Study on the influence of urban construction land expansion on carbon emission based on VAR Model -- a case study of Nanchang City

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Abstract. In the context of promoting high-quality economic development, it is of great significance to study the relationship between the expansion of urban construction land and carbon emission for the transformation of economic development mode and the implementation of green and low-carbon development. Based on the time series data of Nanchang City from 1995 to 2017, this paper analyzes the relationship between urban construction land expansion and carbon emission by constructing carbon emission measurement model, VAR model, using co integration test, Granger causality test, pulse analysis and other research methods. The results show that there is a co integration relationship between urban construction land expansion and carbon emissions, and Granger causality test shows that urban construction land expansion is the Granger cause of carbon emissions, while impulse response analysis confirms that the impact of urban construction land expansion on carbon emissions at the early stage is not significant, and the subsequent impact increases gradually, and the impact on carbon emissions will reach a stable state when urbanization is mature And put forward policy suggestions.

1. The raising of questions
In recent years, low-carbon development and green development have been paid more and more attention, and green and low-carbon has become the trend of the times. As early as 2010, the National Development and Reform Commission took five provinces including Guangdong Province and eight cities including Tianjin as the first batch of national low-carbon pilot areas; Subsequently, in 2012 and 2017, more provinces, cities and regions joined the low-carbon pilot project. The 25th Five-Year Plan proposes that China should achieve a 17% reduction in carbon emission intensity by 2015 compared with 2010; The 13th Five-Year Plan emphasizes the development of a clean, low-carbon, safe and efficient modern energy system. Furthermore, the report of the 19th National Congress of the Communist Party of China put forward: speeding up the establishment of legal system and policy orientation of green production and consumption, and establishing and perfecting the economic system of green, low-carbon and circular development. It can be seen that green and low-carbon development has become an important part of the national development strategy.

However, green and low-carbon development is also under great pressure. In the past 40 years of reform and opening up, China's urbanization process has been continuously advanced, and remarkable
achievements have been made. However, the ecological and environmental problems caused by urban expansion have attracted wide attention from all walks of life, and the economic, social and environmental effects of urban expansion have also been the hot issues studied by scholars at home and abroad in recent years [2]. Traditional urban expansion, which is characterized by economic growth and land non-agriculturalization, promotes the increasing carbon emissions. Studies have shown that land use changes and fossil fuel burning caused by urban construction land expansion are one of the main reasons for global climate change and greenhouse effect [3-4]. Cities have become the focus of human energy activities and carbon emissions [5], and their greenhouse gas emissions account for 80% of the world [4]. Excessive emissions of greenhouse gases lead to global warming, desertification, and salinization are increasingly prominent, and a large number of environmental problems such as rising sea level and global average temperature are increasing day by day [6].

It can be seen that with the continuous development of China's economy and urban expansion, to achieve green and low-carbon development, the pressure of carbon emission reduction will continue to increase. Only by understanding the mechanism of carbon emissions can we make targeted and precise policies. Existing studies have explained the influence mechanism and degree of a variable on carbon emissions from different angles, and have produced fruitful results. However, there are many achievements in studying its impact on carbon emissions from the perspective of urbanization or urban expansion. However, due to the complicated relationship between urbanization and carbon emissions, especially the influencing mechanism, the academic research is not deep enough, and there is no consensus on whether urbanization should promote or inhibit carbon emissions. From the perspective of urban construction land expansion, this paper discusses its influence mechanism and transmission path on carbon emissions, and takes Nanchang, a low-carbon pilot city, as an example to test the degree of its influence on carbon emissions.

