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Factors Affecting Carbon Emissions in the Construction Industry based on STIRPAT Model: Taking Henan Province of China as an Example

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ABSTRACT

The construction industry of China is characterized by its huge consumption and carbon emissions, thereby making this industry one of the most important areas that require energy conservation efforts. Identifying those factors that affect carbon emissions in the construction industry carries great significance in reducing building carbon emissions, promoting low-carbon cities, and achieving China's emission reduction goals. This paper firstly reviews the literature on those factors that affect the carbon emissions in the construction industries of developed countries. Second, by using Henan Province as an example, those factors that influence carbon emissions are measured by using the classical STIRPAT (Stochastic Impacts by Regression on Population, Affluence and Technology) model. Third, some measures for reducing carbon emissions in the construction industry are developed. Those factors that influence the carbon emissions of buildings are multi-dimensional and diversified. Resident population, urbanization rate, building carbon emission intensity, per capita GDP (Gross Domestic Product), and per capita added value of the tertiary industry all have significant effects on the carbon emissions of buildings in Henan Province. Some policy suggestions can be derived from the findings of this work, such as encouraging building energy conservation, improving the energy efficiency of the construction industry, adjusting the use of building materials, and improving the extant policies for building emission reduction. The results also provide a theoretical basis for identifying those factors that affect the carbon emissions in the construction industry and for formulating and implementing strategies for the low-carbon development of this industry.

INTRODUCTION

The amount of carbon emissions has increased along with continuous urbanization and industrialization. At present, carbon emissions are considered the principal causes of climate change, and the CO_2 produced by the construction industry has been considered an important source of greenhouse gas emissions. Cities are important units and research subjects in national and regional carbon emission reduction. Therefore, cities must engage in joint efforts to achieve the carbon reduction targets of buildings at the country level. China is currently in a stage of rapid industrialization, urbanization and modernization that drive a rapid development in its economy. However, China also faces some practical problems like high consumption and high carbon emissions. Reducing carbon emission intensity has become a primary goal for China to overcome its economic growth and environmental pressures. In recent years, the increasing urbanization of China has promoted the development of its construction industry, thereby leading to a continuous increase in the energy consumption of buildings. Therefore, energy-saving control in the construction field has become a core focus for China to fulfil its energy conservation and emission reduction goals, and the construction industry plays an important role in controlling global energy consumption. Despite spending much effort in reducing the energy consumption of buildings in recent years, improving the living standards of people, and expanding the total building area, China is expected to witness a continuous increase in its total building energy consumption in the long run and will continue facing great challenges in reducing its building energy consumption.

Henan is a large province in Central China in terms of population. As the pillar industry in the national economic development of Henan Province, the construction industry has rapidly developed in recent years. As shown in Fig. 1, Henan's GDP and the added value of its construction industry have stably increased from 2007 to 2017, reaching 4455.283 billion yuan and 269.411 billion yuan in 2017, respectively, with the added value of the construction industry accounting for 5% of the province's GDP. The construction industry also plays an indispensable role in the national economic development of Henan Province. However, the environmental pressures on the economic development of the province cannot be ignored. To improve the energy efficiency of buildings and promote the chain development of the entire green building industry, the energy

