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Interaction between urbanization and carbon emission in Guizhou Province

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Abstract
Investigating interplay between urbanization and carbon emissions is crucial for reaching carbon peak objective. This study employs a VAR model to examine correlation between the urbanization rate and carbon emissions specifically within Guizhou Province, VAR model has obvious advantages in studying the dynamic relationship between them. The findings indicate that: (1) In Guizhou Province, there is a nuanced interplay between the urbanization rate and carbon emissions, with the magnitude and direction of their influence varying across different time intervals. (2) Carbon emissions in Guizhou Province exhibit a notable self-propelling effect, while concurrently, the urbanization rate demonstrates an inertia effect, which also contributes to its own advancement. (3) The influence of the urbanization rate on carbon emissions in Guizhou Province experiences gradual rise before plateauing, suggesting that the high-quality advancement of new urbanization in the region facilitates the achievement of carbon reduction objectives. Finally, policy recommendations are put forward: (1) Conscientiously implement the central ecological environment zoning control policies, such as: Guizhou Province Ecological environment zoning control Plan and Guizhou Province Urban and Rural Construction Carbon peak Implementation Plan and other policies. (2) Pay attention to the quality of Guizhou's urbanization process. Solve the relationship between urbanization and carbon emissions, and realize the coordination and unification of urbanization and the carrying capacity of resources and environment. (3) Develop a new type of urbanization rich in Guizhou's mountainous characteristics and promote the construction of low-carbon cities. Give full play to the regional characteristics of Guizhou's mountainous areas, build a new type of urbanization with Guizhou's mountainous characteristics, promote the construction of low-carbon cities in the process of urbanization development, and strengthen the coordinated development of ecological environment construction and urbanization.

Keywords Guizhou Province, Urbanization, Carbon emissions, VAR

Introduction

Since the reform and opening up, China's urbanization has been developing rapidly, and the problem of carbon emission has become increasingly prominent in the process of large-scale urbanization. In the context of rapid urbanization development and high carbon emissions, how to coordinate the relationship between urbanization and carbon emissions has become an urgent problem to be solved. In November 2022, the Guizhou Provincial Government released the Guizhou Province Carbon Peak Implementation Plan. This initiative mandates the integration of carbon peak objectives across all stages and sectors of economic and social progress. The ten major initiatives for achieving carbon peak encompass the focused execution of energy transition towards green and low-carbon practices, enhancing energy efficiency and carbon reduction, promoting green and low-carbon advancement in industries, reaching carbon peak in urban and rural development, upgrading transportation to be green and low-carbon, leveraging the circular economy to reduce carbon emissions, fostering green and low-carbon technological innovation, consolidating and enhancing carbon sink capabilities, advocating for nationwide green and low-carbon awareness, and facilitating orderly carbon peak progression across municipalities and regions (Carbon Peak Implementation Programme in Guizhou Province 2023). It's evident that reaching the carbon peak target in Guizhou Province is intricately linked with urbanization, urban-rural construction, and widespread adoption of green and low-carbon practices. Thus, investigating the interplay between urbanization and carbon emissions in Guizhou province contribute positively to the attainment of the carbon peak objective in the region. In July 2023, the Guizhou Provincial government issued the notice of the Implementation Plan for New Urbanization in Guizhou Province (2023–2025), which aims to promote low-carbon production and life based on resource endowment and industrial base while developing with high quality, and strive to build a modern industrial system with Guizhou characteristics. In January 2023, the Guizhou Provincial government issued the "Carbon Peak Implementation Plan for Urban and Rural Construction in Guizhou Province" to comprehensively implement the new development concept, take green and low-carbon development as the guide, and promote urban renewal and rural construction actions around the "double carbon" goal of the country and Guizhou Province. In this context, the application of VAR model to explore the relationship between urbanization rate and carbon emissions, and the comparative analysis of the impact of urbanization on carbon emissions in different periods have important theoretical and practical significance for Guizhou Province to explore the development path of high-quality urbanization and achieve the "double carbon goal".

