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An inquiry into inter-provincial carbon emission difference in China: Aiming to differentiated KPIs for provincial low carbon development

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ABSTRACT

Reasonable formulation of carbon emission reduction strategies at sub-national scale is an important technique to realize the national target. However, a set of binding unified key performance indicators (KPIs) is usually not conducive to equitable regional development. Our study employs a hybrid carbon emission estimation method and a multi-index joint representation approach to explore the inter-provincial energy-related carbon emission difference in the year of 2012 in China. Stepwise regression method and hierarchical clustering model were used to classify 30 provinces into economically developed low-carbon region, industrially optimized low-carbon region, resource-abundant high-carbon region, and economically developing high-carbon region. Different regions should take differentiated measures and KPIs related to the local government's efforts to promote low carbon roadmap according to local conditions: The lack of natural resource provides the impetus to improve energy structure in the economically developed low-carbon region. The industrially optimized low-carbon region should place great importance on economic growth and per capita GDP improvement. The low-carbon transformation strategy of the resource-abundant high-carbon regions should focus on carbon emission reduction performance and carbon intensity decline. For economically developing high-carbon regions, decision makers should conduct a sound SWOT analysis of regional low carbon development.

1. Introduction

Many countries have publicly promised to achieve clear greenhouse gas reduction targets. In late 2009, the Chinese government proposed a reduction of carbon dioxide emissions per 10,000 Yuan of GDP from the 2005 level of 45% to 40% by 2020. In 2014, China also pledged to achieve peak carbon dioxide emissions around 2030. Reasonable formulations in carbon emission reduction strategy at the sub-national scale are important in realizing the national target. However, different regions have different driving forces of energy-related carbon emission based on economic level, energy structure, lifestyle, geographical location, and other factors (Feng et al., 2009; Kennedy et al., 2009; Wang et al., 2012). A binding unified emission reduction strategy, such as undifferentiated key performance indicators (KPIs) related to the local government's efforts to reduce carbon emission, is usually not conducive to equitable development between different regions in a country. Therefore, implementing the study at the sub-national scale, especially at the provincial-scale, is necessary to determine energy-related carbon emission difference. Thus, differentiated policies that are beneficial to equitable development and suitable for different regional characteristics are proposed in the present research.

Previous studies have focused on carbon inequality. In global scale, the comparison of carbon emission between countries is mainly used for international climatic policy making or negotiation (Heil and Wodon, 2000; Metz et al., 2007; Peters and Hertwich, 2008; Cantore and Padilla, 2010). The carbon emissions of different economic entities vastly differ regardless of whether total carbon emission, per capita carbon emission (carbon footprint), or carbon emissions intensity index is used. Moreover, the carbon emissions of different economic entities are closely related to the economic level and household income (Heil and Wodon, 1997; Duro and Padilla, 2006; Padilla and Serrano, 2006; Hertwich and Peters, 2009; Davis and Caldeira, 2010). Clarke-Sather et al. (2011) argued that the global carbon emission difference could not be mirrored at the sub-national scale. A country generally owns a fixed electricity market, which is different from that at the sub-national scale. More importantly, the goal of inter-regional

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comparison study of sub-countries is different from that of country scale. Inter-regional comparison not only promotes intra-regional carbon emission reduction efficiency but also serves as the realization of national emission reduction target.

A comparative study on inter-urban carbon emission usually adopts a life cycle tool or an input–output model to sketch the consumption-based carbon footprint features of different cities (Satterthwaite, 2008; Kennedy et al., 2009; Baiocchi et al., 2010; Hillman and Ramaswami, 2010; Sovacool and Brown, 2010; Li et al., 2013; Minx et al., 2013; Wiedenhofer et al., 2013; Jones and Kammen, 2014). By analyzing the contribution of technique factor and geographical factor to urban carbon emissions, previous studies have explored the reasons behind carbon emission differences and proposed optimal means of urban carbon emissions. However, the national emission reduction target is always neglected because of the presence of double counting in this process (Lenzen et al., 2007).

Being the country with the largest global carbon emission, the carbon emission of one province in China is almost equivalent to that of a western country. Specific to the inter-provincial energy-related carbon emission difference in China, some research results have been achieved (Yue et al., 2010; Clarke-Sather et al., 2011; Yu et al., 2012; Wang et al., 2013; Zhang and Chen, 2014; Wang and Zhao, 2015). These previous studies aimed to use the model recommended by IPCC to estimate carbon emission, select a certain index to represent space difference, further identify the reasons for the differences, and propose corresponding suggestions. The most used index mainly included the following: (1) correlation coefficient, Gini coefficient, and Theil index, which were used to quantitatively analyze the provincial-scale space difference; and (2) total carbon emission, emission intensity, and per capita carbon emission, which were used to directly describe the regional difference. With the help of Kaya formula and LMDI decomposition model, the major influential factors of the differences were studied. For example, using the STIRPAT model and cluster analysis, Wang and Zhao (2015) examined the differentiated impact factors on energy-related carbon emission and argued that differentiated measures should be adopted according to regions.