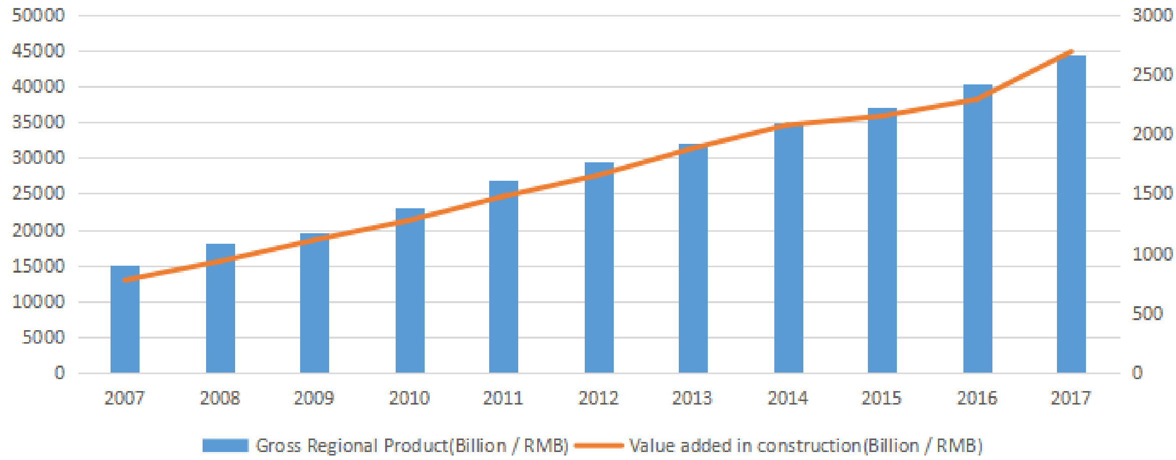

Fig. 1: Henan's GDP and added value of the construction industry from 2007 to 2017.
[Source: China Statistical Yearbook (2018)]

consumption of the construction industry warrants further attention. As a typical energy-intensive industry, the construction industry is characterized by its high energy consumption, high emission, and low efficiency. Moreover, among all of China's economic sectors, the construction industry carries the greatest potential in energy conservation and emission reduction as well as the lowest emission reduction costs. Therefore, the construction industry plays an important role in the development of low-carbon cities. To ensure a healthy and sustainable building energy conservation in Henan Province and to effectively control its building energy consumption, those factors that influence the carbon emissions in the construction industry of Henan Province have been studied, and some practical measures for enhancing its building energy efficiency have been proposed.

PAST STUDIES

As a representative industry with high energy consumption and pollution, the construction industry not only consumes much energy but also emits a large amount of CO_2. How to reduce the CO_2 emissions of this industry has become a problem that requires an immediate solution. Most foreign studies on those factors that influence the CO_2 emissions of this industry have examined energy, economy, and materials from the national macro-level perspective. For example, Torvanger (1991) found that exports and energy efficiency influence the CO_2 emissions of the construction industry to a certain extent and that energy intensity can directly affect the intensity of CO_2 emissions of this industry. Schipper et al. (1995) analysed the energy intensity, the effect of using mixed fuels, and the changes in the CO_2 emissions of the construction industries of 13 IEA countries and found that the differences in the energy intensity of these industries depend on their per capita CO_2 emissions. Cole et al. (2004) found that the improvements in urbanization level increase the total energy consumption and building carbon emissions. Glaeser et al. (2010) studied the carbon emissions in American cities and found that the level of carbon emissions increases along with population and is mainly driven by the fact that the per capita carbon emissions of the new population are higher than those of the stock population. The study of You et al. (2011) identified industrial process, energy consumption, fugitive, and land footprint emissions as the four major sources of CO_2 emissions in the whole life cycle of the urban construction system. Yun et al. (2011) analysed those factors that affect the energy efficiency of residential buildings and found that the behaviour of residents and their socio-economic aspects (i.e., household income) affect building energy efficiency. Zuo et al. (2012) identified market demand, material selection, knowledge of equipment managers, and government policy as the main factors that influence carbon emissions in the construction industry. Wiedenhofer et al. (2013) quantified the energy consumption space and socio-economic driving forces of different categories of building energy demands and found that urban form, income, and population structure all influence the carbon emissions in the construction industry. Hong et al. (2014) identified the stages of material manufacturing, transportation, and site construction as the main drivers of carbon emissions in the construction industry. Weiguang et al. (2014) identified those factors that influence the changes in the energy consumption of buildings in China from 2005 to 2009 by using the logarithmic mean decomposition index and found that the improvement in the living conditions of residents promotes an expansion in building area while an increase in their income promotes the energy consumption of the construction industry; however, both of these influences are not significant. The research of Nejat et al. (2015) reported that the global residential energy consumption increased by 14% from 2000 to 2011, especially in developing countries where population, urbanization, and economic growth are the main driving factors. Cong et al. (2015) studied those factors that drive the CO_2 emissions in the construction industry of China and identified per capita residential building area, building area, consumption level, output value of the tertiary industry, and per unit building area as the five factors that drive the CO_2 emissions of the construction industry. Ma et al. (2017) evaluated those factors that influence the construction industry of China from 2000 to 2015 by using the stochastic impacts of the STIRPAT model and ridge regression analysis. They identified population, urbanization level, per capita public building area, GDP index of the tertiary industry, and carbon emission intensity of public buildings as the main factors that influence the carbon emissions of this industry. Shi et al. (2017) identified the construction industry as one of the primary sources of carbon emissions in China. They investigated those factors that drive the changes in the carbon emission of China's construction industry based on data from the World Input-Output Database and by using the structure decomposition analysis method and then identified demand effect and energy intensity as the main driving factors of carbon emissions in the construction industry. Lu et al. (2018) analysed those factors that promote the carbon emissions of the construction industry based on data from 30 Chinese provinces from 2007 to 2015 and found that the energy consumption of the construction industry has a final contribution rate of more than 50% and that the changes in building energy consumption is mainly driven by area and energy intensity effects.

