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Research article

Application of PVAR model in the study of influencing factors of carbon emissions

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Abstract: Based on the panel data of China from 2003 to 2017, this paper applies the panel vector autoregressive (PVAR) model to the study of the influencing factors of carbon emissions. After the cross-section dependence test, unit root test and cointegration test of panel data, the dynamic relationship between energy consumption, economic growth, urbanization, financial development and CO_2 emissions is investigated by using PVAR model. Then, we used the impulse response function tool to better understand the reaction of the main variables of interest, CO_2 emissions, aftershocks on four factors. Finally, through the variance decomposition of all factors, the influence degree of a single variable on other endogenous variables is obtained. Overall, the results show that the four factors have a significant and positive impact on carbon emissions. In addition, variance decomposition also showed that energy consumption and economic growth strongly explained CO_2 emissions. These results indicate that the financial, economic and energy sectors of China's provinces still make relatively weak contributions to reducing carbon emissions and improving environmental quality. Therefore, several policies are proposed and discussed.

Keywords: CO_2 emissions; PVAR model; energy consumption; economic growth; urbanization; financial development

1. Introduction

There is no doubt that the issue of greenhouse gas emissions and global warming has attracted extensive attention of ecological environment researchers recently. Many researchers have emphasized the importance of reducing greenhouse gas emissions, and point that greenhouse gas is the main reason for global climate change [1–3]. In 2018, the Statement on the State of the Global Climate in 2017 issued by the World Meteorological Organization (WMO) pointed out that atmospheric CO_2 concentration has increased from 360 ppm to more than 400 ppm, which has been far beyond the natural variability range of hundreds of thousands of years (180–280 ppm). Due to the increase in greenhouse gas emissions, the global temperature has increased by 1.9 °F since 1880 (NASA 2020). Moreover, greenhouse gas emissions will also lead to a series of natural disasters such as glacier melting, floods, droughts and sea level rise. According to data from The China Energy Outlook: World Energy Outlook 2017 (IEA, 2018), China has become the largest contributor to global CO_2 emissions. The level of carbon emissions in China has a strongly impact on the global environmental quality. Therefore, in order to control global carbon emissions and curb the global warming trend, the focus is to achieve low-carbon development in China. To this end, during the general debate of the 75th United Nations General Assembly in September 2020, China's President Jinping Xi pledged that China will increase the country's contribution to the world, adopt stronger policies to control carbon emissions, and strive to achieve the goals of carbon peak in 2030 and carbon neutrality in 2060.

In the past 20 years, all walks of life in China have developed rapidly and made great achievements in the economic, financial fields and in the process of urbanization. According to the world bank's data on China's development in 2021, China's GDP ranks second in the world and China's urbanization growth rate in the past 20 years ranks first in the world, rising from 36% in 2000 to 65% in 2021. Moreover, the institute of world economics and politics of the Chinese Academy of Social Sciences recently released the global financial competitiveness report 2021, which pointed out that China's global financial competitiveness ranks first among all developing countries and eighth in the world. However, China's rapid development inevitably leads to energy consumption. According to the statistics of the International Energy Agency, China's primary energy consumption in 2021 ranks first in the world. Under the background of China's rapid development, can its rapid development in energy, economy, finance and other fields over the past decade explain its huge carbon emissions?

In order to find a balance between development and carbon emissions, many scholars have conducted extensive research on the influencing factors of carbon emissions and sought solutions. The influencing factors involved in previous studies include policy [4], financial globalization [5], urbanization [6], land use [7], technological innovation [8], crude oil price [9], energy efficiency [10], etc. Based on China's national conditions and actual development situation, this study selects energy consumption, economic growth, financial development and urbanization level as research variables to explore the dynamic relationship between them and carbon emissions. These indicator variables of China are among the top in the world rankings. They can not only represent the development of China in the past 10 to 20 years, but also cover the hot spots of ecological economy research in recent years, such as economy, energy, finance and urban development.

There are some evidences that economic growth is the main determinant of carbon emissions [11–13]. The Environmental Kuznets (EKC) hypothesis also fully supports this view [14]. Additionally, as observed by developed and developing countries, urbanization, as an important part of economic development and citizen evolution, is also closely related to carbon emissions [15–17]. For energy consumption, many literatures have conducted a large number of studies on the relationship between clean energy consumption (such as nuclear energy [18], renewable or non-renewable energy consumption [19], total energy consumption [20] and CO_2 emissions. These studies have reached a consensus that energy consumption is undeniably one of the factors affecting carbon emissions.

Financial development also has a certain impact on environmental quality. On the one hand, with the development of finance, credit constraints have been eased and economic output has been expanded, leading to more energy consumption and higher CO_2 emissions [21]. On the other hand, financial development reduces carbon emissions and improves environmental quality through technology development, research and development (R&D) [22]. In summary, economic growth, urbanization, total energy consumption and financial development should be considered in the factors affecting carbon emissions. Although some studies have confirmed that the four factors have a certain impact on carbon emissions, this impact needs to be further confirmed in the research at the provincial level in China.

In this paper, the PVAR model is applied to the study of the influencing factors of China's inter provincial carbon emissions to investigate the dynamic relationship between energy consumption, economic growth, urbanization, financial development and carbon emissions. As a dynamic system model, PVAR model is often used in the field of economics to test the influence of time-varying interaction between variables. However, the application of PVAR model in the fields of ecology and environmental science is relatively few. As far as the research of this paper is concerned, first of all, PVAR model regards all variables as endogenous variables, which can be well applied to the situation where the relationship between each variable and carbon emissions is uncertain. Second, PVAR model allows us to examine all variables in an overall way to see the joint impact of each variable on carbon emissions, At the same time, this method can not only capture the lagging impact of various variables on carbon emissions, but also reveal the changing trend of how one variable responds to the impact caused by other variables. Third, for individual countries or groups composed of different countries, the estimation of consistency and validity of PVAR is relatively simple [23]. Therefore, we can clearly understand the impact of all factors on carbon emissions and obtain the dynamic relationship between these influencing factors and carbon emissions by introducing PVAR model into the analysis of carbon emissions and its influencing factors.

On the basis of existing research, this paper attempts to expand in the following three aspects: 1. On the research object, this paper takes China's provinces as the research objects, trying to explore whether the rapid development of China in the fields of energy, economy, finance and urban development can explain its huge carbon emissions. 2. In terms of research methods, cross-section dependence of data is considered, and the panel vector autoregressive (PVAR) model that is not commonly used in previous energy and environment literature is adopted, which solves the problem that the traditional technology does not deal with endogeneity. 3. In terms of the selection of variables, this paper comprehensively analyzes the relationship between energy consumption, financial development, economic growth, urbanization and CO_2 emissions. Finally, according to the empirical research results, this paper puts forward practical policy suggestions for the government, so as to help China fulfill its commitment to achieve carbon peak and carbon neutralization.

