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The Impact of Intensive Utilization of Construction Land on Carbon Emission Efficiency in China

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Abstract: *Under the global climate change, how to continuously improve the efficiency and quality of urban construction land utilization under the premise of energy saving and emission reduction is a key scientific issue that needs to be solved urgently. In this study, we start from exploring the impact of intensive utilization of construction land on carbon emission efficiency, and measure the carbon emission efficiency of construction land in 30 provinces of China using the slacks-based measure (SBM) model with carbon emission as a non-desired output. The spatial analysis and panel Tobit model are also used to analyze the carbon emission efficiency in terms of the quantitative trend, spatial distribution, and the influence mechanism, which is expected to provide a reference for the intensive use of construction land and the construction of low-carbon society in each province.*

Keywords: *Construction Land, Intensive utilization, Carbon emission efficiency*

1. Introduction

Construction land is an important part of land resources and the main carrier of human and socio-economic activities[1]. As a result of population growth and urbanization, construction land has become a scarce resource. Intensive use of land is gradually becoming the main way to solve the contradiction between the shortage of land resources for construction and the advancement of urbanization.[2]The input of factors such as labor, capital and technology is the prerequisite for improving the level of intensive land use, while the construction land, as the most important carrier for urban development, is concentrated on the construction land. The increase of factor inputs promotes the carbon emission of construction land as a source of carbon, which makes construction land also become the main carrier of carbon emission. Research shows that construction land is the largest source of carbon among all land use types[3].

At present, the constraints on economic development imposed by resources and the environment are increasing[4]. The development thinking and path of relying on increasing inputs of production factors can no longer meet the real needs of China's high-quality economic development. Therefore, it is of great significance to study the impact of intensive utilization of urban construction land on carbon emission efficiency, and to improve the carbon emission efficiency of intensive utilization of construction land in order to build a low-carbon city and cope with global warming.

2. Methods

2.1 Carbon Emissions Measurement

Carbon emissions from construction land use mainly come from mining and manufacturing industries, wholesale and retail trade, accommodation and catering industry, construction industry and urban residents' living. The main energy types and the corresponding carbon emission coefficients are shown in the following table (Table 1). The total carbon emissions are indirectly measured based on energy consumption, and the calculation formula is as follows:

$$\boldsymbol{E} = \sum \boldsymbol{e_i} = \sum (\boldsymbol{K_i} \times \beta_i) \tag{1}$$

Where E is the carbon emissions from energy consumption, which is equal to the carbon emissions from construction land (unit t); e_i is the carbon emissions from the ith energy source (unit t); K_i is the ith

energy consumption (unit tce); and β_i is the carbon emission coefficient of the ith energy source (unit t/tce).

Table 1: Carbon Emission Coefficients of Each Energy Type

Energy Type	Carbon Emission Factor	Energy Type	Carbon Emission Factor
Coal	0.7559	Fuel Oil	0.6185
Coke	0.8550	Natural Gas	0.4490
Crude Oil	0.5857	Refinery Dry Gas	0.5714
Gasoline	0.5538	Liquefied Natural Gas	0.5042
Kerosene	0.5714	Coke Oven Gas	0.3548
Diesel oil	0.5921	Blast Furnace Gas	0.4602

Note: Data refer to the United Nations Intergovernmental Panel on Climate Change (IPCC).

2.2 Slacks-Based Measure (SBM) model

The non-angle and non-radial SBM model proposed by Tone [5] can solve both the input-output slack-type problem and the efficiency evaluation problem under non-desired outputs, while avoiding the bias effects of the angle and radial choices, which is applicable to the accurate measurement of carbon emission efficiency in this study.

The model is constructed by assuming that there are n number of decision units and they all contain I inputs and D desired outputs and U undesired outputs. Define their vector matrices respectively as $X=[x_1, \cdots, x_n]$, $Y^D=[y_1^D, \ldots, y_n^D]$, $Y^U=[y_1^U, \ldots, y_n^U]$.The carbon emission efficiency SBM model takes the following form:

$$\rho = \min \frac{1 - \frac{1}{i}\sum_{i=1}^{i} \frac{s_i^-}{x_{ij}}}{1 + \frac{1}{D+U}\left(W^D \sum_{k=1}^{D} \frac{s_k^D}{y_{kj}^D} + W^U \sum_{k=1}^{U} \frac{s_k^U}{y_{kj}^U}\right)}$$

$$s.t. \begin{cases} x_{ij} = \lambda X + s^- \\ y_j^D = \lambda Y^D - s^D \\ y_j^U = \lambda Y^U + s^U \\ s^- \geqslant 0,\ s^D \geqslant 0,\ s^U \geqslant 0,\ \lambda \geqslant 0 \end{cases} \tag{2}$$

Where ρ is the efficiency value of decision-making unit, s is the slack variable of input and output, x_{ij} is the j^{th} input of unit i, y_{kj} is the j^{th} output of unit k. W^D and W^U are the relative weights of desired and non-desired outputs, which are set to 2/3 and 1/3, depending on the number of outputs. λ is the weight vector, s^-, s^U and s^D denote the amount of redundancy between inputs and non-desired outputs and the amount of shortfall in desired outputs, respectively.

