ISSN 2616-5872 Vol.6, Issue 6: 1-12, DOI: 10.25236/AJEE.2024.060601

# Research on the Dynamic Relationship between China's Energy Consumption, Energy Structure, Carbon Emissions and Economic Growth—An Empirical Analysis Based on VAR Model

**Deqiang Li[1,a], Ke Zhang[1,b,*]**

[1]*School of Economics and Management, Shaanxi University of Science and Technology, Xi'an, 710021, China*
[a]*lideqiang@sust.edu.cn*, [b]*13772197354@163.com*
[*]*Corresponding author*

***Abstract:*** *With the continuous growth of China's economy, issues such as energy consumption and carbon emissions have continuously become hotspots of concern. Based on energy consumption, energy structure, economic growth and carbon emission data from 1980 to 2023, this paper establishes a VAR model, uses Granger causality test to examine the causal relationship between these elements, and at the same time uses impulse response function to analyze the long-term dynamic relationship between variables. The research results show that there is a two-way causal relationship between energy consumption and energy structure, and a two-way causal relationship between carbon emissions and energy structure. At the same time, the impulse response function is used to verify the dynamic change relationship between them. The research results reveal that China's economic development at this stage is highly dependent on traditional energy sources. While pursuing economic development, it is necessary to take into account the efficiency of traditional energy consumption, adjust the energy structure, vigorously develop new energy sources, and promote China's economy to embark on a green and low-carbon sustainable development path.*

***Keywords:*** *Energy consumption; energy structure; carbon emissions; economic growth; VAR model*

## 1. Introduction

The process of human's utilization of energy has undergone long-term development and changes from the initial firewood era to the current oil and gas era. Along with the changes in the energy structure, the total amount of energy utilization is also continuously increasing, effectively driving the rapid economic growth. But at the same time, corresponding environmental problems have also emerged. As an important material basis for the survival and development of human society, energy, economy and environment interact and restrict each other [1] .

China is currently in the stage of industrial development, and needs to maintain a certain level of economic growth to meet the requirements of improving the national production environment, maintaining social stability and developing into a developed country. Energy is a pillar industry for the development of the national economy and is applied in various fields such as linking production, living consumption, and transportation. As the world's largest energy-consuming country at present, by the end of 2023, China's total energy consumption has reached 5.72 billion tons of standard coal, accounting for 27.6% of the world's total energy consumption. Among them, the total consumption of fossil energy such as coal and oil in China has accounted for more than 70% for many years. The consumption of a large amount of fossil energy has led to large-scale carbon dioxide emissions, making China the world's largest carbon dioxide emitter and energy-consuming country in 2006 and 2011 respectively[2] .

In addition, although the consumption proportion of China's coal resources has been declining year by year since 2011, it still exceeds 50% on the whole. At present, coal is still a major component in China's energy structure[3]. Compared with abundant coal resources, the output of petroleum resources is low and consumption is high, and it is more dependent on trade imports. Under the current situation of lack of resources and huge consumption, optimizing the energy structure and effectively achieving

ISSN 2616-5872 Vol.6, Issue 6: 1-12, DOI: 10.25236/AJEE.2024.060601

carbon emission reduction are important measures to ensure sustainable economic development. China needs to make improvements to the existing energy structure and energy consumption mode.

Based on the relationship of mutual restraint and interaction among energy, economy and environment, as well as the basic situation of China's energy consumption and economic development, under the premise of environmental protection, optimizing the energy structure and improving energy use efficiency is an important way to promote sustainable economic development. Based on the VAR model, this paper will deeply study the interrelationships among energy, economy and environment. The second part of the article is a literature research review on the interrelationships among energy, economy and environmental elements. The third part mainly describes the selection of relevant variables and the source of data acquisition. The fourth part conducts an empirical analysis of the main variables studied in the article according to the VAR model, including Granger causality analysis and impulse response analysis. Finally, combined with the model results, analyze the dynamic relationship among energy, economy and environment, and provide unified countermeasures and suggestions in terms of energy, environmental protection and economy in China according to the conclusion.