Literature review

Drawing from a regional integration perspective, this study utilizes panel data spanning from 2000 to 2020 across the Yangtze River Economic Belt to develop a multidimensional indicator framework for urbanization and agricultural carbon emissions (Geng et al. 2024). A hybrid approach involving both the Analytic Hierarchy Process (AHP) and the entropy method was employed to assign weights to the indicators, while influence mechanisms and coupling dynamics between urbanization and agricultural carbon emissions are quantitatively analyzed using Partial Least Squares (PLS) regression and a coupling coordination degree model. Using panel data from 195 countries (regions) worldwide spanning from 1990 to 2020, this study measures the comprehensive level of urbanization across various countries (regions) from four dimensions: population, spatial, economic, and social (Gao et al. 2024). Furthermore, it conducts a comparative analysis between China and countries with different income levels to investigate impact mechanisms of urbanization on carbon emissions based on STIRPAT model and Environmental Kuznets Curve (EKC) theory. Drawing from panel data encompassing 262 prefecture-level cities in China over the period 2006 to 2020, this research initially formulates an index framework for the concept of new urbanization and evaluates the degree of new urbanization employing the entropy approach (Li 2024). Drawing on methodologies from relevant scholars, the cumulative carbon emissions of each city are determined by aggregating the carbon emissions arising from electricity consumption, gas and liquefied petroleum gas usage, and heat energy consumption. The results indicate an overall upward trend in the level of new urbanization across Chinese prefecture-level cities from 2006 to 2020. Upon regional comparison, the eastern region generally exhibits higher levels of new urbanization, surpassing the national average. Additionally, the carbon emissions level shows an increasing trend, with the eastern region displaying higher carbon emissions levels compared to the central and western regions. Based on elucidating the regional carbon emission performance mechanism influenced by urbanization and technological innovation, this study selects panel data from 30 provinces in China from 2011 to 2020 (Tian and Wu 2023). Using the NCSE-EBM model, it measures carbon emission efficiency and employs the panel data Tobit model to examine the independent and synergistic effects of urbanization and technological innovation on regional carbon emission performance at the national and three major regional levels. The research findings reveal that urbanization significantly promotes carbon emission efficiency in both the nation and the central-western regions, while technological innovation significantly enhances carbon emission performance in the nation and the eastern region. Utilizing a combination of coupling coordination modeling, spatial autocorrelation analysis, and spatial Markov chain techniques, this study investigates the level of coupling coordination between two systems and analyzes their spatio-temporal differentiation and trend evolution characteristics (Tian and Lu 2023). The findings indicate that in 2020, Beijing exhibited the highest level of new urbanization, while Guangxi had the lowest. Tianjin ranked first in agricultural carbon emission efficiency, while Shanxi ranked last. Additionally, in 2020, the highest degree was observed in Beijing, whereas Xinjiang had the lowest. Compared to 2005, the coupling and coordination degrees of 29 provinces, except Shanghai, have significantly improved, with 27 provinces experiencing hierarchical leap-forward progress. Overall, by 2020, the majority of provinces had reached intermediate or higher levels of coupling and coordination. Employing panel data encompassing 31 provinces, municipalities, and districts in China from 1997 to 2018, this study develops a comprehensive evaluation index system to assess the level of new urbanization (He and Zhang 2022). It aims to investigate the spatial impact and the distinctive attributes of new urbanization's impact on agricultural carbon emission intensity. The index system for new urbanization and carbon emissions level is established, and entropy weight method is applied to assign weights to the evaluation indices (Jiang et al. 2023).

As can be seen from the above, current academic circles have rich research results on the relationship between urbanization and carbon emissions, with different research perspectives, but there are still many problems. For example, the division of endogenous and exogenous variables in quantitative analysis models is complicated. When the variable is unsteady, the assumption will be destroyed, resulting in a more serious pseudo-regression problem. In the case of unidentifiable, in order to facilitate identification, it is often necessary to add different instrumental variables to each equation, and such instrumental variables are often unexplained. Therefore, this paper further optimizes the research model of the relationship between urbanization and carbon emissions, and applies the VAR model to the study of the relationship between urbanization and carbon emissions. This method regards each variable as endogenous and reduces the uncertainties caused by human factors.