2.3 Panel Tobit regression model

This study establishes a panel Tobit regression model to empirically analyze the mechanism of the intensive use of construction land on carbon emission efficiency and explore other factors affecting carbon emission efficiency. The specific model is constructed as follows:

$$y_{it} = \begin{cases} y_{it}^* = \alpha_0 + \sum_{t=1}^{n} \beta_k x_{it} + \varepsilon_{it} & y_{it}^* > 0 \\ 0 & y_{it}^* \leqslant 0 \end{cases} \tag{3}$$

where y_{it} is the explanatory variable, x_{it} is the explanatory variable, β_k is the vector of regression coefficients for the explanatory variable, α_0 is a constant term, and ε_{it} is a random error term obeying an N(0, σ2)distribution.

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3. Indicators and data

3.1 Input-Output Indicators for Carbon Emission Efficiency Measurement

Intensive utilization of urban construction land is the process of continuous accumulation and agglomeration of labor, capital and other factors on land. The input, desired output, and non-desired output indicators selected for this study are as follows (Table 2).

Table 2: Index of Carbon Emission Efficiency of Intensive Use of Construction Land in China

Indicator Type	Indicator	Description
Input indicator	Labor input per unit land	Number of persons employed in secondary and tertiary industries in urban areas/Area of cities and towns
	Capital input per unit land	Investment in fixed assets in secondary and tertiary industries in urban areas/Area of cities and towns
	Energy consumption per unit land	Consumption of energy/Area of cities and towns
	Technical input per unit land	R&D expenditures/Area of cities and towns
Expected output indicator	Realization of value added of GDP of secondary and tertiary industries per unit of carbon emissions	Value added of secondary and tertiary industries/Quantity of carbon emissions
	Total retail sales of consumer goods realized per unit of carbon emissions	Total retail sales of consumer goods/Quantity of carbon emissions
Non-expected output indicator	Carbon emissions per unit of land	Quantity of carbon emissions /Area of cities and towns

3.2 Data

In this study, the data on energy consumption are from the China Energy Statistics Yearbook [6]. The data on urban area, number of employees in the secondary and tertiary industries, investment in fixed assets in the secondary and tertiary industries, value-added of the secondary and tertiary industries, total retail sales of consumer goods of the jurisdictions, greening coverage, and urban population density of provinces are from the website of the National Bureau of Statistics [7].The data on the provincial R&D expenditures are from the National Statistical Bulletin of Science and Technology Investment Statistics Bulletin [8]. In this study, panel data of 30 provinces (municipalities directly under the central government and autonomous regions) in China during 2006-2019 are selected. In view of data availability, the study area excludes Tibet, Hong Kong, Macao and Taiwan.

4. Carbon Emission Efficiency Analysis of Construction Land

In this study, the comprehensive carbon emission efficiency of intensive utilization of construction land was measured based on the SBM model using Max DEA during 2006-2019. In order to visualize the trend of the carbon emission efficiency of intensive use of construction land, this study draws a graph of the average value of the carbon emission efficiency of intensive use of construction land in China from 2006 to 2019 (Figure 1). At the national level, the carbon emission efficiency of intensive utilization of construction land shows a trend of "first decreasing, then increasing, and finally decreasing". However, in general, the fluctuation of the carbon emission efficiency of intensive utilization of construction land in China is not very large, showing a weak overall downward trend.

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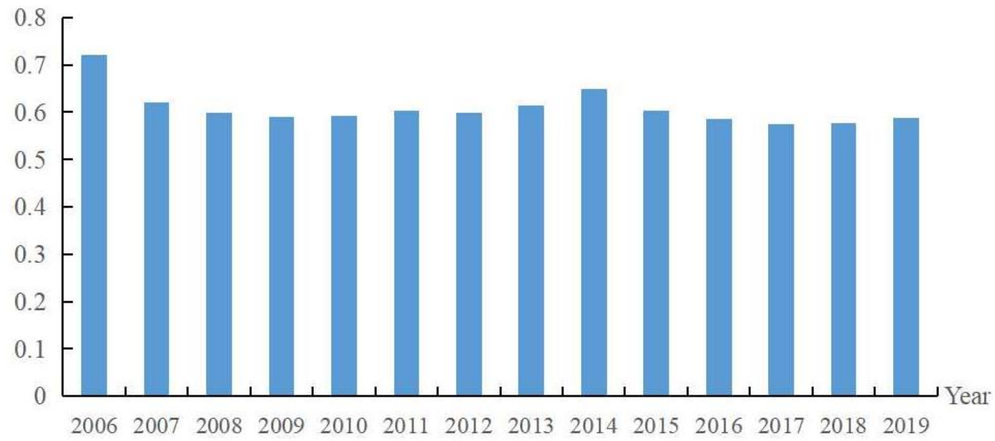

