Carbon Emission Efficiency

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Contributor: Chen Xu Liu, Ruien Tang, Guo Yaqi, Yuhan Sun

Carbon emission efficiency is an important concept in environmental science; it refers to the economic benefits generated by production activities that produce carbon emissions at the same time. The less carbon emissions generated per unit of economic output, the more carbon emission efficient it is.

Keywords: carbon emission efficiency ; spatial connection ; social network analysis ; influencing factors

1. Introduction

Climate change and its impacts have become one of the most serious environmental problems facing the world today [1]. In its fourth Global Climate Assessment, the United Nations Intergovernmental Panel on Climate Change (IPCC) noted that it is an indisputable fact that human activities and massive greenhouse gas emissions are the major causes of global climate change. As CO_2 is one of the most important greenhouse gases, it is closely related to global warming [2]. As the main source of carbon emissions, cities have a profound impact on the realization of carbon emission reduction targets [3]. Establishing low-carbon cities is an inevitable choice for China in order to deal with climate change and to develop a low-carbon economy [4].

Based on the above, carbon emission and carbon emission reduction issues have been given extensive attention, and studies on carbon emission estimation methods [5], influencing factors [6][7][8], emission intensity [9][10], and emission efficiency [11] have been carried out successively. Carbon emission efficiency is an important concept in environmental science; it refers to the economic benefits generated by production activities that produce carbon emissions at the same time [12]. The less carbon emissions generated per unit of economic output, the more carbon emission efficient it is. Carbon emission efficiency considers the promotion and inhibitory effect of carbon emissions on economic growth, and measures the level of economic growth under carbon emission restrictions—this has been widely studied. In the context of tightening carbon dioxide emission constraints, the currently used crude economic development approach is unsustainable, and improving carbon efficiency is an important way to promote a change to the development approach. At present, most studies focus on regional differences in carbon emission efficiency, and less attention has been paid to region-specific carbon emission efficiency correlations.

As a typical representative of the world's major urban agglomerations and metropolitan areas, from an early stage, the Yangtze River Delta region advanced industrialization and urbanization, and is home to a large number of high-emission industries such as petrochemicals, metallurgy, paper making, and automobiles. The energy and carbon emissions brought about by the high-intensity development of industry have put enormous environmental pressure on the Yangtze River Delta urban agglomerations (**Figure 1**), affecting the sustainable development of the region and the fulfilment of emission reduction commitments.

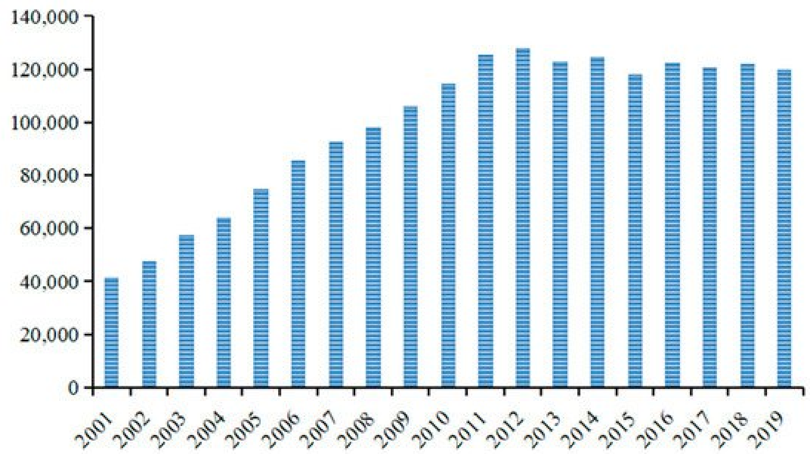

Figure 1. Carbon emissions in the Yangtze River Delta urban agglomeration from 2001 to 2019 (source: extracted from the DMSP/OLS night light data).

At the same time, the gradual formation of a networked transportation system, the continuous development of information technology, and the continuous advancement of regional economic integration have made the spatial connection between the production factors of each city in the Yangtze River Delta increasingly close, and the carbon emission efficiency among the regions has also shown significant spatial correlation characteristics. It is of great theoretical significance and application value to examine the spatial correlation structure and influencing factors of energy carbon emission efficiency in the cities of the Yangtze River Delta urban agglomeration from a network perspective, and to explore the status and role of carbon emission efficiency of each region in the spatial correlation network, in order to build a cross-regional carbon emission efficiency synergy mechanism under the new economic normal and to formulate carbon emission reduction policies that are both targeted and systematic. It can also fill the gap in the current academic field in the study of the spatial correlation of regional carbon emission efficiency.