The remaining sections of the paper are organized as follows. Section 2 sorts out the relevant literature on the relationship between energy consumption, economic growth, financial development, urbanization and carbon emissions respectively. Section 3 mainly introduces the data and empirical methods used in this study. Section 4 puts forward and discusses the results of empirical research, and Section 5 puts forward policy suggestions based on the research results. Finally, Section 6 summarizes the research of this paper and prospects the future work.

2. Related work

This section will review and summarize the research between energy consumption, economic growth, urbanization, financial development and carbon emissions respectively.

2.1. Studies on energy consumption and CO_2 emission

It is a hot topic to explore the relationship between energy consumption and carbon emissions from the aspects of long-term and short-term relationship, causality and interaction. Using cointegration and causality models, Chontanawat [24] found a long-term and two-way causal relationship between energy consumption and CO_2 emissions in ASEAN. Gorus et al. [25] found that in the study of eight countries in the MENA regions, the causal relationship between energy consumption and economic growth varied in different term. In the short term, there is a one-way Granger causality between them, while in the medium and long term, there is a feedback effect between them. Different from the above studies on energy consumption leading to carbon emissions, Muhammed [26] found that CO_2 emissions had a significant and direct impact on energy consumption in groups of developed, emerging, Middle East and North African countries, and the increase in CO_2 emissions would significantly increase energy consumption in the three regions. In the research on the relationship between energy consumption and carbon emissions in China, Wu et al. [27] used spatial Durbin model and dynamic threshold panel model to conduct quantitative research on the relationship between energy consumption, environmental regulation and carbon emissions after fully controlling spatial effects and potential endogenous effects. The results show that energy consumption significantly promotes the carbon emissions of the three regions in China (i.e., east, center and west). Gu et al. [28] found that in the process of technological progress, energy consumption and carbon emissions show an inverted U-shaped relationship. When the level of technological development is low, energy consumption will promote carbon emissions, and when technological development reaches a high level, energy consumption will curb carbon emissions.

2.2. Studies on economic growth and CO_2 emission

Most studies on economic growth and CO_2 emissions are carried out through environmental Kuznets curve (EKC). The EKC hypothesis proposed in 1993 states that environmental pollution increases with per capita GDP at low-income levels and decreases with GDP growth at high-income levels. Munir et al. [29] applied a new Granger non-causality panel test to deal with cross-section dependence and heterogeneity in the study of the countries of the Association of Southeast Asian Nations (ASEAN-5). The empirical study shows support for the EKC hypothesis, and finds that there is a unidirectional Granger causality between GDP and CO_2 in Malaysia, Philippines, Singapore and Thailand. However, Tenaw et al. [30] applied the error correction panel autoregressive distribution lag (ARDL) model to the research of sub-Saharan African (SSA) countries, tested the relationship between environment and development under the sustainability oriented EKC framework, and found that there was a monotonous increasing relationship between the two in non-resource intensive SSA countries. In addition, Rahman et al. [31] and Namahoro et al. [32] found negative effects of economic growth on CO_2 emissions in studies of newly industrialized countries and Africa, respectively. Hu et al. [33] drew different conclusions from the study of 57 BRI countries, finding that CO_2 emissions increased significantly in almost all countries as a result of economic growth. In the research on the relationship between economic growth and CO_2 emissions in China, Li et al. [34] constructed a spatial Durbin model to investigate the spatial effect of energy investment and economic growth on carbon emissions in China's provincial level, and pointed out that economic growth is the reason for the increase of CO_2 emissions in China. Chen et al. [35], based on provincial panel data of China, not only obtained the two-way causality between them, but also found that the EKC hypothesis is almost not supported in the eastern and western regions.

2.3. Studies on urbanization and CO_2 emission

With the development of the global economy, the process of urbanization has been continuously promoted. Many researchers began to use different methods to explore the relationship between urbanization and carbon emissions in different regions, but they have never reached a widely accepted consensus. Wang et al. [36] conducted a study on APEC member states by using dynamic unrelated gradually regression (DSUR), they pointed out that urbanization increased the demand for energy and promoted the flow of customers and commodities, which had a positive and significant impact on CO_2 emission, and for every 1% increase in urbanization, CO_2 emissions will increase by 0.274%. Mahmood et al. [37] took Saudi Arabia as the research object and reached a similar conclusion. They found a short-run and cointegration relationship between urbanization and carbon emissions, and pointed out that urbanization is responsible for environmental degradation by increasing carbon emissions. In contrast, Muhammad et al. [38] found an inverted U-shaped relationship between them in high-income groups. Moreover, a U-shaped relationship was found in other income level groups. In the study of China, Liu et al. [39] also found the positive impact of urbanization on carbon emissions by using the autoregressive distributed lag (ARDL) technology, and the long-term estimation results show that for every 1% increase in urbanization, carbon emissions will increase by 1%. Yao et al. [40] divides urbanization into three dimensions (i.e., population urbanization, economy urbanization and land urbanization). In the study of 351 cities in China, it is found that the impact of urbanization in three dimensions on carbon emissions of different types of cities (i.e., small cities, medium-sized cities, large cities and megacities) is heterogeneous.

2.4. Studies on financial development and CO_2 emission

Many researchers have obtained different results in the study of the relationship between financial development and CO_2 emissions in different countries and regions. According to the panel data of APEC member countries from 1990 to 2016, Zaidi et al. [41] found that financial development would significantly reduce CO_2 emissions by using Westerlund cointegration technology. In the study of 88 developing countries, Khan et al. [42] drew similar conclusions according to five different financial development indicators. Their results support that financial development has played a role in inhibiting carbon emissions of selected countries. On the contrary, Pata [43] found that financial development will aggravate environmental degradation and increase carbon emissions in Turkey by using the method of ARDL. Acheampong et al. [44] reached a broader conclusion through the study of 83 countries. They found that the impact of financial market development on carbon emissions intensity is different in economies at different stages of financial development. Huang et al. [45] found that different financial development indicators in China, such as financial size, financial efficiency and financialization, have different impacts on trade carbon emissions, and there are regional differences. Finally, some researchers believe that there is no significant relationship between the two. Salahuddin et al. [46] found that the long-term and short-term relationship between them is not significant in the study of Kuwait. Charfeddine et al. [47] also found that the negative impact of financial development on environmental degradation is not significant in MANA area.