Based on the relationship of mutual restraint and interaction among energy, economy and environment, as well as the basic situation of China's energy consumption and economic development, under the premise of environmental protection, optimizing the energy structure and improving energy use efficiency is an important way to promote sustainable economic development. Based on the VAR model, this paper will deeply study the interrelationships among energy, economy and environment. The second part of the article is a literature review on the interrelationships among energy, economy and environmental elements. The third part mainly describes the selection of relevant variables and the sources of data acquisition. The fourth part conducts an empirical analysis of the main variables studied in the article according to the VAR model, including Granger causality analysis, impulse response analysis, etc. Finally, combined with the model results, analyze the dynamic relationship among energy, economy and environment, and provide unified countermeasures and suggestions in terms of energy, environmental protection and economy in China according to the conclusion.

## 2. Literature review

### *2.1 Research on the relationship between energy consumption and economic growth*

In order to analyze the relationship between energy consumption and economic growth, Han J proposed a dynamic analysis technology of energy consumption and economic growth based on the PVAR model, and believed that this model can effectively meet the needs of analyzing the dynamic relationship between energy consumption and economic growth[3].Bakirtas et al. studied the panel Granger causality among several emerging market countries such as Colombia and India. Using the Granger causality test, it is shown that there is a panel Granger causality between economic growth and energy consumption [4].Alper et al. used asymmetric causality test methods and autoregressive distributed lag (ARDL) methods to study the causal relationship between economic growth, renewable energy consumption, and capital and labor in new EU member states. The results show that renewable energy consumption has a positive impact on economic growth in all surveyed countries, and there is a causal relationship between the two[5]. intercepted the influencing factors of five dimensions of economy, structure, technology, population and policy from 2010 to 2019, analyzed the relationship between each dimension and energy consumption, and finally concluded that the contribution rate of economic factors has increased significantly to energy consumption, and proposed that on the premise of maintaining a reasonable economic growth rate, guide the change of consumption structure and the reduction of total amount[6]. According to the relevant research of scholars at home and abroad, it can be seen that taking different countries and regions as research objects, there is mostly a causal relationship between the economic growth and energy consumption of the country or region. Based on this basis, this paper can deeply study whether there is a one-way or two-way causal relationship between the energy consumption and economic growth.

### *2.2 Research on the relationship between energy consumption and carbon emissions*

The most important impact of the increase in energy consumption is to promote the increase in carbon emissions, thereby exacerbating the problem of global warming. Alshehry et al. took carbon dioxide as a control variable to study the dynamic causal relationship between energy consumption and economic activities in Saudi Arabia. They believed that there is at least a long-term relationship among energy consumption, carbon dioxide and economic growth, and put forward the view of reducing carbon dioxide emissions from the aspect of green energy policy[7]. Nguyenkh et al. believed that a country's choice of resources depends on the balance between economic growth and environmental degradation and is closely related to its stage of development[8].Song et al. used the modified STIRPAT model to analyze the driving factors of carbon emissions from energy consumption in the Yangtze River Delta region. They believed that energy intensity and energy structure are negative feedback driving factors and have a certain inhibitory effect on carbon emissions. Thus, they proposed an economic development mode of transforming to a low-carbon and intensive type to promote sustainable and high-quality development in the Yangtze River Delta region[9]. After Zhang Jian and others established the STIRPAT model and conducted an empirical study on China's time series data from 2000 to 2020, it was calculated that when the energy consumption structure and carbon emission intensity change by 1% respectively, the carbon dioxide emissions from energy consumption will change by 0.897% and 0.132% respectively. Under the situation of industrial structure optimization and energy structure optimization, China can achieve carbon peaking in 2030.[10]