Based on the panel data of Guizhou Province from 2015 to 2021, adopted the entropy method and coupled coordination degree model to build the evaluation index system for the coordination between new urbanization and ecosystem, and found that the new urbanization in Guizhou Province has a fast construction speed and the development of each subsystem is relatively balanced, but the development of population urbanization is relatively backward. The development of social urbanization is relatively advanced (Song and Shen 2018). Based on the panel data of six prefecture-level cities in Guizhou Province from 2011 to 2020, adopted the comprehensive development level evaluation model to analyze the comprehensive development of new urbanization and rural revitalization in Guizhou Province, and found that the development index of new urbanization and rural revitalization in Guizhou province from 2011 to 2020 showed an overall upward trend (Luo 2022). The index index of new urbanization and land intensive use by comprehensive index method, and the results showed that both land intensive use and new urbanization showed an increasing trend in all cities (prefectures) of Guizhou Province from 2012 to 2016, and the growth rate of new urbanization in most regions was greater than the growth rate of land intensive use (Chen 2002). Carbon emission sources from three aspects: fossil energy combustion, industrial production and solid waste incineration. The research results showed that carbon emissions from coal source accounted for the largest proportion of carbon emissions from fossil energy combustion. The carbon emission of solid waste incineration is relatively small, but its proportion increases year by year with economic development and urban development. In recent years, the carbon emission in Guizhou has shown a decreasing trend, and the carbon emission from fossil energy combustion is still the main source of carbon emission in Guizhou (Zhong 2019). Selected 11 influencing factors of carbon emission from the three directions of total emission, carbon emission source and emission sector, and conducted dimensionality reduction and de-correlation treatment of influencing factors through principal component analysis. The BP neural network model is used to predict the carbon emission, and the prediction results are tested. The prediction results show that: in 2022, Guizhou's carbon emissions reached the highest value of 315.7 million tons, and from 2024 to 2035, Guizhou's carbon emissions will remain at the level of 30 million tons and slowly decline (Liu and Pan 2023). Used the decoupling model to study the relationship between carbon emissions from land use and social economy in Guizhou province. The research results showed that the negative decoupling between carbon emissions from land use and urbanization rate changed from undesirable expansion to ideal weak decoupling and ideal strong decoupling (Han et al. 2023). Analyzed the relationship between urbanization and energy carbon emission in Guizhou province through STIRPAT model, and found that there was a long-term equilibrium relationship between urbanization level, economic development, industrial structure, energy intensity, energy structure and energy carbon emission in Guizhou province. There is a positive correlation between urbanization rate and energy carbon emission in Guizhou province. There is a positive correlation between urbanization level and carbon dioxide emission in Guizhou province (An 2020).

To sum up, current academic research on new-type urbanization and agricultural carbon emissions is relatively rich, and separate research content on urbanization and carbon emissions in Guizhou province is also relatively rich, but few scholars have further explored the interactive relationship between urbanization and carbon emissions in Guizhou province. Therefore, this paper selects 21 years' data of urbanization rate and carbon emission in Guizhou province from 2000 to 2020, and uses VAR model to explore the dynamic relationship between urbanization and carbon emission in Guizhou province. The innovation of this paper is as follows: first, it organically links urbanization and carbon emission, explores the symbiotic development effect of the two strategies, and enriches the theoretical basis of urbanization and carbon emission reduction; Second, the VAR model is used to scientifically analyze the relationship between the two, so as to provide theoretical basis for the relevant departments of Guizhou Province to formulate urban development planning.

Methodology and data origins

Methodology

This paper employs VAR to investigate interactive relationship between urbanization rate and carbon emissions in Guizhou Province. VAR model is an econometric model used to capture the linear dynamic relationship between multiple time series variables. Parameter estimation in VAR model is weakly affected by outliers, and the assumptions applied in the process of data generation are weak, and the tail-dependent structure can be directly described (Yang and Jia 2024). The advantage of VAR model is that it only focuses on the degree of fitting between model and sequence, without assuming and distinguishing whether each variable has endogeneity, that is, all variables are regarded as endogenous variables (Xiong and Wang 2024). Compared with structural econometrics model, VAR model does not have any restrictions on variables in the system, so all current variables are regressive to the lag term of all variables. This model solves a series of complex problems such as subjective division of endogenous variables and exogenous variables due to imperfect economic theory. It is uniquely applicable to the study of dynamic interrelationships among a series of variables (Li and Yang 2024).

Since the time series VAR model mainly focuses on the dynamic relationship between variables and usually does not directly add control variables, this paper establishes a bivariate VAR model for urbanization rate (UR) and carbon emission (CT). Urbanization rate is a comprehensive index, including population migration, economic development, social changes and other aspects of information, can comprehensively reflect the overall process and level of urbanization in a region. Moreover, the calculation method of urbanization rate is unified, and the urbanization rate of different regions can be directly compared, which can quickly judge the regional urbanization development level. Su (Su 2022), Zhou et al. (Zhou et al. 2021), Guo et al. (Guo et al. 2019) and other scholars all adopted the urbanization rate (UR) index to measure the level of regional urbanization development. Carbon emissions provide a concrete, quantitative way to assess the level of carbon emissions in a region. By measuring and comparing carbon emissions in different regions, we can understand the differences of carbon emissions in different regions, find regions with high carbon emission reduction potential, and promote the coordinated development of inter-regional emission reduction.