2. Carbon Emission Efficiency

At present, the definition of carbon emission efficiency can be divided into two types: single factor carbon emission efficiency and total factor carbon emission efficiency. Kaya and Yokobori first defined carbon emission efficiency as carbon productivity from a single-factor perspective; that is, the ratio of GDP to carbon emissions in the same period [13]. Yamaji defined the ratio of total CO_2 emissions to GDP as CO_2 productivity when studying the level of carbon emissions in Japan [14]. Mielnik, Goldember, and Ang used carbon dioxide emissions per unit of energy consumption as an important measure of carbon emission efficiency [15][16]. The single factor only takes into account the proportion between GDP or energy consumption and carbon emissions, but ignores the substitution between factors when multiple factors combined are input into the actual production process. Ramanatha believed that the definition of carbon emission efficiency should be integrated into the three frameworks of energy consumption, economic development, and carbon emission, so that the evaluation results are comprehensive and reasonable [17]. Zaim and Taskin defined carbon emissions as a non-expected output variable, and proposed the concept of the comprehensive efficiency index, and applied this index to the OECD national research [18].

The current research on carbon emission efficiency can be divided into industries and regions according to the research objects. In the research of industry carbon emission efficiency, scholars have used different measurement models to measure the carbon emission efficiency of different industries in the national economy. Wang Kai and Wang Kun used the SBM model, and found that the carbon emission efficiency of China's tourism showed a significant spatial imbalance [19]; Dwyer et al. measured carbon emissions from tourism in Australia using both the production and expenditure approaches [20]; Hampf proposed a new DEA analysis method based on an efficiency analysis perspective to investigate the standard of CO_2 emissions in the U.S. electric power industry [21]; and Erwin et al. used a sample of Indonesian manufacturing firms to explore the determinants of carbon emissions [22]. In terms of regional carbon emission efficiency research, Ramanathan used the data envelope analysis (DEA) to build an input−output index system containing carbon dioxide emissions, energy consumption, and economic activity variables, to compare the carbon emission performance level of various countries [17]. Zhang et al. developed a spatial regression model to study the convergence characteristics and influencing factors of carbon emission intensity in Chinese cities and major strategic regions [23]. Meng et al. used the RAM-DEA model to estimate the low-carbon economic efficiency of the Chinese industrial sector from 2001 to 2013, and found that most industries of low-carbon economic efficiency are still at a low level; however, the carbon emission efficiency was greatly improved during the study period [24].

In addition, many academic studies have confirmed that carbon-emission-related problems do not exist independently among regions, but they have some spatial correlations between them [25][26]. Grunewald and others explored the driving factors of spatial differences in carbon emissions and pointed out that energy intensity and energy structure are the main reasons for the spatial differences in carbon emissions [27]. Marbuah and Mensah performed a statistical test of the spatial association of several pollutants, including CO_2, using 290 Swedish urban areas as the study areas, showing that spatial spillover effects were the main driver of the environmental Kuznets curve [28]. Wu studied the spatial pattern and evolution mechanism of carbon emission reduction in China through spatial econometrics, and analyzed the emission reduction characteristics of key provinces [29]. Zhou determined the determinants and spatial relationship of CO_2 emissions at an urban level in China [30].

Previous studies have also discussed and analyzed the influence mechanism of regional carbon emission efficiency in depth. Wang et al. used the window SBM analysis method to measure the carbon emission efficiency and emission reduction potential of various provinces and cities in China from 2003 to 2016, and analyzed the impact of resource endowment on emission efficiency using the panel Tobit model. The results show an inverse relationship between resource endowment and emission efficiency [31]. Liu et al. proposed the ideal point cross efficiency (IPCE) model, and used this model to analyze the carbon emission efficiency of the top ten urban agglomerations in China in 2008–2015. The results showed that the population effect and economic effect promoted the emission efficiency of mature urban agglomerations, while reducing the efficiency of emerging urban agglomerations [32]. Zhou et al. measured the carbon efficiency of the top 18 global carbon emitting countries from 1997 to 2004 based on a DEA model, and found that technological progress had a significant effect on the improvement of carbon efficiency [33]. Ma Y. and Lu Y. used the ultra-efficiency SBM model to calculate carbon emission efficiency at a provincial level in China from 1995 to 2012, and examined the impact of independent innovation, FDI, and international trade. The results found that FDI could significantly improve the carbon emission efficiency, while independent innovation and import had inhibitory effects [34].

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