In sum, those factors that influence building carbon emissions are multi-dimensional and diversified, and research on this subject can be performed from both the micro and macro perspectives. Most of the existing studies have focused on the carbon emissions of new buildings without analysing regional macro-building carbon emissions, which can help reveal the total building carbon emissions during the preparation, use, disposal, and recovery of construction materials within a region in a specific period. By taking Henan Province as an example and using the classical STIRPAT model, this study measures those factors that influence the carbon emissions in the construction industry of Henan Province. The findings of this work can provide some references for scientifically identifying those factors that drive the carbon emissions of this industry and for formulating relevant carbon reduction policies and plans.

MODEL INTRODUCTION AND DATA DESCRIPTION

Model introduction: A model with the characteristics of randomness and unequal proportional change between the impact factors and the environment was designed based on the simple concept, quantitative analysis, and comprehensive systematics of IPAT (Impact, Population, Affluence, Technology) theory of the STIRPAT model (Dietz 1994). This model can be expressed as:

$$I = aP^b A^c T^d e \quad ...(1)$$

Where I denotes the degree of environmental impact, P denotes the population factor, A denotes the economic factor, T denotes the technical factor, a is a constant, b, c, and d are the elasticity coefficients of the impacts of population, economy, and technology on the environment, and e is an error term. The population factors in the STIRPAT model were decomposed into permanent population and urbanization rate of Henan Province, whereas the degree of prosperity was decomposed into the per capita GDP of Henan Province and the per capita added value of the tertiary industry. The building carbon emission intensity of Henan Province was then used to characterize the technical factor. The final model can be expressed as

$$\ln E = a + b\ln P + c\ln U + d\ln G + e\ln T + f\ln B + \delta \quad ...(2)$$

Where E denotes the carbon emissions of the construction industry (10,000 tons of standard coal), P denotes the population (10,000 people), U denotes the urbanization rate (%), G represents the per capita GDP (10,000 yuan per person), T denotes the per capita added value of the tertiary industry (10,000 yuan per person), B represents the building carbon emission intensity (10,000 tons of standard coal per 10,000 yuan), a is a constant, δ is the residual, and b, c, d, e, and f represent the degrees of impact of the corresponding factors on the environment (with a greater value indicating a more significant effect on the environment). E in Formula (2) cannot be obtained directly and was estimated according to the carbon emission coefficients of the energy consumption of urban and rural residential areas and the other land uses for industry, mine, and transportation. The IPCC (Intergovernmental Panel on Climate Change) list calculation method was applied as follows:

$$E = \sum_{j=1}^{n} A_j \times C_j \quad ...(3)$$

Where E denotes the building carbon emissions, A_j denotes the consumption of energy j, C_j denotes the carbon emission coefficient of energy j, and j denotes the type of energy. The carbon emission coefficients of major energy sources are presented in Table 1.

Data processing: Data from 2007 and 2017 were collected for this study. The carbon emission index of the construction industry of Henan Province was calculated by using the conversion coefficient in Table 1 and Formula (3) according to the building consumption material table in different regions taken from the China Construction Statistical Yearbook. Other indexes, including population, urbanization rate, per capita GDP, per capita added value of the tertiary industry, and intensity of building carbon emissions, were all taken from the Henan Statistical Yearbook (2008-2018).