3. Materials and methods

3.1. Data descriptions

This paper constructs an inter-provincial panel data of the remaining 30 provinces and municipalities in China from 2003 to 2017 except Hong Kong, Macao, Taiwan and Tibet. The variables used in this paper are financial development, urbanization, economic growth, energy consumption and CO_2 emissions. Table 1 lists these variables and their measurement units and economic explanations. Table 2 shows the descriptive statistics of the above variables in Chinese provinces. The data of economic growth, energy consumption and urbanization come from Official website of China National Bureau of Statistics and the data of financial development comes from Wind database. Moreover, based on the calculation method and related data provided by 'IPCC Guidelines for National Greenhouse Gas Inventories' and the energy consumption data of 30 provinces and municipalities directly under the Central Government (excluding Hong Kong, Macao, Taiwan and Tibet) in 'China Energy Statistics Yearbook', nine energy consumption indicators, including coal, coke, gasoline, crude oil, diesel, kerosene, natural gas fuel oil, and electricity, are selected to calculate carbon emissions, and the total carbon emissions of each province are converted to ten thousand tons. The calculation method is as follows:

$$CF_i = ECF_i + \sum_j CF_{ij} \tag{1}$$

$$CF_{ij} = \sum_j EC_{ij} \times A_{ij} \times C_{ij} \times O_{ij} \times T \tag{2}$$

$$ECF_i = ELC_i \times \boldsymbol{\lambda}_i \tag{3}$$

where CF_i is the total carbon emissions of the i-th province, CF_{ij} is the carbon emissions of the j-th energy consumption in i-th province and EC_{ij} is the consumption of the j-th energy in i-th province. A_{ij} is the average calorific value; C_{ij} is the carbon content per unit calorific value; O_{ij} is the carbon oxidation rate and these data are come from the general principles for the calculation of comprehensive energy consumption (GB/t2589-2008) and the guidelines for the preparation of provincial greenhouse gas inventories. T is the conversion coefficient between carbon and CO_2, which is a constant and the value is 44/12. ECF_i is the carbon emissions of power consumption in i-th province, and ELC_i is the consumption of electric energy in i-th Province. $\boldsymbol{\lambda}_i$ is the CO_2 emission coefficient of power in i-th province, and the data is from the guidelines for the preparation of provincial greenhouse gas inventories.

Table 1. List of variables.

Variable name	Unit of measurement	Definition
Carbon emissions (CF)	10,000 tons	The carbon emissions released from using nine kinds of fossil energy and electricity
Financial development (FD)	%	The balance of deposits and loans of banking institutions divided by GDP
Economic growth (GDP)	10,000 RMB	The value of GDP divided by population
Energy consumption (EC)	10,000 tons of standard coal	Total annual energy consumption
Urbanization (UR)	%	Proportion of urban population in total population

Table 2. Descriptive statistics.

Variable	Mean	Max	Min	Std.Dev.
lnCF	19.70833	21.46423	16.97007	0.7759463
lnFIR	0.9736983	2.095688	0.2532363	0.3207476
lnUR	3.910622	4.495355	3.209633	0.2663662
lnGDP	10.17329	11.83244	8.214061	0.7052733
lnEC	9.174916	10.56872	6.527958	0.7374688

3.2. PVAR specification

The panel data vector autoregressive model (PVAR) proposed by love and zicchino [48] is used for the research and analysis of this article. This model combines the panel data model with the traditional vector autoregressive method to investigate the dynamic interaction between multiple variables. Therefore, it combines the advantages of traditional VAR model and panel data analysis and it can not only effectively solve the problem of panel individual heterogeneity, but also does not need to meet the requirements of long-term series of VAR model [49]. PVAR model is different from the setting of other panel data models. It does not distinguish the research variables into endogenous variables and exogenous variables, but treats all variables as endogenous variables, and considers the impact of lag variables on other variables in the model [50]. Additionally, PVAR model is a more suitable technology for studying macroeconomic dynamics, and is of great significance for studying the economic problems of groups composed of different regions or countries. The derivation and construction method of PVAR model are as follows:

First, we consider a set of time data variables Y_t,

$$Y_t = \begin{bmatrix} y_{1t} \\ y_{2t} \\ y_{3t} \\ \vdots \\ y_{nt} \end{bmatrix}, t = 1,2,3,\cdots,T \tag{4}$$

The VAR model with first-order lag of two variables is shown in Eq (5):

$$\begin{cases} y_{1t} = c_1 + \varphi_{11}(1)y_{1,t-1} + \varphi_{12}(1)y_{2,t-1} + \varepsilon_{1t} \\ y_{2t} = c_2 + \varphi_{21}(1)y_{1,t-1} + \varphi_{22}(1)y_{2,t-1} + \varepsilon_{2t} \end{cases} \tag{5}$$

Then rewrite Eq (5) into matrix form as:

$$\begin{bmatrix} y_{1t} \\ y_{2t} \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \end{bmatrix} + \begin{bmatrix} \varphi_{11}(1) & \varphi_{12}(1) \\ \varphi_{21}(1) & \varphi_{22}(1) \end{bmatrix} \begin{bmatrix} y_{1,t-1} \\ y_{2,t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{bmatrix} \tag{6}$$

Let $Y_t = \begin{bmatrix} y_{1t} \\ y_{2t} \end{bmatrix}$, C = $\begin{bmatrix} c_1 \\ c_2 \end{bmatrix}$, $\Phi_1 = \begin{bmatrix} \varphi_{11}(1) & \varphi_{12}(1) \\ \varphi_{21}(1) & \varphi_{22}(1) \end{bmatrix}$, $\varepsilon_t = \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{bmatrix}$, the matrix form of Eq (6) can be simplified as:

$$Y_t = C + \varphi_1 Y_{t-1} + \varepsilon_t \tag{7}$$

To sum up, it can be deduced that the VAR model with k-order lag of n variables can be expressed as:

$$Y_t = C + \Phi_1 Y_{t-1} + \Phi_2 Y_{t-2} + \Phi_3 Y_{t-3} + \cdots + \Phi_k Y_{t-k} + \varepsilon_t \tag{8}$$

where, C = $\begin{bmatrix} c_1 \\ c_2 \\ c_3 \\ \vdots \\ c_n \end{bmatrix}$ is the intercept term vector, $\Phi_j = \begin{bmatrix} \varphi_{11}(j) & \varphi_{12}(j) & \cdots & \varphi_{1n}(j) \\ \varphi_{21}(j) & \varphi_{22}(j) & \cdots & \varphi_{2n}(j) \\ \vdots & \vdots & \ddots & \vdots \\ \varphi_{n1}(j) & \varphi_{n2}(j) & \cdots & \varphi_{nn}(j) \end{bmatrix}, j = 1,2,3,\ldots,k$

is the parameter matrix, $\varepsilon_t = \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \\ \vdots \\ \varepsilon_{nt} \end{bmatrix}$ is the random error column vector.