Figure 1: Average Efficiency Index of Carbon Emission Efficiency of Construction Land in China from the year 2006 to 2019

5. Impact of Intensive Utilization of Construction Land on Carbon Emission Efficiency

5.1 Models and Indicators.

This study analyzes the influencing factors of carbon emission efficiency of urban construction land in 30 provinces of China from 2006 to 2019 based on the panel Tobit regression model. Combining the principles of indicator selection and considering the urban development trend as well as data availability, carbon emission efficiency (CE) measured based on the SBM model was determined as the explanatory variable, and intensive land use (IILU) was selected as the explanatory variable, including four specific indicators, i.e., labor force (LB), capital (CI), energy (ER), and technology (TE), which represent the elemental land use of urban construction land respectively input level. In addition, the greening level (GR), population density (PO), and industrial structure (IS) were added as control variables based on the reality of the carbon emission efficiency of China's construction land and related research results (Table 3). The panel Tobit regression model expression is given below:

$$y_{it} = c + \delta_1 \ln LB_{it} + \delta_2 \ln CI_{it} + \delta_3 \ln ER_{it} + \delta_4 \ln TE_{it} + \delta_5 \ln CON_{it} + \varepsilon_{it} \tag{4}$$

Where ***i*** and ***t*** are different years and provinces, y_{it} is the carbon emission efficiency of intensive utilization of construction land in each province, $lnLB_{it}$, $lnCI_{it}$, $lnER_{it}$ and $lnTE_{it}$ are the logarithmic values of the explanatory variables, which all belong to the indexes of intensive utilization of land.$lnCON_{it}$ is the control variables, including the greening level, population density, and industrial structure. ***c*** is the constant term, δ_k is the regression coefficients of the respective variables, andε_{it} is the random error term.

Table 3: Carbon Emission Efficiency Index Selection of Urban Construction Land

Indicator Propertie	Indicator	Description
Dependent Variable	Carbon emission efficiency(CE)	Carbon emission synthesis efficiency value
Independent Variable	Labor force(LB)	Number of persons employed in secondary and tertiary industries in urban areas/Area of cities and towns
	Capitalism(CI)	Investment in fixed assets in secondary and tertiary industries in urban areas/Area of cities and towns
	Energy consumption(ER)	Quantity of carbon emissions /Area of cities and towns
	Technical(TE)	R&D expenditures/Area of cities and towns
Control Variable	Greening level(GR)	Coverage rate of urban greenery
	Population density(PO)	Urban population/Area of cities and towns
	Industrial structure(IS)	Value added of tertiary industry/value added of secondary industry

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5.2 Analysis of Empirical Results.

Table 4: Results of Panel Tobit Regression

variant	Stochastic Effect	Fixed Effect
lnLB	-0.1687***(0.0467)	-0.2997***(0.0523)
lnCI	0.1119***(0.0183)	0.1412***(0.0190)
lnER	-0.6822***(0.1058)	-0.7176***(0.1312)
lnTE	0.0179(0.0643)	0.1153**(0.0851)
lnGR	0.3007(0.1836)	0.6853***(0.2271)
lnPO	0.1226*(0.0636)	0.1382*(0.0643)
lnIS	0.5296***(0.0731)	0.2863***(0.1077)
_cons	0.6049(0.8294)	-3.6451(1.0868)
Adjust R^2	0.8678	0.9168
F	——	324.65

Note: ***, **, * indicate significance at 1%, 5%, and 10% confidence levels, respectively.

When using the panel Tobit regression model, the fixed effect model and the random effect model can be utilized respectively to make a comprehensive judgment on the indicator factors and determine the optimal explanatory model through the Hausman test. This study combines the Hausman test (Prob>chi2=0.0000) and compares the regression results, and finds that the fixed effect model is better than the random effect model, so this study chooses the regression results of the fixed effect model for the analysis of impact factors (Table 4).

Labor input per unit of land (lnLB) has a significant negative effect on regional carbon emission efficiency and is significant at the 1% level. The concentration of labor indicates that there are a large number of labor-intensive industries and traditional service industries in the industrial structure, with low efficiency of technological transformation, and the output process is accompanied by a large amount of carbon emissions. In addition, a large influx of labor leads to the expansion of urban scale, which also increases the transportation and logistics costs of intra-city operation, and indirectly leads to the decrease of carbon emission efficiency.

