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Low Carbon Transformation of Chinese Cities: Theoretical Evolution, Empirical Progress and Future Prospects

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Abstract

In the context of global warming, cities are the core source of carbon emissions, and promoting their low-carbon transformation is the key to China's implementation of the "double carbon" goal. This paper aims to systematically sort out the frontier achievements of China's urban low-carbon transformation, and build a comprehensive theoretical analysis framework. At the theoretical level, it traces the evolution of the concepts of decarbonization, LCD and LCT, clarifies the logical relationship, and integrates the theories of ecological modernization and sustainable development to lay the foundation for transformation. At the empirical level, this paper analyzes the suitability of IPCC, IOA and LCA carbon accounting methods and the index evaluation system, identifies that per capita income, energy structure, population size, industrial structure and green technology innovation are the main driving factors affecting carbon emissions, and summarizes the emission reduction effects of low-carbon city pilot, carbon trading market and other policy tools, revealing that the distribution pattern of carbon emissions is high in the East and low in the west, with significant spatial spillover effect, and that individual behavior plays an important role in low-carbon transformation. At the same time, this paper also points out that the current research still faces challenges such as insufficient theoretical localization, lack of micro mechanism mining, incomplete data system and poor policy adaptability, and puts forward corresponding future policy prospects, so as to provide theoretical reference and practical guidance for promoting the development of low-carbon transformation in Chinese cities.

Keywords

low carbon transformation of Chinese cities, theoretical evolution, empirical progress

1. Introduction

At present, climate change, led by global warming, has become a major social issue for all mankind. As one of the most important greenhouse gases, the continuous increase of carbon dioxide emissions is an important factor leading to the rise of temperature. Although there are many reasons for the increasing trend of carbon emissions, with the rapid progress of urbanization in recent years, cities have become the main source of carbon emissions. As the world's largest emitter of carbon dioxide, it is urgent for China to promote urban low-carbon transformation and ecological environment governance. At the same time, China's commitment to the goal of carbon peak and carbon neutrality is not only a responsibility to actively respond to international climate governance, but also a strategic choice to promote its low-carbon transformation and achieve high-quality economic development.

Based on the above background, this paper reviews the frontier achievements of China's urban low-carbon transformation, and explores the dynamic evolution of the progress of China's urban low-carbon transformation. First of all, it reviews the theoretical development of the theme of low-carbon transformation governance in Chinese cities. Secondly, it summarizes the applicable conditions and implementation effects of relevant policies. Finally, it constructs the theoretical analysis framework of China's urban low-carbon transformation, and puts forward policy implications combined with its development trend.

2. Theoretical Evolution and Research Paradigm

2.1 Conceptual Evolution of Urban Low Carbon Transformation

As the core subject of carbon emissions, cities' low-carbon development path has shown Phased Evolution Characteristics in the past two decades, which is closely related to the global urban development situation. The term "decarbonization" was first proposed by (Ausubel, 1995), which is defined as a method to reduce the carbon emission coefficient of energy [1]. In 2005, the concept of "low carbon development (LCD)" was gradually clarified. Low carbon transformation (LCT) was pointed out by geels, Berkhout and Van vuuren (2016) as a long-term process of the transformation of the energy system to renewable energy, which requires the collaborative reconstruction of technology, society and system[2]. At the same time, LCT is the foundation for the construction of a net zero carbon city, which can further completely get rid of the dependence on fossil fuels in the urban energy and transportation system and eliminate greenhouse gas emissions from the source.

In general, decarbonization is a specific means, emphasizing the process of carbon dioxide decoupling, which is the method to realize LCD and LCT. While low-carbon development focuses on the emission reduction of economic activities, low-carbon transformation focuses on the optimization and transformation of energy system structure, and the formation of a net zero carbon city is to further emphasize deep decarbonization and obtain quantitative results on this basis. Each of the four focuses has evolved from partial reduction of carbon emissions to systematic coverage of the entire economy and society. At present, China's cities are at a critical stage of moving from low-carbon transformation to a net zero carbon city[3, 4].