2. Effect mechanism of urban construction land expansion on carbon emission

The expansion of urban construction land and its resource agglomeration are an extension and visible urban development model. The expansion and spread of urban area will bring about carbon emission problems in many aspects such as industry, transportation, construction, population consumption, land use change and so on. Researchers have also explored the influence of urban construction land expansion on carbon emissions from various aspects. Zeng Deheng et al. [7] analyzed its impact on carbon emissions from two angles of urban expansion and urban transformation, and considered that urban expansion and transformation have various impacts on carbon emissions, and the degree of impact varies in different stages of urban development; Wang Xing [8] believes that the transmission path of urbanization to carbon emissions includes human capital, technological innovation, industrial structure and household consumption; Xiong Jiashu [6] believes that land change effect, industrial structure adjustment effect, investment growth, scientific and technological progress effect and human capital accumulation effect are the five major paths of urbanization affecting carbon emissions. It can be seen that the impact mechanism of urbanization or urban construction land expansion on carbon emissions is quite complex, because urbanization or urban construction land expansion itself has a weak impact on carbon emissions, but the investment growth, industrial structure changes and population size changes brought by it have a greater impact on carbon emissions.

Based on the above understanding and the research results of comprehensive scholars, it is not difficult to find: The impact of urban construction land expansion on carbon emissions is mainly achieved through three paths. First, the path of "production", that is, the process of urbanization is the process of non-agriculturalization, which will affect carbon emissions; The second is the path of "land", that is, the process of urbanization is the process of transforming agricultural land into construction land, which leads to the reduction of carbon reserves and further affects carbon emissions; Third, the path of "people", that is, the process of urbanization is the process of population gathering in cities, and the increase of urban population affects carbon emissions. It is urbanization, the path of "production-land-people", which leads to the impact of urban construction land expansion on carbon emissions.
The impact of non-agriculturalization on carbon emissions is mainly manifested in the change of industrial structure. With the development of economy and the continuous expansion of cities, the industrial structure has changed from the primary industry with low added value to the secondary and tertiary industries with high added value, and the energy demand and utilization efficiency of each industry are greatly different, thus producing different amounts of carbon emissions. When the industrial structure evolved into the secondary industry, the energy demand increased greatly, especially the fossil energy consumption increased greatly. Most of the industries with high energy consumption, high emission and high pollution were concentrated in the secondary industry, and the carbon emission increased greatly at this time. When the industrial structure evolves to the tertiary industry, the carbon emission gradually reaches its peak and decreases, because the tertiary industry consumes less energy than the secondary industry.

The impact of land conversion on carbon emissions is mainly manifested in the change of land use types. With the continuous expansion of urban construction land, a large number of agricultural land is converted into construction land. Woodlands, grasslands, gardens and so on can absorb carbon in the atmosphere through photosynthesis, and soil also has carbon fixation. After these land types are transformed into construction land, their role in absorbing or fixing carbon elements is lost, resulting in an increase in carbon emissions in the air; Farmland can not only fix carbon elements but also release carbon dioxide because of the influence of human activities. Therefore, the impact of farmland conversion to construction land on carbon emissions is uncertain.

The impact of non-agricultural population on carbon emissions is mainly manifested in the change of consumption patterns or habits. With the development of economy and the further expansion of cities, more and more rural people are pouring into cities, and the scale of urban population is increasing. With the continuous improvement of urban residents' income, their original consumption patterns and habits have also changed, which has a greater impact on urban energy consumption and carbon emissions. The data show that the carbon emissions caused by industrial production have taken a larger weight in the total carbon emissions, and the household energy demand in some developed countries has come to the top, even exceeding the energy consumption of industrial production [8]. Some studies on developing countries also show that the per capita consumption level is the biggest driver of carbon emissions in the industrialization stage, and even household consumption contributes nearly 75% of carbon emissions [9-10].

Although this paper classifies the impact of urban construction land expansion on carbon emissions into three paths, it does not mean that these three paths are independent and have no influence on each other. On the contrary, these three paths are coordinated, unified and mutually influenced. The impact of land non-agriculturalization on carbon emissions includes a part of the impact of industry non-agriculturalization on carbon emissions, while the impact of industry non-agriculturalization and land non-agriculturalization on carbon emissions can finally settle on the impact of population non-agriculturalization on carbon emissions. Therefore, the degree and direction of the impact of urban construction land on carbon emissions need to look at its comprehensive effect.