To detect the dynamic impact of the system, that is, to systematically predict the relevant time series and analyze the system impact caused by random interference items (Deng and Chao 2024). In this paper, Granger causality, cointegration test, impulse response function, variance decomposition analysis and other steps are used to study the long-term equilibrium relationship between urbanization rate and carbon emissions in Guizhou province, and the correlation influence relationship.

The methodology used to formulate the multivariate VAR(p) model in this paper is as follows Eq. (1)(Dai 2024):

$$Y_t = \emptyset_1 Y_{t-1} + \emptyset_2 Y_{t-2} + \ldots + \emptyset_p Y_{t-p} + HX_t + \varepsilon_t \tag{1}$$

Here Y_t is a k-dimensional endogenous variable, and Y_{t-i} (i =1,2,... ,p) are lagged endogenous variables, and X_t is the d-dimensional exogenous variable. The lag order, denoted by (p), is determined based on the information criterion. ϵ_t is a vector consisting of random error terms. The final model is of the form Eq. (2):

$$\begin{bmatrix} \mathrm{UR_t} \\ \mathrm{LIGHT_t} \end{bmatrix} = \emptyset_1 \begin{bmatrix} \mathrm{UR_{t-1}} \\ \mathrm{LIGHT_{t-1}} \end{bmatrix} + \ldots + \emptyset_p \begin{bmatrix} \mathrm{UR_{t-p}} \\ \mathrm{LIGHT_{t-p}} \end{bmatrix} + \begin{bmatrix} \varepsilon_{\mathrm{1t}} \\ \varepsilon_{\mathrm{2t}} \end{bmatrix} \tag{2}$$

Data origins

The data for this study were obtained from a variety of sources, including the "China Statistical Yearbook," "China Energy Statistical Yearbook," "China Environmental Statistical Yearbook," "Agricultural Statistical Yearbook," "Provincial Greenhouse Gas Emissions Inventory Guidelines (Trial)," "Guizhou Statistical Yearbook," "Guizhou Provincial Economic and Social Development Statistical Bulletin," and carbon emission inventory guidelines released by the Guizhou Provincial Government, covering the period from 2000 to 2020.

All the data in this paper are from official statistics and professional databases. Data collection follows the principles of science, system and comprehensive to ensure the authenticity and integrity of data; In order to ensure the accuracy and consistency of data, every step of data processing is recorded and audited.

Process of empirical analysis

Stationarity test

In this study, 21 years of data on urbanization rate (UR) and carbon emissions within the period from 2000 to 2020 in Guizhou Province, are analyzed to investigate their dynamic relationship. Firstly, the original series undergoes a stationarity test, and the test outcomes are presented in Table 1.

Table 1 indicates that the joint probability of the original series UR and CT exceeds 0.05, indicating that the series is not smooth. For further analysis, the series needs to undergo first-order differencing. Here, dlnUR represents the first-order differencing of the urbanization rate series, and dlnCT represents the first-order difference of carbon emissions. The outcomes of the stationarity test for the first-order difference series are presented in Table 2.

Table 1 Results of ADF stationarity test for variable sequences

Variable sequence	Type of test variable	ADF value	Contingent probability	1 per cent threshold	5 per cent threshold	10 per cent threshold	Steadiness
Ur	Original sequence	2.85	1.0000	-3.81	-3.02	-2.65	Uneven
Ct	Original sequence	-1.83	0.3541	-3.81	-3.02	-2.65	Uneven

Table 2 Results of ADF stationarity test for first order difference series

Variable sequence	Type of test variable	ADF value	Contingent probability	1 per cent threshold	5 per cent threshold	10 per cent threshold	Stationarity
dlnur	Original sequence	-6.62	0.00	-3.86	-3.04	-2.66	stable
dlnct	Original sequence	-8.24	0.00	-3.89	-3.05	-2.67	stable

Table 3 Selection of optimal lag

Lag	LogL	LR	FPE	AIC	SC	HQ
0	63.39	NA*	2.50e-06*	-7.22*	-7.12*	-7.21*
1	64.52	1.88	3.53e-06	-6.59	-6.59	-6.86
2	65.71	1.68	5.06e-06	-6.06	-6.06	-6.51
3	68.74	3.56	6.07e-06	-6.44	-5.75	-6.37

Note: (1) Lag, LogL, LR, FPE, and HQ stand for lag order, maximum value of the log-likelihood function, likelihood ratio test, final prediction error, and Hannan Quinn information criterion, respectively;

Based on the observations from Table 2, it is evident that the concomitant probabilities for the first-order difference series dlnUR and dlnCT are both 0.00, which is less than 0.05. This rejection of the original hypothesis suggests that the series are smooth. Both the urbanization rate and carbon emissions exhibit characteristics consistent with first-order single integer time series, thereby enabling further analysis in subsequent stages.