2.2 theoretical basis and Analysis Framework

The theory of ecological modernization is the dominant perspective for early understanding of low-carbon development, emphasizing the establishment of a complete low-carbon green market system and the use of market-oriented means such as carbon emissions trading system, carbon tax and other measures to achieve green and recycling[5], but its excessive reliance on market regulation inevitably ignores the synergy of non market players. The sustainable development theory jumps out of the single market dimension and advocates the production and consumption mode of "low input, low emission and low pollution". It requires that we adhere to overall planning and dynamic development, and provide a reference for building a low-carbon city from the philosophical level[6]. On this basis, the Journal of urban political ecology focuses on the specific spatial scale, extracts the concept of carbon footprint, accurately quantifies the total amount of urban greenhouse gas emissions, and puts forward some core ideas, such as increasing the density of cities, reducing carbon emissions[7], controlling the flow of material carbon emissions as a whole, and paying attention to carbon emissions at the consumer end[8]. The theory of low-carbon economy is further deepened in practical methods, focusing on the innovation of energy technology and the optimization of industrial layout, and reducing the emission intensity of greenhouse gases such as carbon dioxide by improving the efficiency of resource utilization, so as to achieve the purpose of economic growth and sustainable development [6, 9].

To sum up, the theory of ecological modernization puts forward the basic concepts and provides the ideological basis for the low-carbon transformation strategy of Chinese cities. The theory of sustainable development extends it and emphasizes the balance between social equity and economic development. Urban political ecology focuses on the social ecological mechanism of urban scenes. The low-carbon economy theory takes the technical and economic level as the core, and jointly constructs the theoretical framework for the low-carbon transformation of Chinese cities.

3. Empirical Research Progress of Urban Low Carbon Transformation

3.1 Low Carbon Performance Measurement and Evaluation System

The two existing carbon accounting principles are based on production and consumption respectively. The main difference between the two is that production based accounting allocates the emissions of all products and services to producers, while consumption based accounting allocates them to final consumers. At present, there are three mainstream and commonly used carbon accounting methods, namely the accounting method issued by the Intergovernmental Panel on climate change (IPCC), input-output analysis (IOA) and life cycle assessment (LCA)[10].

According to IPCC inventory guidelines, there are three main carbon accounting methods, including emission factor method, carbon mass balance method and experimental method. However, these methods are based on the national level, and have not yet discussed whether they are suitable for urban accounting. In addition, the classification basis of the emission guidelines is derived from the greenhouse gas production sector, which does not directly define the contribution of carbon emissions from all dimensions of urban consumption and further integrate carbon emissions with the economic system, so it lacks direct guidance value for the formulation of carbon reduction planning strategies[10, 11].

The input-output analysis (IOA) can make up for the above defects. This method can calculate the urban carbon emissions related to production activities, track the source and destination of carbon emissions in the flow of products, and then describe the flow characteristics of economic activities and the economic cycle mechanism. It can be divided into single region and multi region input-output models according to the number of regions. The main difference between the two in the actual application process is that the single regional input-output model focuses on the regional internal economic ties and derived environmental and social effects, while the multi regional input-output model has the additional function of analyzing the regional economic ties[12], which can help the low-carbon transformation of cities and regions[10, 11].

Life cycle assessment (LCA) can be used to calculate and assess the environmental impact related to road carbon emissions. However, since it cannot completely cover the production process of all final products, it is not suitable for urban level carbon emission accounting[10, 11].

The above three carbon accounting methods are not independent but cross compatible. In general, the carbon accounting method provided by IPCC takes the national scale carbon emissions as the core consideration and provides corresponding default values. However, due to data limitations, it is not suitable for detailed analysis of the industry or a single product. Similarly, top-down IOA is usually used to collect emission data at the national level, while LCA is more suitable for fine analysis of production processes.

In order to estimate the development potential of low-carbon economy and comprehensively and objectively evaluate the development level of a country’s low-carbon economy, the low-carbon development index system should be mainly constructed from five levels: low-carbon output, low-carbon consumption, low-carbon resources, low-carbon policies and low-carbon environment. These five dimensions reflect the synergy effect of technology level, consumption mode, resource endowment and development and utilization, transformation efforts, emission reduction and environmental protection[13].

3.2 Analysis of Driving Factors

The level of per capita income is the most important factor affecting urban carbon emissions, and there is a significant positive correlation between them. The growth of per capita income will increase production and consumption, lead to more energy consumption, and push up urban carbon emissions. However, this effect will vary with the industrial structure of the city, and the effect is more obvious in heavy industrial cities, while the effect is not significant in cities with low proportion of productive industries. At the same time, the improvement of the level of urban economic development is conducive to improving the efficiency of carbon emissions, including increasing investment in carbon emissions and promoting innovation driven transformation[14-16].