### *2.3 Research on the relationship between carbon emissions and economic growth*

On the basis of large amounts of carbon emissions caused by energy consumption, Chen J studied the relationship between carbon emissions and economic growth. Using the decoupling model, he measured the elasticity between the two. Using the Granger causality test model, he analyzed the Granger causality between the two. Finally, he concluded that the urban economic growth rate is faster than the carbon emission growth rate, and economic growth is the Granger causality of carbon emissions, but carbon emission reduction measures will not hinder economic growth [11].Jin et al. collected data from 28 greenhouse gas emitting countries to explore the relationship between energy, economy and environment in countries with different levels of development, and concluded that there is a causal relationship between carbon emissions and economic growth. However, on the basis of inconsistent development levels, developed countries are more inclined to have a two-way causal relationship than developing countries[12]. Domestic scholars' research on economic growth and carbon emissions mostly focuses on regional scopes, such as carbon emission prediction and research on the relationship with economic growth in Liaoning Province, Fujian Province, Sichuan Province, and the Beijing-Tianjin-Hebei region. These studies mostly tend to start from multiple factors affecting carbon emissions, analyze specific impact effects, and propose reasonable emission reduction measures [13][14]. Wang Zheng and Fan Jie sorted out and summarized relevant domestic and foreign literature on factors affecting carbon emissions, and put forward the view that carbon emission research should combine regional development status, be based on the direction of regional development, and combine social and economic levels to conduct classified management and control of carbon emissions[15].

Research on economic growth, energy consumption and carbon emissions has been relatively common. However, more research is based on the study of the relationship between economic growth, energy consumption and carbon emissions in pairs. The research results on pairwise relationships are not uniform because the research objects are different, and the differences in economic development or policy implementation in different regions have different effects on the research objects. Based on this, this article will add energy structure factors to study the dynamic relationship between energy consumption, energy structure, economic growth and carbon emissions, and analyze the interrelationships among several elements from a more comprehensive perspective, and put forward its own insights for the research on such issues.

## 3. Variable analysis and data acquisition

### *3.1 Variable selection*

Before establishing the model, internal and external influencing factors should be comprehensively considered to analyze the dynamic relationship among several elements such as energy consumption, carbon emissions and economic growth from a comprehensive perspective.

(1)Economic growth

According to the research of Lin Boqiang and others, economic growth will promote the process of urbanization, and the urbanization process will promote the overall energy consumption level. The lack of energy also restricts China's economic growth[16]. Therefore, economic growth is closely related to energy consumption. Since GDP can largely reflect the level of economic growth, referring to the

ISSN 2616-5872 Vol.6, Issue 6: 1-12, DOI: 10.25236/AJEE.2024.060601

research of Lin Boqiang and others, this paper uses GDP as an indicator to measure economic growth and is denoted as *EG*.

(2)Energy consumption

China has a huge population. With the continuous growth of the social economy, it has also generated huge energy consumption. China's energy consumption level is also at the forefront of the world. How to improve energy utilization efficiency under limited resource levels has always been a key issue in China's research. In specific empirical modeling, this paper uses the power generation coal consumption method to calculate and uses the total primary energy consumption to represent the energy consumption intensity, and studies the specific influence relationship with other variables, denoted as *EC*.

(3)Energy structure

Energy structure refers to the composition and proportion of various types of energy in the total energy consumption. A country's energy structure not only reflects whether the economy is dependent on this type of energy consumption, but also reflects the implementation intensity of the country's energy optimization and upgrading measures[17]. Therefore, in the process of energy consumption, the energy structure needs to be taken into account. Referring to Li Lichun's research method, this paper uses the proportion of coal consumption in total energy consumption to represent the intensity of the energy structure, denoted as *ES*[18].