Optimal lag selection

To determine the optimal lag order of the VAR model, this study employs various criteria, including LR, FPE, AIC, SC, and HQ. Selecting an appropriate lag order is crucial as a small lag order may result in autocorrelation issues and inconsistent parameter estimates, while a large lag order may reduce degrees of freedom and affect the validity of parameter estimates. The analysis and discussion of the optimal lag order in this paper are based on the criteria mentioned above. In the table, LR represents the results of the Likelihood Ratio Test for optimal lag order analysis, FPE represents the optimal lag order determined by the Final Prediction Error criterion, AIC represents the optimal lag order determined by the Akaike Information Criterion, SC represents the optimal lag order determined by the Schwarz Criterion, and HQ represents the optimal lag order determined by the Hannan-Quinn Criterion.

Table 3 displays the results of the LR, FPE, AIC, and SC criteria for determining the optimal lag order. LR and FPE both reach their maximum values at lag order 0, with FPE value being 2.50e-06, while AIC and SC attain their minimum values of -7.22 and −7.12, respectively. These analyses indicate that the optimal lag order in this paper is 0.

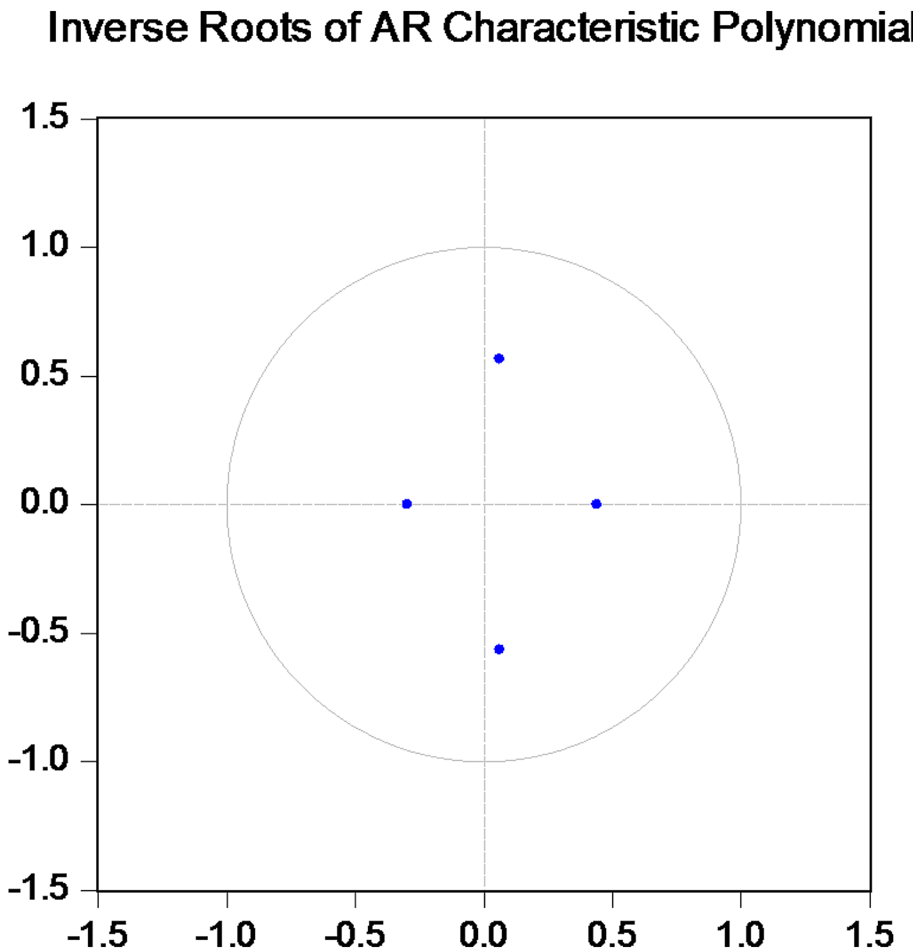

Fig. 1 AR characteristic root inverse

As depicted in Fig. 1, all the outcomes of the unit circle test for the VAR model in this study lie within the unit circle. This observation suggests that the VAR model developed for examining the interaction between urbanization rate and carbon emissions in Guizhou Province exhibits robust stability, thereby affirming its validity and effectiveness. Subsequently, the regression analysis for the VAR model is conducted.