There is a significant positive correlation between energy intensity and urban carbon emissions, and its decline helps to slow down carbon emissions. Cities with rich energy endowment are prone to energy waste and inefficient utilization, which will push up carbon emissions. At the same time, resource-based cities dominate high energy consuming industries with loose resource constraints, and their carbon emission efficiency is significantly lower than that of non resource-based cities[14, 15, 17].

The population size factor has a significant positive effect on the overall urban carbon emissions, and its expansion will promote the improvement of carbon emissions. While urban population density is positively correlated with carbon emission efficiency, because densely populated cities are more likely to form scale effects, which can promote infrastructure sharing, optimize resource allocation, reduce the marginal cost of emission reduction, promote technological progress and human capital improvement, and further improve carbon emission efficiency[14, 15, 17].

The optimization and upgrading of industrial structure can positively improve the efficiency of carbon emissions. Factors of production flow from high consumption and low efficiency production sectors to low consumption and high efficiency production sectors, promoting the transformation of economic growth mode. China’s industrial sector is gradually turning to a high-quality development model. After a long period of industrial restructuring and low-carbon transformation, the expansion of industrial scale may improve carbon emission efficiency[16, 17].

Green technology innovation can significantly improve the efficiency of urban carbon emissions. The improvement of its level can optimize energy utilization, improve carbon storage and carbon utilization methods, reduce emission reduction costs, promote the improvement of human capital and the green and low-carbon transformation of industry, promote the flow of production factors to low consumption and high value-added industries, and become an important driving force to improve carbon emission efficiency[16, 17].

3.3 Research on Policy Tools and Governance Models

The low-carbon city pilot policy has five core tasks, including establishing a carbon emission target responsibility mechanism, building a carbon emission data control system, introducing low-carbon supporting policies, building a low-carbon industrial system, and promoting low-carbon lifestyles. The implementation of this policy not only facilitates the implementation of command and control tools, but also promotes the application of market incentive and public participation tools. It also relies on reducing energy consumption, optimizing industrial structure, and enhancing technological innovation paths to effectively improve urban carbon emission efficiency[18, 19].

The carbon emission trading policy achieves carbon dioxide emission reduction through market-oriented means. Each emission unit can freely trade their emission shares in the secondary market, that is, emission reduction units can sell their remaining quotas, while excess emission units need to purchase carbon dioxide emission rights. This policy mainly achieves the goal of carbon emission reduction by controlling the scale of energy consumption, incentivizing enterprise technological innovation, promoting green technology progress, and promoting industrial structure upgrading[20].

The implementation of energy transformation policies can continuously promote the optimization of energy structure towards new energy and accelerate the development of non fossil energy. As the core utilization carrier of non fossil energy, electricity needs to expand its application scope in all sectors of society. At the same time, it is necessary to vigorously promote electrification and power systems, especially the deep decarbonization of wind and solar power, to further improve energy utilization efficiency[21].

3.4 Spatial Pattern and Regional Differences Analysis

The spatial distribution of total carbon emissions in county-level cities in China mainly presents a pattern of high emissions in the east and low emissions in the west. High emission areas are mostly concentrated around major cities in the east and central regions, as well as in the central and northern parts of Inner Mongolia, showing an overall clustering pattern. The per capita carbon emissions and economic carbon emission intensity are both high in the north and low in the south, mainly concentrated in the border areas of central and northern Inner Mongolia and Xinjiang Qinghai. For cities at the prefecture level and above, such as the Beijing Tianjin Hebei urban agglomeration, the spatial distribution of net carbon emission intensity generally shows a trend of “cold in the east and hot in the west”. Carbon source hotspots are mainly concentrated in the southern and northwestern regions of Beijing Tianjin Hebei, while carbon sink hotspots are in the Taihang Mountains, Yanshan Mountains, and Bashang Gaoyuan area[22, 23].

There is a significant spatial spillover effect on carbon emission intensity in Chinese cities, and this effect exhibits heterogeneity depending on regional backgrounds. Being in high emission areas can easily promote an increase in carbon emission intensity, while being in low emission areas can promote a decrease in carbon emission intensity. This result further reflects the spatial correlation and interaction of energy intensity. In addition, influenced by inter provincial competition effects, demonstration effects, and economic correlation effects, there is also a significant positive spatial spillover effect on carbon emission performance. The improvement of local carbon emission performance will have a positive driving effect on the carbon emission performance of spatially correlated regions, which can better assist China's urban low-carbon transformation[24, 25].