At this point, when we consider a set of panel data Y_{it}:

$$Y_{it} = \begin{bmatrix} y_{1it} \\ y_{2it} \\ y_{3it} \\ \vdots \\ y_{nit} \end{bmatrix}, i = 1, 2, 3, \cdots, n;\ t = 1, 2, 3, \cdots, T \tag{9}$$

we can obtain a simplified matrix form of the PVAR model with k-order lag of n variables, as shown in Eq (10), by introducing panel data into the above VAR model.

$$Y_{it} = C_i + \Phi_1 Y_{i,t-1} + \Phi_2 Y_{i,t-2} + \Phi_3 Y_{i,t-3} + \cdots + \Phi_k Y_{i,t-k} + \varepsilon_{it} \tag{10}$$

where, $C_i = \begin{bmatrix} c_{1i} \\ c_{2i} \\ c_{3i} \\ \vdots \\ c_{ni} \end{bmatrix}$, $\Phi_j = \begin{bmatrix} \varphi_{11}(j) & \varphi_{12}(j) & \cdots & \varphi_{1n}(j) \\ \varphi_{21}(j) & \varphi_{22}(j) & \cdots & \varphi_{2n}(j) \\ \vdots & \vdots & \ddots & \vdots \\ \varphi_{n1}(j) & \varphi_{n2}(j) & \cdots & \varphi_{nn}(j) \end{bmatrix}, j = 1,2,3,\ldots,k,\ \varepsilon_t = \begin{bmatrix} \varepsilon_{1it} \\ \varepsilon_{2it} \\ \varepsilon_{3it} \\ \vdots \\ \varepsilon_{nit} \end{bmatrix}$.

The final form of PVAR model can be obtained by introducing individual fixed effect variables and time dummy variables, and simplifying the lag coefficient matrix, as shown below:

$$Y_{it} = C_i + A(L) \cdot Y_{it} + \alpha_i + \delta_t + \varepsilon_{it} \quad (11)$$

where, Y_{it} is a matrix containing all endogenous variables, namely carbon emissions, financial development level, urbanization level, economic development level and total energy consumption. $A(L)$ is the coefficient matrix of the lag variable in the model. α_i is the unobservable individual fixed effect variable, indicating the specific effects of each province and city found in the regression. δ_t represents the specific time dummy variable of each province and city, and ε_{it} is a random interference term obeying normal distribution. According to the research variables in this paper, following the matrix form rewritten by Charfeddine (2019), the PVAR model in Eq (11) can also be rewritten as follows:

$$\Delta Ln(CF_{it}) = C_{1i} + \alpha_{1i} + \delta_{1t} + \varepsilon_{1it} + \sum_{j=1}^{k} a_{1j}\Delta Ln(CF_{i,t-j}) + \sum_{j=1}^{k} b_{1j}\Delta Ln(FD_{i,t-j}) + \sum_{j=1}^{k} c_{1j}\Delta Ln(EC_{i,t-j}) + \sum_{j=1}^{k} d_{1j}\Delta Ln(GDP_{i,t-j}) + \sum_{j=1}^{k} e_{1j}\Delta Ln(UR_{i,t-j}) \quad (12)$$

$$\Delta Ln(FD_{it}) = C_{2i} + \alpha_{2i} + \delta_{2t} + \varepsilon_{2it} + \sum_{j=1}^{k} a_{2j}\Delta Ln(CF_{i,t-j}) + \sum_{j=1}^{k} b_{2j}\Delta Ln(FD_{i,t-j}) + \sum_{j=1}^{k} c_{2j}\Delta Ln(EC_{i,t-j}) + \sum_{j=1}^{k} d_{2j}\Delta Ln(GDP_{i,t-j}) + \sum_{j=1}^{k} e_{2j}\Delta Ln(UR_{i,t-j}) \quad (13)$$

$$\Delta Ln(EC_{it}) = A_{3i} + \alpha_{3i} + \delta_{3t} + \varepsilon_{3it} + \sum_{j=1}^{k} a_{3j}\Delta Ln(CF_{i,t-j}) + \sum_{j=1}^{k} b_{3j}\Delta Ln(FD_{i,t-j}) + \sum_{j=1}^{k} c_{3j}\Delta Ln(EC_{i,t-j}) + \sum_{j=1}^{k} d_{3j}\Delta Ln(GDP_{i,t-j}) + \sum_{j=1}^{k} e_{3j}\Delta Ln(UR_{i,t-j}) \quad (14)$$

$$\Delta Ln(GDP_{it}) = A_{4i} + \alpha_{4i} + \delta_{4t} + \varepsilon_{4it} + \sum_{j=1}^{k} a_{4j}\Delta Ln(CF_{i,t-j}) + \sum_{j=1}^{k} b_{4j}\Delta Ln(FD_{i,t-j}) + \sum_{j=1}^{k} c_{4j}\Delta Ln(EC_{i,t-j}) + \sum_{j=1}^{k} d_{4j}\Delta Ln(GDP_{i,t-j}) + \sum_{j=1}^{k} e_{4j}\Delta Ln(UR_{i,t-j}) \quad (15)$$

$$\Delta Ln(UR_{it}) = A_{5i} + \alpha_{5i} + \delta_{5t} + \varepsilon_{5it} + \sum_{j=1}^{k} a_{5j}\Delta Ln(CF_{i,t-j}) + \sum_{j=1}^{k} b_{5j}\Delta Ln(FD_{i,t-j}) +$$

$$\sum_{j=1}^{k} c_{5j}\Delta Ln\left(EC_{i,t-j}\right) + \sum_{j=1}^{k} d_{5j}\Delta Ln\left(GDP_{i,t-j}\right) + \sum_{j=1}^{k} e_{5j}\Delta Ln\left(UR_{i,t-j}\right) \quad (16)$$

where, j is an optimal lag length of the model. The optimal lag length j is 2 with the smallest Akaike information criteria (AIC) and Bayesian information criteria (BIC).

3.3. Panel unit root test and panel cointegration tests

Before using the PVAR model framework for analysis, our first step is to check the data attributes of all sequences, that is, panel unit root test. At present, panel unit root test is divided into two generations. The first generation of panel unit root tests assumes that each section unit is independent of each other, such as LLC test [51], IPS test [52], etc. However, the second generation panel unit root test method fully considers the existence of cross-section dependence, such as Pesaran [53] and Moon and Perron [54]. While conducting unit root test under the panel framework, they overcome cross-section independence by introducing heterogeneous impact into multiple unobservable factor models or using single factor structure to consider heterogeneous components, making the test results more reliable. In view of this, when analyzing panel data, cross-sectional dependence test is particularly important for selecting appropriate unit root test method.

3.3.1. Diagnostic test for panel cross-section dependence

Breusch and Pagan [55] believe that if the cross-section dependence of the data is not considered, it is likely to cause a large deviation in the research results, thus affecting the authenticity of the results. Considering that the LM test proposed by Breusch and Pagan has great limitations when N is large and t is small in the panel data, Pesaran [56] proposed a cross-sectional dependence test (CD) with reasonable small sample performance that does not depend on a specific spatial weight matrix. Unlike the LM Test, this test is based on the paired correlation coefficient of the residuals obtained in the standard augmented Dickey-Fuller specification of each variable in the panel data. The principle of the test is as follows:

Considering a general panel data model:

$$y_{it} = \mu_i + \beta_i x_{it} + u_{it} \quad (17)$$

where, μ_i is the individual fixed effect, and β_i is the estimation coefficient. y_{it}, x_{it} is the explained variable and the explanatory variable respectively, and i and t represent the section and time span respectively.