Johansen cointegration test

The cointegration test is a method employed in time series analysis to determine the presence of a prolonged equilibrium association among two or more time series. To delve deeper into the association between urbanization rate and carbon emissions in Guizhou Province, study performs a stationarity test under the condition of same-order single integration for the variables, as described in prior research. Subsequently, the trace test is employed to identify the cointegration relationship between the variables individually. The specific findings are outlined in Table 4 below.

At a 5% significance level, under the assumption of at most one cointegration relationship, the characteristic root associated with it is 0.25. The trace statistic is calculated to be 5.16, surpassing the critical value of 3.84 at the 5% significance level. The corresponding P-value is computed to be 0.02, which is less than 0.05, leading to the rejection of the null hypothesis. This rejection indicates the presence of a long-term equilibrium

Table 4 Cointegration test results

original hypothesis	characteristic root	trace statistic	5 per cent threshold	*P*-value	reach a verdict
disordered	0.51	18.18	15.49	0.02	rejection
Up to one covariance	0.25	5.16	3.84	0.02	rejection

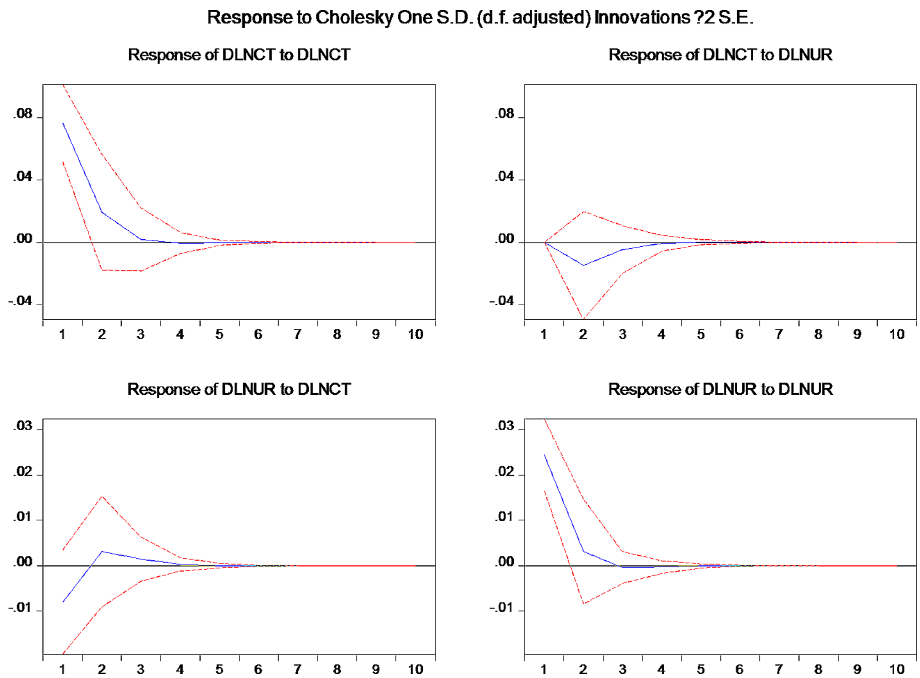

Fig. 2 Plot of impulse response function

relationship between urbanization rate and carbon emissions. The relationship can be succinctly expressed by the cointegration equation as follows Eq. (3):

$$\mathrm{dlnC_t} = 0.25^*\mathrm{dlnUR} \quad (3)$$

Impulse response analysis

The impulse response function quantifies the dynamic reaction of one variable (referred to as the shock variable) when another variable (referred to as the response variable) undergoes a one-unit impulse (a random shock of one standard deviation)(Huang and Yu 2024). Based on the optimal lag order of 0 determined in the previous section, this paper presents the impulse response function plots for each variable (with a lag of 10) of the established VAR model, as shown in Fig. 2. In the impulse response plots, the horizontal axis typically denotes time, while the vertical axis represents the response values of the variables. The solid lines depict the trajectory of the impulse response function over the lag period, while the dashed lines represent the two-fold standard deviation bands, encompassing both positive and negative deviations.