3. Model setting and data description

3.1. Carbon emission measurement model

According to the analysis of the second part of this paper, the total amount of carbon emissions caused by the expansion of urban construction land should be based on the energy, industrial structure and population factors of a certain region, and calculated by a certain model. This paper refers to the method of carbon emission decomposition model provided by the Guide to Compilation of Provincial Greenhouse Gas Inventories, and uses relevant data such as Nanchang Statistical Yearbook to summarize and calculate the total energy consumption from the perspective of end consumption and intermediate consumption. The specific formula is as follows:
In which,

- $E_{CO_2}$ — The total amount of $CO_2$ produced by burning fossil fuels in Nanchang in a certain year;
- $E_i$ — The total energy consumption of the $i$-th energy;
- $CF_i$ — Combustion heating value of the $i$-th energy source;
- $CC_i$ — The average carbon content of the $i$ energy is the carbon emission factor;
- $COF_i$ — Carbon oxidation factor of $i$ energy, that is, carbon oxidation coefficient;
- $\frac{44}{12}$ — The ratio of the chemical molecular weights of $CO_2$ and $C$;
- $n$ — Types and quantities of energy consumption.

3.2. Vector autoregressive model (VAR model)
Because the data used in this study are time series data, and the causal relationship between urban construction land expansion and carbon emissions is studied, the vector autoregressive model (VAR model) is used to test the relationship between them. VAR model was put forward by Sims in 1980 [11], which is a commonly used econometric model. It uses all the current variables in the model to regress some lagging variables of all variables, so as to estimate the dynamic relationship of all endogenous variables. The general form is as follows:

$$Y_t = \alpha_1 Y_{t-1} + \alpha_2 Y_{t-2} + \cdots + \alpha_p Y_{t-p} + \epsilon_t$$

In the formula, $Y$ represents the endogenous variable vector of $K$ dimension; $\alpha$ represents the corresponding coefficient matrix; $P$ represents the order of lag of endogenous variable. It should be noted that when constructing VAR model, it is most important to determine the lag order (i.e. the value of $P$), which is generally determined according to common information criteria.

3.3. Variable declaration

3.3.1. Carbon dioxide emissions ($E_{CO_2}$ / $E$). The expansion of urban construction land is also a process of industrialization, and the carbon emission in this process mainly comes from fossil energy consumption. In the second part of this study, it is also pointed out that the direct or indirect carbon emissions caused by the expansion of urban construction land can be classified as fossil fuel combustion. Therefore, this paper takes the total amount of carbon emissions generated by urban fossil energy consumption as an explanatory variable. According to the availability of data, the fossil fuels in this paper include coal, coke, gasoline, kerosene, etc., which are converted into standard coal and multiplied by their respective carbon emission coefficients. Among them, the conversion coefficient and carbon emission coefficient come from China Energy Statistics Yearbook and Provincial Greenhouse Gas Inventory Compilation Guide respectively.

3.3.2. Expansion of urban construction land ($F$). The expansion of urban construction land is a symbol of urban spatial expansion, and spatial expansion is mainly the expansion of regions. Therefore, in this study, the total area of built-up area will be taken as a token of the expansion of urban construction land. With the continuous advancement of urbanization, the built-up area of the city is getting larger and larger, and its area is also increasing.
3.4. Data description
The research object of this paper is Nanchang from 1995 to 2017. On February 20th, 2010, Nanchang was listed as a pilot city to develop low-carbon economy, which is of certain significance. The data used in this paper come from Nanchang Statistical Yearbook, China Urban Construction Statistical Yearbook and China Energy Statistical Yearbook from 1996 to 2018, and some of the data also refer to the Guidelines for Compilation of Provincial Greenhouse Gas Inventories published by the National Development and Reform Commission.

