore raising the economic growth of the less developed area, as long as both areas update their industrial facilities. This concept includes the geographical pattern and time series of the region, and is a dynamic process in the dimensions of time and space. It is an important way for industrial structure adjustment of the two areas.

2.2. Carbon accounting

According to the method introduced by the IPCC Guidelines for National Greenhouse Gas Inventories (Lanza et al., 2006), the total industrial carbon emissions from energy consumption can be estimated by multiplying individual fuel consumption with its carbon emission coefficients as follows (Zhang et al., 2015):

$$C = \sum_{ij} C_{ij} = \sum_{ij} E_{ij} f_{ij} \tag{1}$$

where, C refers to industrial total carbon emissions from energy consumption, C_{ij} refers to carbon emissions from energy j in sector i. Whereas, E_{ij} refers to energy consumption of energy j from sector i, f_{ij} refers to carbon emission coefficient of energy j from sector i.

2.3. The multi-region LMDI method

Kaya introduced the traditional carbon emission decomposition method using LMDI (Kaya, 1990). To highlight the significance of economic growth and industrial structures on carbon emissions, we simplified the expression by combining energy intensity factor and carbon emission factor. Therefore, the carbon emissions from energy consumption was calculated as followed.

$$C = \sum_{ijk} C_{ijk} = \sum_{ijk} Q_k \frac{Q_{ik}}{Q_k} \frac{C_{iji}}{Q_{ik}} = \sum_{ij} Q_k S_{ik} I_{ijk} \tag{2}$$

where, Q_k refers to total industrial GDP, that is total industrial added value of city k, while Q_{ik} is the industrial added value of sector i in city k, and S_{ik} represents industrial structure in city k, I_{ijk} represents the carbon intensity of energy j of sector i.

In consequence, industrial carbon emissions could be decomposed into three driving forces: the economic growth effect (*ΔCeg*), which reflects changes in the gross industrial output value from base year *0* to year *T*; the industrial structure effect (*ΔCis*), which reflects the changes in the ratio of each industrial output to the