ANALYSIS OF RESULTS

The multiple co-linearity between variables represents the linear correlation between these variables during the multi-regression. If a serious multiple co-linearity exists between variables, then the regression parameter estimate obtained by using the ordinary least square regression method is considered less stable. The ridge regression method was used to eliminate the multiple co-linearity in the model and SPSS19.0 was used for the ridge regression fitting. The linear regression results based on ridge regression are presented in Table 2.

The findings in Table 2 reveal that:

1. The determination coefficient of the ridge regression model is 0.945, which has a high goodness of fit. In the hypothesis test of the ridge regression model, the *F-value* is 187.458. The significance test *Sig F* of the whole equation is less than 0.001, thereby indicating that the whole regression equation is significant.
2. The permanent population of Henan Province has the most significant impact on building carbon emissions with an elasticity coefficient of 5.984%, which means that each 1% increase in population will increase the total building CO_2 emissions by approximately 5.984%. Henan Province is a populous province in China, and its population has steadily increased in recent years. As a result, the demand for building areas and activities in construction sites has been increasing, which subsequently promotes building CO_2 emissions.
3. Urbanization rate greatly influences the building carbon emissions in Henan Province with an elasticity coefficient of 2.145%, which means that every 1% increase in urbanization level will increase the building carbon emissions by approximately 2.145%. This finding can be primarily attributed to the fact that urbanization increases the number of buildings in Henan Province and promotes total building carbon emissions.
4. Building carbon emission intensity is computed as the proportion of building carbon emissions in the total output value of the construction industry. This index also reflects the level of construction technology and has a certain influence on the building carbon emissions of Henan Province with an elasticity coefficient if 0.869%, which indicates that every 1% increase in building carbon emission intensity will increase the building carbon emissions by 0.869%. A higher building carbon emission intensity corresponds to higher carbon emissions generated by the output value of the construction industry per unit as well as a lower level of construction technology in the construction industry of Henan Province. In other words, a high building carbon emission intensity may indicate an unnecessary waste of energy and resources or the ineffective exploration of emission reduction potential in the construction process.
5. The elasticity coefficient of per capita GDP is 0.326%, which means that every 1% increase in the per capita GDP of Henan Province will increase the building carbon emissions by about 0.326%. The growth of per capita GDP in Henan Province reflects an improvement in the people's living standards, an increase in the number of luxury goods purchased by residents, and an increase in the demand for various service products. Many of these activities take place in buildings, thereby increasing building carbon emissions.

Table 1: Carbon emission coefficients of representative energies.

No.	Energy type	Carbon emission coefficient
1	Raw coal	0.7559
2	Coking coal	0.8550
3	Fuel oil	0.6185
4	Gasoline	0.5538
5	Kerosene	0.5714
6	Diesel oil	0.5921
7	Natural gas	0.4483
8	Electricity	0.7559

Table 2: Linear regression results based on ridge regression.

	Non-standardized coefficient		Standardized coefficient
lnP	5.984		0.475
lnU	2.145		0.268
lnG	0.326		0.146
lnT	0.187		0.684
lnB	0.869		0.647
a	-84.57		-47.45
R-Square		0.945	
Adj R-Square		0.912	
F-value		187.458	
Sig F		0.000	

6. The per capita added value of the tertiary industry has the least influence on building carbon emissions with an elasticity coefficient of 0.187%, which means that every 1% increase in the per capita added value of the tertiary industry will increase the building carbon emissions by 0.187%. The tertiary industry mainly refers to the service industry. Compared with the primary and secondary industries, the tertiary industry mostly takes place in construction sites, such as catering, accommodation, and shopping malls. Therefore, an increase in the added value of the tertiary industry will inevitably promote service activities in construction sites, which in turn will increase the energy consumption and CO_2 emissions in these sites.

POLICY SUGGESTIONS

The following policy suggestions are proposed based on the findings of this work.