From Fig. 2, it can be observed that: On the one hand, a one-standard deviation shock in carbon emissions exhibits a positive effect on its own information, indicating a rapid positive response following the shock. However, over time, this positive effect gradually diminishes and stabilizes. This suggests that while carbon emissions have a certain

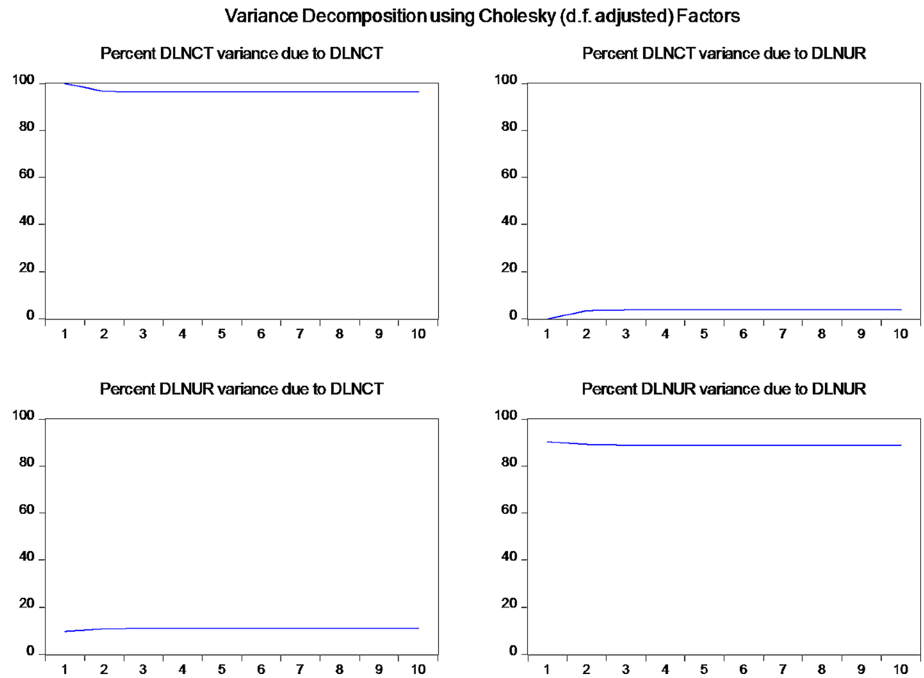

Fig. 3 Plot of variance decomposition function

Table 5 Results of variance decomposition

Phase	Variance decomposition of urbanization rate		Variance decomposition of carbon emissions	
	Dlnur	Dlnct	Dlnur	Dlnct
1	90.29103	9.708972	0. 000000	100 00000
2	89.14057	10.85943	3.419868	96. 58,013
3	88.86827	11.13173	3.750501	96. 24,950
4	88.85945	11.14055	3.756570	96. 24,343
5	88.85953	11.14047	3.756588	96. 24,341
6	88.85951	11.14049	3.756636	96.24336
7	88. 85,951	11.14049	3.756639	96. 24,336
8	88.85951	11.14049	3.756639	96.24336
9	88.85951	11.14049	3.756639	96.24336
10	88.85951	11.14049	3.756639	96.24336
Mean value	89.03164	10.9683602	3.718524333	96.28147444

driving effect on themselves, this effect weakens over the long term. In the first lag period, this effect reaches a maximum of 0.076 and then gradually stabilizes. On the other hand, a one-standard deviation shock in the urbanization rate shows a positive impact on its own information. However, as the lag period extends, the impact gradually weakens, reaching zero after four lag periods, and eventually stabilizes. This indicates that while the urbanization rate has a promoting effect on itself, this effect also diminishes over the long term.

Furthermore, as shown in Fig. 2, a one-standard deviation shock in the urbanization degree exhibits negative impact on carbon emissions, characterized by an immediate negative response following the shock, followed by gradual increase and fluctuation around zero. Simultaneously, a one-standard deviation shock in carbon emissions on urbanization degree initially shows negative impact in the first lag period, then gradually increases, reaching a maximum value of 0.003 in the second lag period, followed by a decrease and stabilization. This cross-effect suggests a complex relationship between urbanization rate and carbon emissions, with degree and direction of influence between two potentially varying over different time periods.

Variance decomposition analysis

In this paper, the variance decomposition method under the VAR model is employed to decompose the variance of the urbanization rate and carbon emissions indicators. The purpose of variance decomposition is to evaluate the extent of interaction between urbanization rate and carbon emissions, accurately calculating the numerical contribution of each structural shock to the changes in each endogenous variable. In other words, based on the VAR model, the predictive variance of one variable is decomposed, breaking down the contributions made by shocks to each variable in the system for evaluation.

From the variance decomposition in Fig. 3, it is evident that carbon emissions have a significant impact on themselves, contributing 100% to their own variance in the first period. Subsequently, there is a gradual weakening trend in the contribution, although the fluctuation amplitude is not substantial. In comparison, the impact of urbanization rate on itself is relatively smaller, fluctuating around the 90% level. This suggests that carbon emissions in Guizhou Province significantly propel themselves.