(4)Carbon emissions

China's economic development model belongs to extensive development with high input, high consumption and low output. The high consumption of fossil energy leads to a large amount of carbon dioxide emissions. According to the research of scholars such as Wang Zheng, no matter what stage of development China is in, economic growth is always one of the core elements affecting carbon emissions [15], In studying the relationship between energy consumption and economic growth, carbon emissions need to be considered as a variable closely related to the two. Referring to the carbon emission formula adopted by scholars such as Xu Guoquan, it is specifically expressed as $C=\sum_{\mathrm{i}} E \times F_i \times \delta_{\mathrm{i}}$, $C$ represents carbon emissions, $E_i$ represents the total energy consumption in that year, $F_i$ represents the proportion of energy consumption of type $i$ in total energy consumption, $\delta_{\mathrm{i}}$ the carbon emission coefficient of energy of category $i$. In this paper, the calculation is carried out according to the emission coefficients of the three main fossil energies specified by the *IPCC*. The carbon emission coefficients of various energies are shown in Table 1 below.

*Table 1: Carbon emission coefficients of coal, petroleum, and natural gas*

| Data source | Coal | Oil | Natural Gas |
|---|---|---|---|
| IPCC | 0.7476 | 0.5825 | 0.4435 |

Note: The unit of carbon emission coefficient of various energy sources is $tC/10^4\ tce$.

### *3.2 Data acquisition*

This paper mainly selects time series data from 1980 to 2023. The relevant data on energy consumption, economic growth and carbon emissions involved mainly come from "China Energy Statistical Yearbook" and "China Statistical Yearbook", and are obtained by direct quotation or indirect calculation of the data.

Figure 1 is the trend chart of China's real GDP, total energy consumption, total carbon emissions and energy structure from 1980 to 2023. It can be seen that China's real GDP, total energy consumption and total carbon emissions generally show an upward trend, and there is a significant increase in 2000. The changes in total energy consumption and carbon emissions are relatively similar. The overall change in energy structure shows a downward trend, which to a certain extent indicates that the proportion of coal consumption in various energy consumptions is continuously declining, but the fluctuation is large. And it was in an upward stage around 1980-1990, and then in a downward trend from 1990 to 2001. From 2001 to 2007, there was a small increase. Finally, after 2007, it was in a downward trend as a whole.

ISSN 2616-5872 Vol.6, Issue 6: 1-12, DOI: 10.25236/AJEE.2024.060601

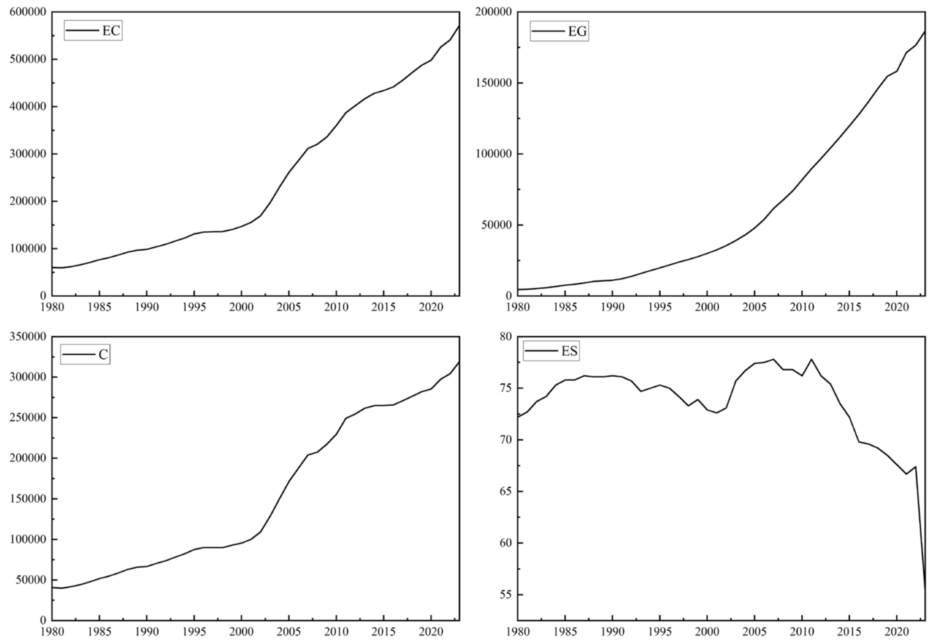


*Figure 1: Trend chart of changes in EC, EG, C, and ES from 1980 to 2023.*

In order to eliminate the possible heteroscedasticity in the data and maintain the changing characteristics of the original data, take the logarithm of several variables such as economic growth, energy consumption and carbon emissions. Finally, the new variable names, calculation methods and unit representations are obtained as shown in Table 2 below:

*Table 2: Variable symbols and units.*

| Variable | Calculation method. | Symbol | Unit |
|---|---|---|---|
| Economic growth | Logarithm of real GDP. | *LEG* | 100 million yuan |
| Energy consumption | Logarithm of total primary energy consumption. | *LEC* | Ten thousand tons |
| Energy structure | Proportion of coal consumption in total energy consumption. | *ES* | % |
| Carbon emissions | Take the logarithm of carbon emissions. | *LC* | Ten thousand tons |

## 4. Empirical research of VAR model

The VAR model, namely the vector autoregression model, is often used to predict interconnected time series systems and analyze the dynamic impact of random disturbance terms on variable systems. It is mostly used in fields such as macroeconomics. This paper mainly studies the interrelationships between energy consumption, economic growth and carbon emissions. Based on the time period from 1980 to 2023, the vector autoregression model can be perfectly applied to the issues to be studied in this paper to study the interrelationships of several time series variables.

### *4.1 Unit root test*

Before establishing the vector autoregression model, it is necessary to test the time series data to ensure that the time series is stationary without random or definite trends and avoid spurious regression. This paper uses the ADF test method to conduct stationarity tests on LEG, LEC, LC, and ES. The test results are shown in Table 3.

The unit root test results show that the ADF test of the original time series variables LEG, LEC, LC, and ES does not reject the null hypothesis that there is a unit root, that is, the time series is non-stationary. The ADF test t-statistics of ΔLEG, ΔLEC, ΔLC, and ΔES formed after the first-order difference processing of each variable are all less than the corresponding critical values at the 10% significance level, rejecting the original hypothesis that there is a unit root. Therefore, the first-order difference sequence of the original sequence is stationary, indicating that ΔLEG, ΔLEC, ΔLC, and ΔES

ISSN 2616-5872 Vol.6, Issue 6: 1-12, DOI: 10.25236/AJEE.2024.060601

are first-order integrated sequences.

*Table 3: Unit root test results of LEG, LEC, LC, ES and their differences.*

| variable | ADF test value | 1%critical value | 5% critical value | 10% critical value | conclusion |
|---|---|---|---|---|---|
| *LEG* | -0.333 | -3.648 | -2.958 | -2.612 | Not stationary |
| *LEC* | -0.492 | -3.648 | -2.958 | -2.612 | Not stationary |
| *LC* | -1.008 | -3.648 | -2.958 | -2.612 | Not stationary |
| *ES* | 2.290 | -3.648 | -2.958 | -2.612 | Not stationary |
| *ΔLEG* | -6.105 | -3.655 | -2.961 | -2.613 | stationary |
| *ΔLEC* | -2.616 | -3.655 | -2.961 | -2.613 | stationary |
| *ΔLC* | -2.581 | -3.655 | -2.961 | -2.613 | stationary |
| *ΔES* | -4.232 | -3.655 | -2.961 | -2.613 | stationary |

### *4.2 Establishment of VAR model*

After determining that the time series after the first-order difference is stationary, use the time series data after the difference to establish a VAR model. The general VAR model is as shown in (1) below:

$$Y_t = \alpha + A_1 Y_{t-1} + A_2 Y_{t-2} + \cdots + A_p Y_{t-p} + \varepsilon_t \text{ , } t = 1, 2, \cdots, n \tag{1}$$

$Y_t$ represents an n-dimensional endogenous variable, $Y_{t-1}$( i=1, 2,$\cdots$, $p$) represents the subsequent vector of endogenous variables, $A_t$ is an $n{\times}n$ -dimensional coefficient matrix, $p$ is the lag order of endogenous variables, $\varepsilon_t$ is a vector composed of n-dimensional random error terms, Elements can be contemporaneously correlated, but not correlated with their own lagged terms.