The CD statistic is derived as follows:

$$CD = \sqrt{\frac{2T}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i-1}^{N} \rho_{ij} \quad (18)$$

where,

$$\rho_{ij} = \frac{\sum_{t=1}^{T} e_{it} e_{jt}}{\sqrt{\sum_{t=1}^{T} e_{it}^2}\sqrt{\sum_{t=1}^{T} e_{jt}^2}} \quad (19)$$

and e_{jt}, e_{it} is the residual value estimated by OLS estimation.

Pesaran [56] demonstrated that the CD test may have excellent small sample properties. Under the null hypothesis that there is no cross-sectional dependence, once the existence of cross-sectional dependence is confirmed by rejecting the null hypothesis, the appropriate panel unit root test shall be used for subsequent testing.

3.3.2. Pesaran panel unit root test

The CADF and CIPS panel unit root test proposed by Pesaran [53] is used to research the degree of stationary of selected series between different cross sections. On the basis of revisiting the assumption of cross-sectional independence, Pesaran proposed a simple factor model, which replaces the original method of using orthogonalization type program to asymptotically eliminate the cross-correlation of sequences on the basis of traditional Augmented Dickey-Fuller (ADF) and is augmented by the cross-sectional mean value of the lag level and the first-order difference of a single sequence. The cross-section augmented ADF (CADF) is represented as follows:

$$\Delta Y_{it} = \alpha_i + \beta_i Y_{i,t-1} + \gamma_i \bar{Y}_{t-1} + \delta_i \Delta \bar{Y}_{t-1} + \varepsilon_{it} \tag{20}$$

where,

$$\bar{Y}_t = \frac{1}{N}\sum_{i=1}^{N} Y_{it} \tag{21}$$

$$\Delta \bar{Y}_t = \frac{1}{N}\sum_{i=1}^{N} \Delta \bar{Y}_{it} \tag{22}$$

ε_{it} is the regression error. Pesaran CIPS panel unit root test is a modified version of IPS test. It is proposed based on the average value of augmented individual ADF statistics in the cross section. Its statistics are as follows:

$$CIPS = \frac{1}{N}\sum_{i=1}^{N} CADF_i \tag{23}$$

where, $CADF_i$ represents the cross-section augmented Dickey-fuller statistic of the i-th cross-section unit, which is derived from the t-ratio of β_i in the above Eq (19).

3.3.3. Westerlund cointegration test

In the cointegration test of panel data, most researchers usually use the panel cointegration method proposed by Pedroni [57], but the Pedroni panel cointegration method is proposed under the assumption of independent panel cross-section and has great limitations. Therefore, we choose the panel cointegration method proposed by Westerlund [58]. This method fully considers the dependence of panel cross-section. Different from other panel cointegration methods, the Westerlund cointegration test is based on structural dynamics rather than residuals, so the constraint of common factor is avoided. Westerlund cointegration test puts forward four statistics: GT, GA, Pt and Pa. The calculation method is as follows:

$$G_t = \frac{1}{N}\sum_{i=1}^{N}\frac{\hat{\alpha}_i}{SE(\hat{\alpha}_i)} \quad (24)$$

$$G_a = \frac{1}{N}\sum_{i=1}^{N}\frac{T\hat{\alpha}_i}{\hat{\alpha}_i(1)} \quad (25)$$

$$P_t = \frac{\hat{\alpha}}{SE(\hat{\alpha})} \quad (26)$$

$$P_a = T\hat{\alpha} \quad (27)$$

The idea is to verify the null hypothesis of noncointegration by assuming that the error correction term in a conditional error correction specification of the panel is equivalent to zero. Two tests can be considered to check the alternative hypothesis that at least one unit is cointegrated.

4. Results and discussion

The experimental arrangement of this study is as follows: this study gives priority to the cross-sectional dependence of panel data and the cross-sectional dependence test is carried out for panel data firstly. On the basis of the cross-sectional dependence test results, we conducted unit root test and cointegration test on the panel data. Then, GMM estimation method is used to estimate the parameters of PVAR model. Finally, the impulse response function tool and variance decomposition analysis are used to analyze the response of the main interest variable carbon emissions to the impulse of each variable and the contribution of each variable to the main interest variable.

4.1. Panel unit root and panel cointegration tests

Table 3 shows the results of Pesaran cross-sectional dependence diagnostic test. The results show that the null assumption of cross-sectional independence is rejected by high significance, with a significance of 1%, which indicates that the variables of Chinese provinces investigated in this study have cross provincial correlation. In addition, Table 4 shows the unit root test results of two second-generation panels. According to the results in the table, some horizontal data failed the unit root test, but after the first-order difference, all the data passed the unit root test, indicating that each variable is integrated with first order, which means that the first-order difference is enough to make all sequences stable. This is the necessary condition before estimating the PVAR models of these sequenses. Since all variables are cross-section dependent and integrated with first order, we want to test the long-term equilibrium relationship of them. Westerlund panel cointegration test is used to examine the possible existence of long-term relationships. Table 5 shows the results of Westerlund panel cointegration tests. The results in the table show that the null hypothesis that there is no cointegration relationship cannot be highly rejected by these four statistics, that is, the long-term equilibrium relationship between variables has not been found. In consequence, estimating the first-order difference of all variables in the model is the best way to investigate possible significant relationship between these variables.

Table 3. Results of cross-sectional dependence (CD) test.

Test	Series	Statistics	P-Values
	lnCF	78.229	0.000***
	lnGDP	80.361	0.000***
CD	lnEC	78.413	0.000***
	lnFD	66.598	0.000***
	lnUR	6.428	0.000***

Notes: Under the null hypothesis of cross-section independence, CD ~ N (0, 1), P-values close to zero indicate data are correlated across panel groups, *** indicates a 1% significant level.

Table 4. Results of panel unit root test.

Variable	Level		First difference	
	CADF	CIPS	CADF	CIPS
lnCF	-1.359	-2.631*	-2.336***	-3.605***
lnFD	-1.588	-1.672	-2.291***	-2.730**
lnUR	-2.096**	-2.805**	-3.057***	-3.451***
lnGDP	-2.101**	-2.807**	-2.280***	-3.067***
lnEC	-1.583	-2.225	-2.608***	-3.123***

Notes: The level of significance is determined by 1, 5, and 10% indicated through ***, ** and * respectively.

Table 5. Results of Westerlund ECM panel cointegration tests.

Statistic	Value	Robust P-value
G_t	-3.012	0.137
G_a	-6.328	0.063*
P_t	-10.237	0.163
P_a	-6.546	0.353

*Notes: Results for H0: No cointegration. * Critical values at the 10% significance level.