4. Results and analysis of urban construction land expansion and carbon emission index in Nanchang city

4.1. Analysis on the result of urban construction land expansion in Nanchang city.
In order to visually display the changing trend of urban construction land expansion in Nanchang from 1995 to 2017, this paper standardized the original data by Z-score with Excel software, and drew the change chart of urban construction land expansion index in Nanchang from 1995 to 2017. This index reflects the deviation of the expansion level of urban construction land in a certain year from the average level in the sample period [7], as shown in Figure 1.

![Figure 1. Expansion curve of urban construction land in Nanchang from 1995 to 2017.](image)

It can be seen from Figure 1 that the expansion of urban construction land in Nanchang from 1995 to 2017 can be roughly divided into three stages: the first stage is 2000 and before, during which the expansion of urban construction land is relatively slow; The second stage is from 2001 to 2009, during which the urban construction land keeps expanding steadily. The third stage is 2010 and later, during which the urban construction land is expanding rapidly. The reason is that the economic development in the first stage is relatively stable, and the expansion of urban construction land has been slow and orderly due to the impact of the Asian financial turmoil and the housing system reform in 1998; In the second stage, with the rapid development of Nanchang Economic and Technological Development Zone, High-tech Zone and Honggutan New District, the urban construction land has been expanded to a certain extent, and the built-up area has increased from 108.5 square kilometers to 201.5 square kilometers, almost doubling; Although the third stage has been influenced by the government's regulation and control for many times, with the implementation of Nanchang metropolis strategy and the rapid leap-forward development of Ganjiang New Area, the urban construction land shows a rapid expansion trend.

4.2. Analysis of carbon emission results in Nanchang city
Figure 2 shows the trend of total carbon emissions in Nanchang from 1995 to 2017. With the growth of population and economy in Nanchang, the total carbon emissions also increased correspondingly.
Figure 2. Total carbon emissions in Nanchang from 1995 to 2017 (10,000 tons).

On the whole, the total amount of carbon emissions fluctuated constantly: the total amount of carbon emissions decreased from 1995 to 2000, mainly because Nanchang's economy was affected by the Asian financial turmoil, and thus industrial production was affected to a certain extent; Subsequently, the total carbon emissions increased rapidly from 2001 to 2007, during which the proportion of the secondary industry in Nanchang also increased continuously, resulting in the continuous increase of the total carbon emissions; From 2008 to 2009, carbon emissions declined to a greater extent, which was mainly affected by the subprime mortgage crisis in 2008, which led to a significant decline in industrial production in Nanchang; Since 2010, carbon emissions have been stable at the same level. On the one hand, industrial production has been restored; on the other hand, Nanchang, as a low-carbon city pilot after 2010, has great pressure to reduce carbon emissions, so the total carbon emissions have remained stable.

Figure 3. Carbon emission intensity and per capita carbon emission in Nanchang from 1995 to 2017.

Figure 3 shows the changing trend of per capita carbon emissions and carbon emission intensity in Nanchang from 1995 to 2017. It can be seen from the figure that, similar to the total amount of carbon emissions, per capita carbon emissions also fluctuated, but declined to a greater extent after 2015. This is because environmental protection has been paid more and more attention by government departments, and the continuous progress of science and technology and the increasing population have led to a decline in per capita carbon emissions. However, in 2017, the per capita carbon emissions in Nanchang
remained above 4 tons/person, and there was still a certain gap with the per capita carbon emissions in
developed areas, so there was a great pressure on carbon emission reduction.

Carbon emission intensity is the ratio of total carbon dioxide to GDP in that year. From the figure,
from 1995 to 2017, the carbon emission intensity has been in a downward trend, and after 2010, it is
basically in a stable state, and the carbon emission reduction intensity is basically less than 1 ton/10,000
yuan. This shows that since Nanchang was established as a low-carbon pilot city in 2010, it has been
making great efforts in technological progress, energy conservation and emission reduction, and
controlling the total amount of carbon emissions, so that the carbon emission intensity is stable within
the policy objectives.