The construction of low-carbon cities can effectively narrow the economic gap between non central cities and central cities, especially for cities with lower development levels, high industrial dependence, and closer proximity to central cities, this effect is more prominent. The core transmission path originates from the low-carbon transformation of urban industries, the improvement of technological innovation, and the influx of human capital. This indicates that promoting low-carbon transformation can help achieve a win-win situation of carbon neutrality and regional coordinated development[26].

3.5 Micro Behavior and Social Level Research

Consumer spending is the core driver of carbon emissions from residents' lives. With the steady improvement of residents' quality of life, consumption related carbon emissions are also rising. It is estimated that by 2035, the comprehensive energy consumption of residents' consumption will account for more than 40% of the total energy consumption of the whole society. In order to reduce the pressure of consumption on resources and environment, it is necessary to establish and improve the green consumption policy framework, help the implementation of green and low-carbon lifestyle, enhance residents' low-carbon awareness through strengthening low-carbon consumption publicity, and effectively regulate residents' carbon emissions. At the same time, we should also promote and popularize low-carbon products, cultivate the public's concept of green and low-carbon life, promote the upgrading of residents' consumption structure and the optimization of consumption behavior, and provide strong support for China's urban low-carbon transformation[27, 28].

The low-carbon city pilot policy can promote enterprises to carry out overall green technology innovation to a certain extent, especially for high-carbon industries and non-state-owned enterprises. It is mainly reflected by applying for two kinds of patents, namely, energy conservation and alternative energy production. Under the guidance of the carbon peak goal, enterprises actively carry out green technology innovation activities, which can not only improve their own business performance, but also enhance the performance of environmental and social responsibility, so as to achieve the goal of sustainable development. This process not only provides ideas for achieving economic growth and environmental protection, but also cultivates new economic growth force points for carbon peaking work, and also provides practical basis for the optimization and upgrading of economic structure forced by policies[29, 30].

4. Conclusions

This paper systematically reviews the theory and empirical research of China's urban low-carbon transformation, summarizes its related concepts, basic theories, carbon accounting methods and evaluation index system, explores the driving factors of carbon emissions from multiple dimensions, summarizes the policy tools and governance models, analyzes the spatial pattern and regional differences, and studies the micro subject behavior from the social level, so as to provide reference for the practice of China's urban low-carbon transformation.

However, the current research is still insufficient. First, there is a lack of native theoretical framework that fits China's national conditions; The interpretation of the interaction mechanism of multiple subjects is not perfect. Second, the mining of individual behavior decision logic is insufficient; Cross city investigation is relatively blank. Third, there are blind spots and lack of standardization in data collection; The accounting results lack continuity, timeliness and transparency; The evaluation index system for low-carbon transformation of national cities has not been unified. Fourth, the policy failed to fully consider the differences in resource endowments and development among cities, and the scene adaptation was insufficient; Lack of dynamic tracking and system feedback mechanism; Low public participation.

Based on the above conclusions, this paper puts forward the following policy suggestions for the low-carbon transformation of Chinese cities. First, the government should build a theoretical framework of localization based on China's national conditions and integrate multiple disciplines to explain its complexity; The problem of information asymmetry can be solved by establishing a diversified collaborative governance framework with clear rights and responsibilities. Second, the micro level needs to form a landing strategy, with the help of high-resolution carbon data, spatial measurement and AI model to develop targeted technology paths and control methods, build a digital management platform, and establish a unified national accounting standard. Third, carry out the research on the low-carbon path of urban typology, and each city can choose the optimal path according to its own factor endowment; At the same time, it is necessary to promote cross-scale research to achieve collaborative carbon reduction. Fourth, cities should strengthen the green financial mechanism, broaden diversified participation channels, reduce the threshold of public participation, and strengthen policy communication and awareness popularization.

Most of the existing case studies are targeted at large cities. Future studies can broaden the scope of subjects in the cases, focus on small and medium-sized cities, county and township units for analysis, improve regional comparison, and fill the research gap of cross city and cross regional collaborative transformation. At the same time, with the help of digital technology to study its deep integration mechanism with low-carbon transformation, based on China's practical problems, combined with Chinese and Western theoretical innovation, build a theoretical framework with Chinese characteristics.

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