To construct a VAR model, it is necessary to determine the optimal lag order of the model. The judgment results of the lag order are shown in Table 4.

*Table 4: Lag order test of VAR model.*

| Lag | LL | LR | FPE | AIC | SC | HQ |
|---|---|---|---|---|---|---|
| 0 | 169.643 | NA | 1.2e-09 | -9.20237 | -9.14096 | -9.02643* |
| 1 | 195.99 | 52.694 | 6.7e-10* | -9.7772* | -9,47015* | -8.89747* |
| 2 | 208.93 | 25.881 | 8.3e-10 | -9.60723 | -9.05454 | -8.02371 |
| 3 | 219.537 | 21.214 | 1.2e-09 | -9.30761 | -8.50928 | -7.0203 |
| 4 | 235.133 | 31.191* | 1.5e-09 | -9.28514 | -8.24117 | -6.29405 |

Note: The "*" marks the lag order selected according to the corresponding criterion.

Table 4 gives the AIC, SC and HQ values of the VAR model of order 0-4. According to the results, it can be seen that the lag order selected by most criteria is the first order. Therefore, the optimal lag order determined by the VAR model is the first order. Thus, the specific expression form of the VAR model is as shown in Equation (2) below.

$$\begin{bmatrix} \Delta LEG_t \\ \Delta LEC_t \\ \Delta LC_t \\ \Delta ES_t \end{bmatrix} = \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \end{bmatrix} + \begin{bmatrix} A_{11,n} & A_{12,n} & A_{13,n} & A_{14,n} \\ A_{21,n} & A_{22,n} & A_{23n} & A_{24n} \\ A_{31,n} & A_{32,n} & A_{33,n} & A_{34,n} \\ A_{41,n} & A_{42,n} & A_{43,n} & A_{44,n} \end{bmatrix} \begin{bmatrix} \Delta LEG_{t-1} \\ \Delta LEC_{t-1} \\ \Delta LC_{t-1} \\ \Delta ES_{t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \\ \varepsilon_{4t} \end{bmatrix} \tag{2}$$

Bringing the time series data after the first-order difference into the VAR model and using stata17 software to analyze, the specific VAR regression model obtained is as follows:

$$\begin{bmatrix} -0.2526 \\ 0.0218 \\ -0.9883 \\ 0.0149 \end{bmatrix} + \begin{bmatrix} -0.1813 & -0.0183 & -0.6497 & -0.2101 \\ 14.1101 & 2.2355 & 92.6615 & 2.5858 \\ -0.0310 & 0.0180 & 0.7330 & 0.0212 \\ -7.0514 & -1.5692 & -80.9703 & -1.8586 \end{bmatrix} \begin{bmatrix} \Delta LEG_{t-1} \\ \Delta LEC_{t-1} \\ \Delta LC_{t-1} \\ \Delta ES_{t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \\ \varepsilon_{4t} \end{bmatrix} \tag{3}$$

ISSN 2616-5872 Vol.6, Issue 6: 1-12, DOI: 10.25236/AJEE.2024.060601

In order to measure whether the parameters of the constructed VAR model have certain stability, the AR characteristic root test is used to measure the stability of the model. The test results are shown in Figure 2. The VAR model includes four endogenous variables and the lag length is 1. The moduli of these four roots are all less than 1, indicating that all the sequence characteristic values of the model are within the unit circle. Therefore, the estimated VAR model satisfies the stability condition.

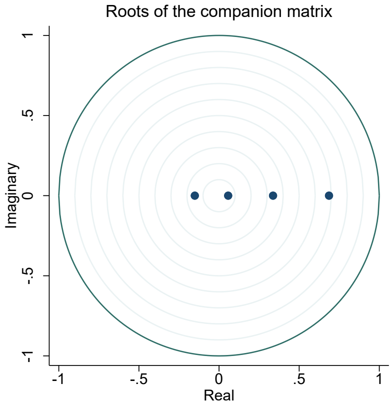


*Figure 2: Unit root test results.*

### *4.3 Granger causality test*

The Granger causality test is mainly used to test whether the lagged terms of a certain variable have predictive power for one or several other variables. After determining that each sequence is stationary, the Granger causality test can be performed on the relationship between several variables such as energy consumption, economic growth, and carbon emissions to determine whether there is a causal relationship between them and what the specific direction of effect is. The test results are shown in Table 5.