1. Constructing policies to encourage and guide building energy conservation, resource intensiveness, and environmental protection: Policy makers should encourage intensive and economical use of resources, improve the energy efficiency of buildings, promote harmonious coexistence between man and nature, and facilitate the formation and sustainable development of a resource-intensive and environment-friendly society. A systematic tax preferential policy, including income, turnover, and property taxes, can be implemented for low-carbon and environment-friendly enterprises, and financial subsidies and tax preferences can be offered to the purchase of low-carbon products and services. Several measures can also be taken to accelerate the establishment and popularization of building energy efficiency labelling, improve the building energy efficiency design standard, or implement hierarchical preferential tax policies for buildings with high energy efficiency labels in order to establish a positive guiding mechanism for resource intensiveness and environmental protection.
2. Improving the energy utilization efficiency and optimizing the building energy consumption structure of the construction industry: The total economic output of China's construction industry has been growing rapidly along with its energy consumption and carbon emissions. This industry is currently characterized by its high consumption and emission. Given that the energy intensity effect restrains the improvements in the carbon emission intensity of China's construction industry, the energy efficiency of this industry must be increased while reducing its energy intensity effect. The construction industry should also improve the low-carbon literacy of its workers, promote a rational use of energy, reduce its inefficient use and waste of energy, and encourage the effective use and recycling of energy in the construction process. The industry should also further optimize its energy consumption structure, work out the consumption structures of different types of energy resources, reduce its use of coal, improve the level of its low-carbon technology innovation, and accelerate its development and utilization of sustainable and green energies.
3. Adjusting the use of construction materials and optimizing construction technologies: The consumption of cement, steel, aluminium, and other building materials account for a huge amount of the total carbon emissions of the construction industry, among which the consumption of cement and steel account produces the highest emissions. The high consumption and emission of building materials is the primary driver of the high carbon emission intensity of the construction industry. Therefore, this industry must improve its level of technological innovation in its production of building materials, encourage construction enterprises to adopt energy-saving and renewable building materials, and increase its use of high-intensity and high-performance building materials. The industry should also optimize its construction technology, promote the recycling of building materials, enhance its construction of assembly buildings, and promote the development of intelligent and integrated buildings.
4. Improving the building emission reduction policy and encouraging the development of building technologies: The building energy-saving and emission reduction policy plays a role in the formulation of laws and regulations, issuance of energy saving standards, development of energy saving plans, production of energy saving statistics, and application and promotion of energy saving technologies. Additional efforts must be allocated to strengthening the energy-saving and emission-reduction renovation of existing residential buildings, the energy-saving and emission-reduction renovation and supervision of large public buildings, enhancing the application of renewable energy in buildings, and demonstrating and promoting the use of green buildings. The implementation of energy saving and emission reduction standards for new buildings and the energy-saving and emission-reduction renovation for existing buildings are key areas for the implementation of building energy saving and emission reduction policies, while the demonstration and promotion of green buildings and the application of renewable energy buildings are key support directions of recent policies.

CONCLUSION

The further urbanization of China will increase the country's building energy consumption and carbon emissions, thereby hindering China's realization of its carbon emission reduction targets. Identifying those factors that influence the carbon emissions of the construction industry is of great significance in alleviating the pressures caused by energy consumption and carbon emissions in this industry and in formulating the relevant carbon emission reduction policies and plans. By taking Henan Province as an example and using the classical STIRPAT model, this paper measures those factors that influence building carbon emissions. Some measures for reducing the carbon emissions in this industry are also proposed. Five factors, namely, resident population, urbanization rate, building carbon emission intensity, per capita GDP, and per capita added value of the tertiary industry, all have significant effects on the carbon emissions of the construction industry in Henan Province. Some measures, such as constructing policies for encouraging building energy conservation, improving the energy efficiency of the construction industry, adjusting the use of building materials, and encouraging the development of construction technologies, can be adopted to realize the emission reduction goal of the construction industry. Future studies should spatially measure the relationship between building carbon emissions and related factors in different provinces and cities, investigate the regional characteristics and differences of building carbon emissions, examine the energy efficiency of the construction industry, and scrutinize the carbon emission trading market system of the construction industry.

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