4.2. GMM Estimation of PVAR model

This section describes and analyzes the results of GMM Estimation of PVAR model in Table 6. First, for the CO_2 emissions equation, the column 2 of the table shows that six coefficients are statistically significant at the conventional significance level, of which four coefficients are significant at the 1% level. It is found that the second lags of carbon emissions is negatively correlated with the current level, which is significant at the level of 10%. We also find that both the first and second lags of urbanization level are positively correlated with the current level of carbon emissions at the significant level of 1 and 10% respectively, and the relevant estimation coefficients are 0.467 and 0.266, indicating that the advancement of urbanization process will lead to the increasingly serious environmental degradation represented by CO_2 emissions. It is particularly noteworthy that both the first and second lags of energy consumption are also positively correlated with the current level of carbon emissions. The estimated coefficients of the first and second lags are equal to 0.274 and 0.371,which are significant at the level of 5 and 1% respectively, indicating that the increase of total energy consumption will lead to the increase of CO_2 emissions. Additionally, the first lag of financial development and economic development level is also positively correlated with carbon emissions at a significant level of 1%, which indicates that with the improvement of social financial development level and economic development level, CO_2 emissions will be increased.

Second, regarding the financial development equation, the estimation results show that seven variables have a certain impact on the current level of financial development, and the first lag of financial development level is negatively correlated with its current value at the significance level of 1%. The first lag of carbon emissions is also negatively correlated with the current value of financial development at the level of 1%, which shows that improving environmental quality helps to promote the development of regional financial industry. The study also found that both the first and second lags of energy consumption are negatively correlated with the current level of financial development at a significant level of 1%, indicating that the positive impact of the increase of energy consumption can not be reflected in financial development. Furthermore, the first and second lags of economic development level are positively correlated and negatively correlated with the current level of financial development respectively, and their significance has reached 5 and 1% respectively. Finally, unexpectedly, the first and second lagged values of urbanization level also have a significant negative effect on the financial development, but this result is only significant at the level of 10 and 5%.

Third, for the urbanization equation, only the first lag value of carbon emission is significant, which is positively correlated with the current value of urbanization at the significant level of 10%.

Forth, regarding the economic groth equation, We find that the first lag of economic development has a significant and positive impact on the current value at the significant level of 1%, while the second lags has a significant and negative impact on the current value at the significant level of 1%. We also find that the first lag of financial development level is at the significant level of 1%, which has a significant positive effect on the current level of economic development, indicating that the development of regional financial industry will promote regional economic development to a great extent. It is also worth mentioning that the first lag of energy consumption is positively correlated with the current level of economic development at a significant level of 1%, indicating that energy consumption will promote economic development to a certain extent. Finally, the significant positive effect of the first lag of carbon emissions on the current value of economic development has been found.

Finally, regarding the energy consumption equation, there are seven variables have a significant impact on energy consumption. First, the research shows that the first and second lags of total energy consumption are strongly affects its current value at the significant level of 1%. Second, regarding the lagged value of carbon emissions, we find that both the first and second lags determine the current value of energy consumption at the significant level of 1 and 5% respectively, but the two lagged values have opposite effects. Third, the study found that the first lag of economic growth, the first and second lags of financial development have a significant positive effect on the total energy consumption, which clearly indicates that the expansion of economic and financial activities will increase the total energy consumption prominently.

4.3. Impulse-response functions (IRFs) discussion

This section introduces and analyzes the results of impulse response function (IRF) of PVAR model (see Figure 1). The impulse response function of PVAR model can obtain the pure dynamic relationship between the two variables under the control of other variables. Because the orthogonal decomposition of impulse response function is very sensitive to the order of variables, it is particularly important to select the appropriate order of variables for impulse response function analysis. According to economic theory and previous studies, each variable should be sorted according to the order of variable impact. Therefore, this study sorts the variables in the following order: UR, FD, EC, GDP and CF. Since FD is an influencing factor of EC and GDP, and EC also affects GDP, the order of the three is FD, EC, GDP. In additon, CE is the least exogenous variable affected by all other variables. Therefore, it should be ranked last. Finally, UR is placed in front of FD because UR affects FD.

Figure 1 reports the IRF of CO_2 emissions with an error of 5%. The figure successively illustrates the reaction of CO_2 emissions to one standard deviation shock in financial development, urbanization, economic growth and energy consumption.

Table 6. Estimation results of PVAR model.

Response to	Response of				
	$D(CF_t)$	$D(FD_t)$	$D(UR_t)$	$D(GDP_t)$	$D(EC_t)$
$D(CF_{t-1})$	$0.191(1.21)$	$-0.243^{***}(-2.86)$	$0.308^{*}(1.71)$	$0.145^{**}(2.27)$	$0.108^{*}(1.73)$
$D(FD_{t-1})$	$0.483^{***}(8.05)$	$-0.293^{***}(-4.31)$	$0.041(1.51)$	$0.510^{***}(8.20)$	$0.331^{***}(7.62)$
$D(UR_{t-1})$	$0.467^{***}(2.95)$	$-0.315^{*}(-1.88)$	$0.061(1.53)$	$0.244(1.48)$	$0.295(1.63)$
$D(GDP_{t-1})$	$0.599^{***}(4.84)$	$-0.277^{**}(-2.20)$	$0.005(0.13)$	$0.853^{***}(8.46)$	$0.551^{***}(7.16)$
$D(EC_{t-1})$	$0.274^{**}(2.02)$	$-0.289^{***}(-3.00)$	$0.023(1.32)$	$0.218^{***}(2.84)$	$0.218^{***}(3.21)$
$D(CF_{t-2})$	$-0.254^{*}(-1.80)$	$0.055(0.54)$	$-0.145(-0.70)$	$-0.043(-0.81)$	$-0.139^{**}(-2.34)$
$D(FD_{t-2})$	$0.019(0.23)$	$0.013(0.17)$	$0.012(0.73)$	$-0.069(-1.06)$	$0.076^{*}(1.68)$
$D(UR_{t-2})$	$0.266^{*}(1.67)$	$-0.472^{**}(-2.08)$	$0.006(0.18)$	$0.257(1.53)$	$0.223(1.59)$
$D(GDP_{t-2})$	$-0.784(-0.68)$	$0.670^{***}(5.05)$	$0.023(1.02)$	$-0.288^{***}(-2.78)$	$0.049(-0.60)$
$D(EC_{t-2})$	$0.371^{***}(3.70)$	$-0.322^{***}(-3.35)$	$0.015(1.10)$	$0.189^{**}(2.26)$	$0.231^{***}(3.56)$

Notes: Probability values are reported in parentheses. Panel root test includes intercept and trend. *** and ** denotes the significance at 1 and 5% level, respectively. D(.) denotes the first differences.