5. Empirical results and analysis

5.1. Stationarity test

In order to avoid the pseudo-regression phenomenon caused by non-stationary data, firstly, the
stationarity test should be carried out on the used time series data [12]. In this study, the common ADF
unit root test method is used for testing. In order to eliminate the heteroscedasticity of data, this paper
deals with the variables by natural logarithm, and records them as \( LNE \) and \( LNF \) respectively. See
Table 1 for inspection results.

| Test variable | ADF statistics | Critical value | Prob value | Test form formula\((c,t,k)\) | Test result |
|---------------|----------------|----------------|------------|-----------------------------|-------------|
| \( LNE \)     | 1.257371       | 3.769597 3.004861 2.642242 | 0.6300 | \((c, 0, 4)\) | Nonstationary |
| \( \Delta LNE \) | 4.808979       | 2.679735 1.958088 1.607830 | 0.0000 | \((0,0,4)\) | Stable |
| \( LNF \)     | 0.129846       | 3.769597 3.004861 2.642242 | 0.9342 | \((c, 0,4)\) | Nonstationary |
| \( \Delta LNF \) | 3.530841       | 3.788030 3.012363 2.646119 | 0.0173 | \((c, 0,4)\) | Stable |

Note: \( \Delta \) in the table is the first-order difference; \( c \), \( t \) and \( k \) represent intercept term, time trend and
lag order in ADF test respectively. Intercept term, time trend are determined according to significance,
and lag order is determined according to S criterion.

Table 1 shows that no matter which variable, under the significance level of 5%, the ADF statistics
value of the original sequence of data is less than the absolute value of the critical value of 5%, which
means that the assumption that the original sequence has unit root cannot be rejected, that is, each
original sequence of data has unit root, which is an unstable sequence. After the first-order difference
of the original sequence of each variable, the ADF statistical value is greater than the absolute value of 5%
critical value, so rejecting the hypothesis that the first-order difference sequence has unit root means
that the first-order difference sequence does not have unit root and is a stationary sequence. That is, each
variable is the first-order monointeger sequence I(1), which has the basis of cointegration analysis.

However, the VAR (1) model should also satisfy the stability condition, otherwise the subsequent
analysis has no practical significance. The method to test whether the VAR model is stable is to judge
whether its characteristic roots are all in the unit circle. We can see from Figure 4 that the characteristic
roots of VAR (1) are all in the unit circle, which meets the stability requirements.
5.2. Johansen cointegration test

ADF test shows that both \( LNE \) and \( LNF \) are first-order integers, which can be further cointegration test. In order to judge whether there is a long-term equilibrium relationship between urban construction land expansion and carbon emissions, Table 2 gives the test results.

Table 2. \( LNE \) and \( LNF \) cointegration test results.

| Null hypothesis | Eigenvalue | Trace test quantity | Critical value of 5% significance level | \( P \) value |
|-----------------|------------|---------------------|----------------------------------------|--------------|
| None*           | 0.513631   | 21.38847            | 15.49471                               | 0.0057       |
| At most 1*      | 0.332971   | 7.693513            | 3.841466                               | 0.0055       |

It can be seen from Table 2 that under the significance level of 5%, there is a long-term equilibrium relationship between urban construction land expansion and carbon emissions, that is, there is a cointegration relationship.

5.3. Granger causality test

Through cointegration test, it can be found that there is a long-term equilibrium relationship between urban construction land expansion and carbon emissions, but the relationship between them cannot be clearly reflected. At this point, it is necessary to further determine the relationship between the two through Granger causality test. The inspection results are shown in Table 3.