From the variance decomposition results of urbanization rate in Table 5, it can be observed that as the number of periods increases, the contribution of carbon emissions to the variance of urbanization rate shows a slow upward trend. By the 4th period, the explanatory power of carbon emissions on the level of urbanization reaches 11.14%. However, the coefficient of urbanization rate is significantly influenced by itself, with an average contribution rate of 89.03% over a lag of 10 periods. As the lag period increases, the contribution rate of urbanization rate to itself gradually decreases, indicating a pronounced inertia effect of urbanization rate, which is greatly influenced by itself.

From Table 5, it can be observed that for the variance decomposition of carbon emissions, initially, carbon emissions are predominantly influenced by themselves, with a contribution rate of 100% in the first period, which gradually diminishes thereafter. Meanwhile, the influence of urbanization on carbon emissions gradually increases, starting from nearly 0 and growing to 3.75% by the 3rd period, after which it stabilizes. This indicates that the impact of urbanization rate on carbon emissions gradually strengthens and then stabilizes.

In summary, it can be seen from the results of stationary test, cointegration test, impulse response and variance decomposition analysis that there is a long-term equilibrium relationship between urbanization rate and carbon emissions, and both urbanization rate and carbon emissions have a certain promoting effect on themselves, and in the long run, the promoting effect on themselves is gradually decreasing. Overall, there is a complex relationship between urbanization rate and carbon emissions, and the degree and direction of the influence between the two may change in different time periods.

Conclusion and suggestion

This study examines the evolving correlation between the urbanization rate and carbon emissions in Guizhou Province spanning from 2000 to 2020 based on the construction of a VAR model, along with impulse response function and variance decomposition analyses. The findings are as follows: (1) There exists a complex interactive relationship between the urbanization rate and carbon emissions in Guizhou Province exhibit varying degrees and directions of influence across different time periods. (2) Carbon emissions in Guizhou Province significantly drive themselves, while the urbanization rate exhibits inertia effects and also promotes itself to some extent. (3) The influence of both is gradually increasing gradually strengthens and then stabilizes, suggesting that the high-quality advancement of new urbanization in the province has contributed to accomplishing carbon reduction objectives. This paper studies the interactive relationship between urbanization and carbon emission in Guizhou province. From a theoretical perspective, on the one hand, it reveals the internal mechanism of the relationship between urbanization and carbon emission, enriching and developing the existing theories on the relationship between urbanization and carbon emission. On the other hand, the coordinated development approach of urbanization and carbon emission reduction is discussed to promote the friendly development of urban construction and energy emission in Guizhou Province. From the perspective of practice, on the one hand, the carbon emission pressure faced by Guizhou Province in the process of urbanization should be accurately assessed to provide scientific basis for formulating effective carbon emission reduction policies; On the other hand, we should scientifically guide the development of low-carbon cities and towns in Guizhou Province, and strive to build a new type of urbanization with Guizhou characteristics.

Based on the empirical analysis results of this paper, in order to promote the coordinated development of urbanization and carbon emission in Guizhou Province and achieve the "dual carbon" goal as soon as possible, the following policy suggestions are put forward: (1) From the policy level, conscientiously implement the central ecological environment zoning control policy, such as: "Guizhou Province ecological environment zoning control Plan" and "Guizhou Province urban and rural Construction carbon peak implementation plan" and other policies. Taking Guizhou Province as an example, this paper analyzed the interactive relationship between urbanization process and carbon emissions in Guizhou province by using vector autoregressive analysis (VAR). However, there are few studies on the correlation between urbanization and carbon emissions at the county level. This is mainly due to the incompleteness of the data at the county scale, the wide area covered and the difficulty of data acquisition, which restrict the research on the mechanism of the two. (2) Focus on the quality of Guizhou's urbanization process from the perspective of development path. Solve the relationship between urbanization and carbon emissions, and realize the coordination and unification of urbanization and the carrying capacity of resources and environment. (3) From the planning level, develop a new type of urbanization with Guizhou's mountainous characteristics and promote the construction of low-carbon cities. Give full play to the regional characteristics of Guizhou's mountainous areas, build a new type of urbanization with Guizhou's mountainous characteristics, promote the construction of low-carbon cities in the process of urbanization development, and strengthen the coordinated development of ecological environment construction and urbanization.

Limited by the availability of data, the time span of urbanization rate and carbon emission in Guizhou Province is from 2000 to 2020. In the follow-up study, more abundant data will be collected and data sources will be optimized to make the research results more abundant and accurate.

Author contributions
Jingjing Jia wrote the main manuscript text.

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Data availability
The datasets generated or analyzed during this study are available from the corresponding author on reasonable request.

Declarations

Ethical approval
Not applicable.

Consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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