For financial development, the results show that the effect of one standard deviation shock in the growth of financial development on the CO_2 emissions growth was positive from the first year to second year but then negative instantaneously and was weak positive from year 4 to10. Overall, the impact of financial development on CO_2 emissions is not very high and from a short-term and long-term perspective, the growth of financial development level has also had a positive impact on the CO_2 emissions. It may be because the improvement of the financial system reduces information asymmetry and expands financing channels by providing capital loans at a lower cost. This will help to expand the scale of products, such as increasing workers, leasing equipment and expanding new production lines, which will eventually lead to an increase in carbon emissions.

For urbanization level, it can be seen from the figure that the effect of one standard deviation shock in the growth of urbanization level on the CO_2 emissionst growth is also positive in both the long-term and short-term. After the rapid response in the first year, the response reaches the peak in the second year, and then the response gradually decreases. This result also shows that in the process of urbanization, carbon emissions will increase with the improvement of urbanization rate. While promoting urbanization, it will also have a negative impact on environmental quality. This phenomenon may be explained by the scale effect and agglomeration effect of economy and the energy consumption characteristics of urban residents in the process of urbanization development. Therefore, encouraging green and sustainable urbanization is very important to reduce environmental pollution and achieve high-quality economic development.

For economic growth, the results show that the response of the growth of CO_2 emissions to one standard deviation shock in the growth of economy was reached the positive peak in the first year. Then, it is strongly positive from year 2 to 4, and the impact of shocks gradually decreases after year 4. This indicates that economic growth will significantly promote the increase of carbon emissions and have a negative impact on the environment. Sun et al. [59] also supports this conclusion. The increase of carbon emissions caused by economic growth may be because economic growth is accompanied by industrial development, while the demand of industrial development will promote the consumption of fossil fuel energy, thus increasing CO_2 emissions to a certain extent.

For energy consumption, it can be seen from the figure that the response of one standard deviation shock in the growth of energy consumption on the CO_2 emissions is also positive from year 1 to 10,and reaches peak in second year and then the response gradually decreases. This shows that the total energy consumption is also one of the influencing factors to promote carbon emissions, which is also consistent with some previous empirical research results [50–62]. These research results confirm the negative impact of energy consumption on environmental quality, and also believe that vigorously developing energy-saving technology and enhancing the development of renewable energy sources is an effective way to reduce CO_2 emissions.

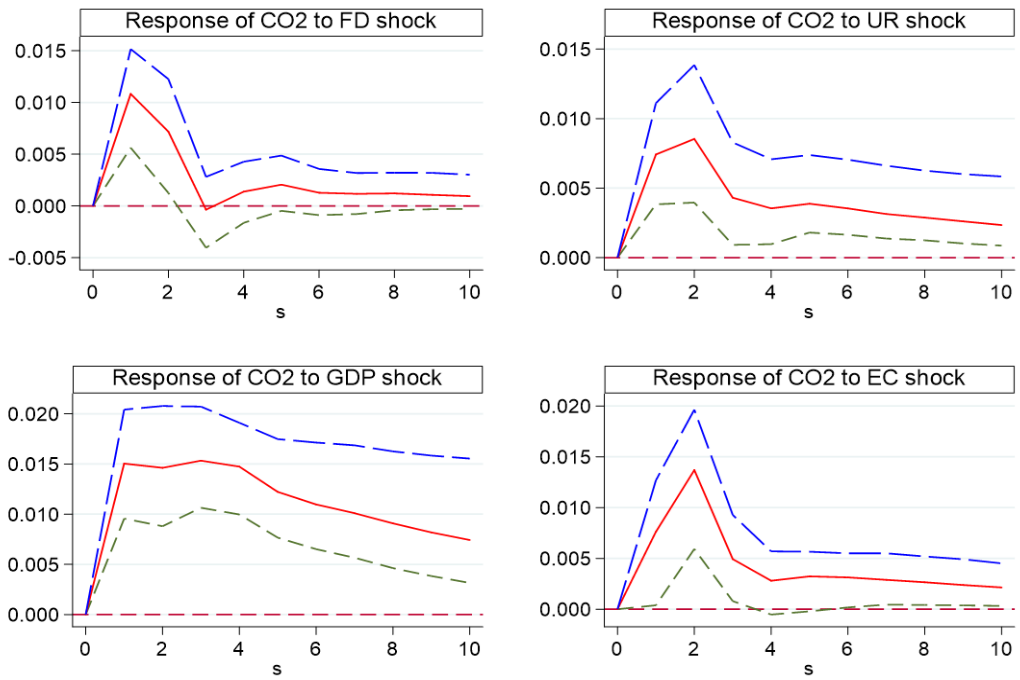

Figure 1. Reaction of CF to FD, UR, GDP and EC one standard deviation shock.

4.4. Variance decomposition analysis

Although the impulse response function can provide details of the impact of other variables on carbon emissions, it does not show the magnitude and extent of its impact. The variance decomposition of PVAR model can solve this problem. Variance decomposition can analyze the contribution of a single variable to other endogenous variables, and more accurately obtain the degree of interaction between variables. Furthermore, variance decomposition provides the percentage of information about the sequence changes of dependent variables. These changes can be attributed not only to their own impact, but also to the impact of other variables. Table 7 reflects the results of variance decomposition of various variables. The results of variance decomposition show that the contribution rate of carbon emissions to itself is more than 50% from phase 10 to 30, that is, more than 50% of the change of carbon emissions can be explained by itself. Meanwhile, the contribution rate of carbon emissions to economic development has also reached more than 25% in the 10-th to 30-th periods, but the impact on other variables is relatively small. For the level of financial development, the contribution rate to itself is as high as 78% during 10-th to 30-th periods, which indicates that Chinese financial development has a certain inertia and good self growth effect. At the same time, the level of financial development also explains about 12% of the fluctuation of carbon emissions and about 3% of the fluctuation of economic growth. However, for the level of urbanization, except for itself, the impact on other variables is relatively small. It is worth noting that the level of economic development in the 10-th to 30-th periods not only contributes more than 50% to itself, but also explains about 16% of the fluctuation of financial development and about 21% of CO_2 emissions. Finally, we also find that energy consumption explains about 27% of the fluctuation of carbon emissions and about 36% of economic growth. This shows that the utilization rate of energy in China is not high, and it still relies heavily on the consumption of traditional energy to meet the growing demand of the economy, thereby promoting the generation of carbon emissions to a large extent.

Table 7. Variance decomposition of the PVAR model (%).