Table 3. Granger causality test results.

| Null hypothesis | Lag order | \( F \) Statistic | \( P \) value |
|-----------------|-----------|-------------------|--------------|
| \( LNE \) is not the Granger cause of \( LNF \) | 1         | 1.42336           | 0.2475       |
| \( LNF \) is not the Granger cause of \( LNE \) | 1         | 6.72458           | 0.0178       |

It can be seen from Table 3 that carbon emission is not the Granger cause of urban construction land expansion, but the Granger cause of carbon emission. That is to say, there is a one-way causal
relationship between the expansion of urban construction land and carbon emissions, that is, the expansion of urban construction land leads to the increase of carbon emissions, which verifies the theoretical analysis proposed in this paper.

5.4. Impulse response analysis

Granger causality test can't provide information such as the degree and size of short-term shocks among variables and the dynamic characteristics of such shocks. Therefore, it is necessary to conduct impulse response analysis on the causal relationship between urban construction land expansion and carbon emissions, with the purpose of analyzing what changes the variables have aftershocks, how large and small the changes are, and when the variables begin to be affected. Figure 5 shows the response function of total carbon emissions caused by the impact of urban construction land expansion.

The horizontal axis in fig. 5 represents the lag order, and the maximum lag order is 10; the vertical axis represents the rate of change of variables. It can be seen from Figure 5 that the impact of urban construction land on carbon emissions is small in the initial stage, but with the continuous expansion of construction land, the impact is increasing, reaching the maximum in the fifth year; And then gradually decline, and has been in a stable state. It can be expected that when urbanization develops from the growth stage to the mature stage, carbon emissions will gradually decrease and remain stable, which is also the natural result of economic development.

6. Conclusion and countermeasures

6.1. conclusion

Based on the data of urban construction land expansion and carbon emissions in Nanchang from 1995 to 2017, this paper empirically analyzes the relationship between urban construction land expansion and carbon emissions in Nanchang by constructing carbon emission calculation model, VAR model, cointegration test, Granger causality test and impulse analysis. Come to the following conclusions:

(1) From 1995 to 2017, the urban construction land in Nanchang experienced three stages of expansion, namely slow expansion, stable expansion and rapid expansion; overall, the total carbon emissions showed an upward trend, fluctuated in the middle, and finally showed a stable emission trend.

(2) There is a long-term equilibrium relationship between the expansion of urban construction land and carbon emissions at a significant level of 5%, that is, there is a counteraction relationship.
(3) Granger causality test shows that the expansion of urban construction land is the Granger cause of carbon emission, that is, the expansion of urban construction land leads to carbon emission, which verifies the theoretical analysis of this paper.

(4) Impulse analysis shows that the impact of urban construction land expansion on carbon emissions is small in the initial stage, but after a period of time, the impact gradually increases, and when urbanization matures, the impact gradually stabilizes and the total carbon emissions decrease.

6.2. Countermeasure and suggestion

From the conclusion, it can be seen that the expansion of urban construction land will bring about an increase in carbon emissions, while the population agglomeration and changes in consumption habits, the evolution of industrial structure and the transformation of land use types caused by the expansion of urban construction land are the main culprits of carbon emissions. Therefore, this paper puts forward the following policy recommendations:

(1) Control the boundary of urban growth. Efforts will be made to promote the development of new urbanization and high-quality urban development, take the road of low-carbon and intensive urbanization, and strive to improve the quality of urban development. Promote the transformation of urban development from extensional expansion to connotative development, control the boundary of urban growth and realize intensive development.

(2) Accelerate the upgrading of industrial structure. The transformation of industrial structure is an important means to solve the increase of carbon emissions, and efforts are made to promote the industrial structure from the secondary and tertiary industries to the tertiary industry. At the same time, improve the technical level, increase investment in research and development, promote technological progress, transform and upgrade industries with high energy consumption, and gradually reduce the total carbon emissions.

(3) Improve the income level of residents. Efforts will be made to promote economic development, raise the income level of residents, continuously reduce Engel's coefficient and promote the improvement of residents' quality of life. Advocate the concept of low-carbon life, and promote residents' low-carbon travel.

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