Capital input per unit of land (lnCI) passes the 1% significance test and has a significant positive effect on regional carbon emission efficiency. Compared with the average labor force, the increase of capital input per unit of construction land can promote the transformation of labor-intensive industries to asset-intensive industries in the industrial structure, which can strengthen the innovation effect and cost-saving effect of land spatial agglomeration.

Energy consumption per unit of land (lnER) has a significant negative effect on regional carbon emission efficiency and is significant at the 1% level. On the one hand, the intensive use of construction land in the process of urban development will inevitably consume a large amount of energy, and the increase in energy consumption will bring significant efficiency improvement for urban economic growth. On the other hand, China's industrial growth has long relied on the consumption of fossil fuels dominated by coal, and energy combustion is the main source of current greenhouse gas emissions.

Technology input per unit of land (lnTE) passes the 1% significance test, showing a significant positive effect. The reason is that the technology R&D investment itself will not increase the average local carbon emissions, and the economic growth, industrial production and energy consumption pattern change driven by the technology investment will further promote the carbon emission efficiency. At present, China's industries are undergoing technological transformation, and the proportion of technological industries is increasing rapidly, which is an important reason for China's carbon emission efficiency to increase.

Among the control variables, the greening level (lnGR) passes the 1% significance test and the coefficient is positive, indicating that improving the greening and intensification level of construction land helps to improve the efficiency of carbon emission. The study of the carbon emission effect of land use modes concluded that the carbon emission of forest land, grassland, etc. is less than the absorption, which is a carbon sink, while the construction land is the carbon source with the highest carbon emission level. Therefore, increasing landscaping and greening in construction land can not only reduce the proportion of pure carbon sources, but also offset part of the carbon emissions due to the absorption of carbon sinks, which reduces the land-averaged output carbon emissions in both directions, and is conducive to improving the efficiency of carbon emissions.

Population density (lnPO), although the effect is significantly positive at the 10% significance level, the significance level is relatively weak. This indicates that although urban population density itself has a positive impact on carbon emission efficiency, the main way of the current urbanization process is outward expansion, rather than vertical intensification of population. Except for a few developed provinces, the difference in the number of people per unit of construction land in each province is limited, and the impact on carbon emission efficiency is also relatively small.

Industrial structure (lnIS) passes the 1% significance test and the coefficient is positive, indicating that reducing the secondary industry and increasing the proportion of the tertiary industry in the national economy has a contributing effect on improving the efficiency of carbon emissions. This indicates that the newly emerging tertiary industry, including information, technology, finance and other industries, produces minimal carbon emissions while driving economic growth. However, the proportion of traditional service industries such as catering and transportation is still high in China, and optimizing the internal structure of the industry will help to further enhance carbon emission efficiency.

6. Summary

In terms of the time evolution trend, the carbon emission efficiency of urban construction land use in each province from 2006 to 2019 shows the change characteristics of first decreasing, then increasing and finally decreasing, but the overall trend is decreasing. In terms of spatial evolution characteristics, the southern region of China as a whole consistently had higher carbon emission efficiency than the northern region of China during the period 2006-2019. From 2006 to 2010, the phenomenon of high carbon emission efficiency in the southern region of China gradually receded, and gradually shifted from a wide cross-regional distribution to a concentration along the southeast coast. From 2010 to 2019, China's carbon emission efficiency gradually shows the characteristic of the center circle again, with the highest in the southern region of China and decreasing to the outer circle.

At the national level, the per capita technical input and per capita capital input in the indicators of intensive utilization of construction land have a significant positive effect on carbon emission efficiency, while the per capita labor input and per capita energy consumption have a significant negative effect on carbon emission efficiency. In addition, the greening level, population density and industrial structure also have different degrees of significant contribution to the improvement of carbon emission efficiency.

In the context of reducing carbon emissions, China's regional development model of high input, high growth and high emissions needs to be further optimized. Comprehensive consideration should be given to the problems and shortcomings in the development and utilization of urban construction land in different regions, and policies on industrial transformation, optimization of the energy structure, as well as energy conservation and environmental protection should be implemented in accordance with the actual situation in different regions. The southern region should focus on the intensive and economical use of existing construction land, and transfer the excess fixed asset investment in the secondary and tertiary industries to technical research funding, so as to improve technological efficiency and realize an increase in the efficiency value of carbon emissions. The northern region, on the other hand, should focus on doing a good job of optimizing the allocation of construction land when undertaking the transfer of industries from developed regions, raising the threshold for the entry of high-energy-consuming industries, eliminating excess production capacity that is inefficient and polluting, and forcing enterprises to accelerate their transformation and upgrading. In addition, the sharing of scientific and technological achievements between the eastern region and the central and western regions should be encouraged to enhance the green and low-carbon industrial agglomeration capacity. A development pattern with complementary advantages and a clear division of labor in the industrial chain should be constructed, so as to fundamentally reduce carbon emissions.

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