Variables	period	D(CF)	D(FD)	D(UR)	D(GDP)	D(EC)
D(CF)	10	59.6	3.4	4.0	26.1	6.1
	20	56.8	3.3	4.2	29.6	6.0
	30	56.5	3.3	4.2	30.0	6.0
D(FD)	10	12.0	78.6	2.1	3.0	4.4
	20	12.0	78.3	2.1	3.2	4.4
	30	12.0	78.2	2.1	3.3	4.4
D(UR)	10	1.7	4.3	90.8	2.8	0.5
	20	1.8	4.2	90.1	3.3	0.5
	30	1.8	4.2	90.1	3.4	0.5
D(GDP)	10	21.2	17.3	4.7	52.2	4.6
	20	21.1	16.0	4.9	53.4	4.7
	30	21.1	15.8	4.9	53.5	4.7
D(EC)	10	27.5	3.5	4.5	33.6	30.9
	20	26.9	3.3	4.7	36.2	28.9
	30	26.8	3.3	4.7	36.6	28.6

5. Policy implications

Many researchers agree that a developed financial system must be related to environmental protection and security [63–65]. However, our empirical research shows that financial development promotes CO_2 emissions and has a negative impact on environmental quality. The Chinese government and policy makers should fully recognize this result and analyze the reasons for it. On the basis of the rapid development of the financial sector in the past, they should continue to promote the process of financial reform, strengthen financial innovation, improve technical effects, make reasonable capital investment, increase investment in environmental governance, energy conservation and emission reduction technologies. At the same time, improve the utilization rate of primary energy by promoting the technological progress of enterprises, so as to achieve the purpose of carbon emissions reduction. Government department should also pay attention to the structural effect of financial scale, and promote the upgrading and optimization of industrial structure through the development of securities and bank financial scale system. In particular, green finance should be vigorously develop and the traditional concept of financial industry development should be change. Commercial banks and other financial institutions should vigorously support projects that can promote carbon emissions reduction.

From the above empirical analysis results, it can be found that the continuous advancement of the urbanization process has exacerbated the generation of carbon emissions and the deterioration of the environment. Therefore, it is very important to improve the development quality of urbanization and take a high-quality urbanization development path. We cannot blindly pursue the improvement of the urbanization rate while ignoring the protection of the environment. Policy makers should encourage green and sustainable urbanization, so as to achieve economic growth without causing environmental degradation. The Chinese government should also balance urban and rural development, further reduce the pressure of urbanization, accelerate the upgrading of urban industrial structure, and promote the coordinated and sustainable development of urbanization population, economy, society, living standards, space and ecosystem. At the same time, government propaganda department should strengthen ideological education and publicity for urban residents, guide consumers to better understand energy conservation, environmental protection and green consumption, promote low-carbon consumption, and accelerate the transformation of residents' consumption mode and lifestyle.

With regard to energy consumption, many researchers believe that this is an important part of the increase in carbon emissions [66–68]. Without affecting economic growth, reducing energy consumption to curb carbon emissions is an urgent problem for the Chinese government and policymakers. The Chinese government must formulate relevant policies to improve energy utilization and energy intensity per unit of GDP. In addition, the Chinese government should also focus on long-term energy technology investment, especially the R&D of more sustainable and value-added technologies, and enhance investment in renewable energy, such as bioenergy, marine energy, wind energy, etc. At the same time, establish renewable energy and clean energy institutions to encourage the use of renewable and clean energy. Setting mandatory renewable energy targets for China's high energy consuming provinces is also a good way to reduce national carbon emissions.

According to EKC hypothesis, China is currently in the stage of developing country, and its economic growth and environmental pollution are occurring at the same time. How to develop economy, reduce environmental pollution and achieve sustainable development is an important task for China's development. The Chinese government should speed up the process of marketization, reduce its intervention in the economy, and change its ruling philosophy. Furthermore, in the process of economic development, policy makers should give full consideration to China's current severe environmental situation, resolutely not take the road of "pollution first and then treatment", but should take the road of simultaneous economic development and environmental treatment, and focus on environmental protection while ensuring a certain economic growth rate. The government department should not only pay attention to the welfare of economic development, but also strengthen the welfare of environmental governance. Encouraging local functional departments to pay attention to environmental protection. More importantly, local functional departments should be encouraged to pay attention to environmental protection, and promote all departments to change from the development model of relying on sacrificing the environment to achieve economic growth to the high-quality, green and sustainable development model.

6. Conclusions

This study uses PVAR technology to investigate the impact of energy consumption, financial development, economic growth and urbanization on CO_2 emissions of 30 provinces in China. The most important results of the paper can be summarized in four important points. First, we found that energy consumption, financial development, economic growth and urbanization has a positive impact on CO_2 emissions. Second, we also find that financial development and total energy consumption have a significant positive impact on economic growth. It shows that although financial development and energy consumption have damaged environmental quality, they have also made important contributions to economic development to a certain extent. Third, we unexpectedly found that the level of urbanization has a weak negative effect on financial development, with a significance of 10%. Forth, we also found that both financial development and economic growth significantly promoted energy consumption, indicating that the financial sector and the department of Treasury did not play the expected role in controlling energy consumption.

Regarding the impulse response results, our empirical findings showed that the response of CO_2 emissions to a standard shock of all other variables is positive, and the response lasts for a long time, which indicating that economic growth, financial development, energy consumption and urbanization are the culprits of the increase of carbon emissions. Additionally, the response of economic growth to one standard shock on financial development displays a positive sign but its effect is decreasing overtime until period 3 where it will completely die. Regarding energy consumption, the results provide evidence that the response of financial development to one standard deviation shock on energy consumption is negative during the first four periods and dies completely after that. For economic growth, the impact is positive during all periods and from period two to ten with a decreasing behavior.

Additionally, The result of variance decomposition can confirm that compared with other variables, the urbanization level have a slight influence and can slightly explain CO_2 emissions. The contribution rate of financial development to carbon emissions is relatively significant, which can explain the increase of carbon emissions to a certain extent. It is worth mentioning that the impact of economic growth and energy consumption on carbon emissions is very huge, and the contribution rate has reached more than 20%, especially the contribution rate of energy consumption has reached more than 25%, which can make a strong explanation for carbon emissions. It also shows that while developing the economy and financial industry, China should also pay attention to the sustainable development of the environment, save the use of energy, and curb the promotion of carbon emissions by developing a high-quality and sustainable economy.

Finally, the research of this paper has some limitations. First of all, this paper takes Chinese provinces as the research object, ignoring the heterogeneity between samples. The possible expansion is to divide the samples of Chinese provinces into different sub samples according to the corresponding indicators, so as to assess the main determinants of environmental degradation in each type of province. Or narrow the scope of the study to a certain region in China, a relatively prominent province or at the prefecture city level or county level. Secondly, this paper uses the PVAR model to obtain the interaction and dynamic relationship of the variables studied on the basis of considering the endogenous nature of the variables, but neglects the impact of the interaction between the variables on carbon emissions. Perhaps we can solve this problem by improving the traditional PVAR model or use the intermediary effect model to study the transmission mechanism of the impact of each variable on carbon emissions in the future work. Other possible subsequent expansions of this study include the inclusion of other impact indicators and other environmental degradation indicators.

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Conflict of interest

The authors declare there is no conflict of interest.

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