However, three concerns need to be addressed in this study. (1) Estimation method. Based on the producer accounting principle, the IPCC method reflects the direct carbon emission within the regional geographical scope. This approach has been used in most precious studies. However, with the increase of inter-regional trade, embodied carbon emission has accounted for a larger proportion in relatively developed economic areas. Implementing a carbon emission reduction policy is expected to impart economic hardships on regions. Therefore, determining the equity of these burdens is an important premise of regional carbon emission reduction policy making (Clarke-Sather et al., 2011). IPCC method is beneficial to statistical analysis. However, the IPCC method is not conductive to policy making (Hertwich and Peters, 2009). Therefore, the IPCC method is not the optimal tool for the comparative study of sub-national carbon emission. Consumption-based method places the carbon emission responsibility to consumers but neglects the advantages of the carbon emission process to producers (Munksgaard and Pedersen, 2001; Peters, 2008; Peters and Hertwich, 2008; Mozner, 2013). From the internal perspective, such is not a fair choice. Our study adopted a hybrid estimation method that gives more attention to regional equitable development, which is used for calculations at the provincial-scale and for energy-related carbon emission. (2) Assessment index. Energy-related carbon emission can be influenced by geographical and technical factors. Most previous studies have simply adopted a single carbon emission index and intuitively described the spatial distribution difference. This scheme failed to comprehensively reflect the regional carbon emission features. In this study, we used statistical analysis on nine potential influence variables of carbon emission and screened four indexes to jointly represent the space features of provincial-scale carbon emission. The procedure used in this study can provide a reference for the regional differentiated carbon emission reduction policy. (3) Per capita carbon emission was the frequent concern of most studies. Previous studies have carried out analysis from carbon footprint index. The target officially promised by China is carbon emission intensity (Wang et al., 2010). At present, few studies on the inter-regional difference of carbon emission intensity in China exist. Furthermore, most of these studies have been divided into three sub-countries, namely, eastern, central, and western China. The three sub-countries reflect the traditional division by economic level (Yu et al., 2012). To assist Chinese governments in formulating effective provincial-scale low-carbon development strategies, implementing difference studies on inter-provincial energy-related carbon emission intensity and proposing differentiated KPIs for provincial low carbon development in China are needed.

We aim to address the three issues mentioned above. Our study is the first to attempt the application of a hybrid carbon emission estimation method and a multi-index joint representation approach to explore the difference in the inter-provincial carbon emission of China. With the supplementation of stepwise regression method and hierarchical clustering model, 30 provinces in China were classified into economically developed low-carbon region, industrially optimized low-carbon region, resource-abundant high-carbon region, and economically developing high-carbon region. Tibet, Taiwan, Hong Kong, and Macao were excluded from this study because data were not available.

This paper will be organized as follows. In Section 2, carbon estimation method, as well as the data analysis method, is described and studied in detailed. In Section 3, we explore the inter-provincial carbon emission difference in China and the differentiated KPIs for provincial low carbon development are proposed. Section 4 summarizes our findings and provides policy suggestions.

2. Methods

2.1. Carbon estimation method

The selection of proper estimation method of regional energy-related carbon emission is important for policy making. Different methods may result in different policy orientations (Bento and Klotz, 2014). As discussed above, the production-based method (IPCC model) places the emission responsibility to production regions and aims to prompt regions to reconstruct the production mode and improve emission reduction efficiency. The production region attracts investment and increased profits, so it should accept responsibility for the corresponding carbon emissions.

However, energy industries, such as those concerned with thermal power, are different in the industrial sector. Thermal power plants in China are generally located in the vicinity of the coal base. They are usually close to consumers in the last few decades to avoid the need for long distance power transmission. Besides, with the restriction present in the national energy layout strategy, the location of thermal power enterprises is difficult to change. It is difficult for provincial governments to play a significant role in emissions reductions by the electric power industry. Therefore, assigning responsibility for electricity emissions to the production area is not conducive to equitable regional development. Consumer responsibility for electricity emissions contributes to enhanced electricity use efficiency by consumers, which will lead to actual reductions in electricity production. Moreover, electricity generation is usually the largest carbon emission source in regions with coal electric