*Table 5: Granger test results.*

| **Original hypothesis** | **F-statistics value** | **P value** | **Conclusion** |
|---|---|---|---|
| $dLEG$ is not the Granger cause of $dLEC$ | 0.9403 | 0.332 | acceptance |
| $dLEG$ is not the Granger cause of $dES$ | 0.0844 | 0.771 | acceptance |
| $dLEG$ is not the Granger cause of $dLC$ | 0.2432 | 0.622 | acceptance |
| $dLEC$ is not the Granger cause of $dLEG$ | 3.2523 | 0.071 | rejection |
| $dLEC$ is not the Granger cause of $dES$ | 6.3681 | 0.012 | rejection |
| $dLEC$ is not the Granger cause of $dLC$ | 2.6994 | 0.100 | acceptance |
| $dES$ is not the Granger cause of $dLEG$ | 2.0568 | 0.152 | acceptance |
| $dES$ is not the Granger cause of $dLEC$ | 4.5594 | 0.033 | rejection |
| $dES$ is not the Granger cause of $dLC$ | 3.6052 | 0.058 | rejection |
| $dLC$ is not the Granger cause of $dLEG$ | 3.0874 | 0.079 | rejection |
| $dLC$ is not the Granger cause of $dLEC$ | 5.0631 | 0.024 | rejection |
| $dLC$ is not the Granger cause of $dES$ | 6.3938 | 0.011 | rejection |

As can be seen from Table 5, the main causal relationships between several variables are as follows: (1) Energy consumption accepts being the Granger cause of economic growth and energy structure, indicating that energy consumption plays a certain role in driving economic growth and also has an impact on changes in energy structure. (2) Energy structure accepts being the Granger cause of energy consumption and carbon emissions, indicating that the optimized change of energy structure promotes energy consumption and carbon emissions to a certain extent. (3) Carbon emissions accept being the Granger cause of economic growth, energy consumption, and energy structure, indicating that the increase in carbon emissions promotes energy consumption and economic growth and is conducive to

ISSN 2616-5872 Vol.6, Issue 6: 1-12, DOI: 10.25236/AJEE.2024.060601

the optimization and adjustment of energy structure. Combining the above results, it can be seen that there is a two-way causal relationship between energy consumption and energy structure, and there is a two-way causal relationship between carbon emissions and energy structure.

### *4.4 Impulse response analysis*

To further study the dynamic impact relationship of the shock of one variable on any other variable when other factors remain unchanged, we introduce the impulse response function and conduct further impulse response analysis on the variables with Granger causality in the VAR model.

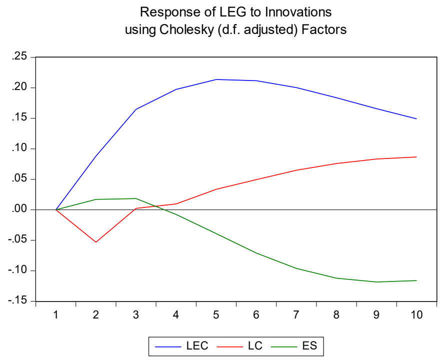


*Figure 3: Impulse response of LEG to LEC, LC, and ES*

As can be seen from Figure 3, the responses of energy consumption, carbon emissions, and energy structure to economic growth shocks are different. The impact of energy consumption on economic growth has been in a growing trend in the first five periods, and from the fifth period, it begins to decline at a slower speed. The impact of carbon emissions on economic growth is negatively affected in the early stage. After the third period, the impact begins to show a positive increase, but the overall growth rate of the impact is not significant. The impact of energy structure on economic growth is initially weak, and the response is zero around the fourth period.

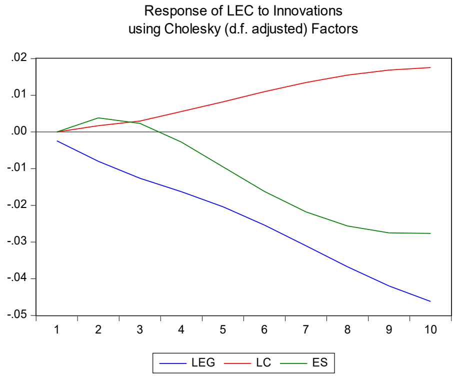


*Figure 4: Impulse response of LEC to LEG, LC, and ES*

As can be seen from Figure 4，the impact of carbon emissions on energy consumption is initially weak but has been showing an increasing trend. The impacts of economic growth and energy structure on energy consumption both show a decreasing trend. Moreover, the impact of energy structure on energy consumption tends to zero around the third period, indicating that in the later stage, the impacts of changes in economic growth and energy structure on energy consumption gradually disappear.

ISSN 2616-5872 Vol.6, Issue 6: 1-12, DOI: 10.25236/AJEE.2024.060601

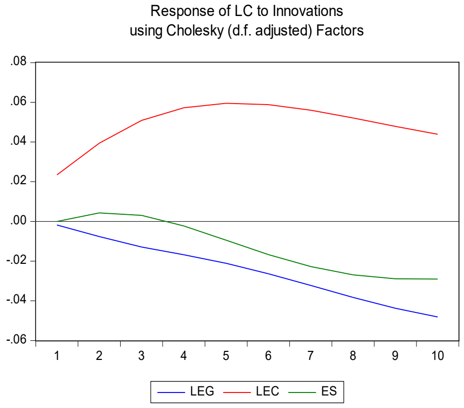


*Figure 5: Impulse response of LC to LEG, LEC, and ES*

As can be seen from Figure 5, in the first five periods, energy consumption shows a continuously increasing trend in response to the impact of carbon emissions. However, as the number of periods increases, the impact trend gradually weakens. After the fifth period, the impact of carbon emissions on energy consumption shows a downward trend. This indicates that in the early stage of energy consumption, a large amount of carbon emissions will be generated. As corresponding measures for energy consumption are taken in the later stage, the impact on carbon emissions begins to weaken. The impact of energy structure on carbon emissions decreases and drops to zero around the 3.5th period.

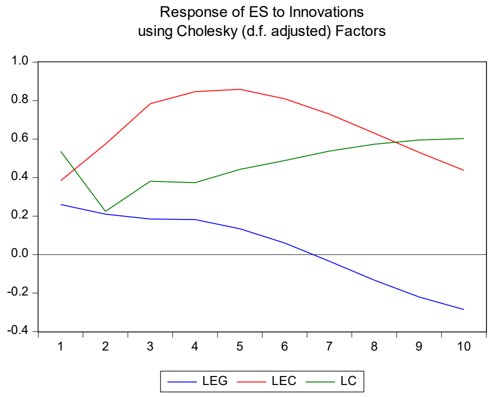


*Figure 6: Impulse response of ES to LEG, LEC, and LC*

As can be seen from Figure 6, the impact of economic growth on energy structure is continuously decreasing and becomes negative after the 6.5th period. This indicates that with economic growth, the energy structure will show certain adjustments and optimizations in the early stage, but the response to economic growth begins to weaken in the later stage. The impact of energy consumption on energy structure shows a trend of increasing first and then decreasing. In the first four periods, as energy consumption increases, the energy structure changes accordingly and continuous adjustments and optimizations occur. After the fourth period, the response to energy consumption gradually weakens.

### *4.5 Variance decomposition*

In order to further analyze the influence degree of different structural shocks on the endogenous variables of the model, variance decomposition is performed on the VAR model. The results are shown in Figure 7.

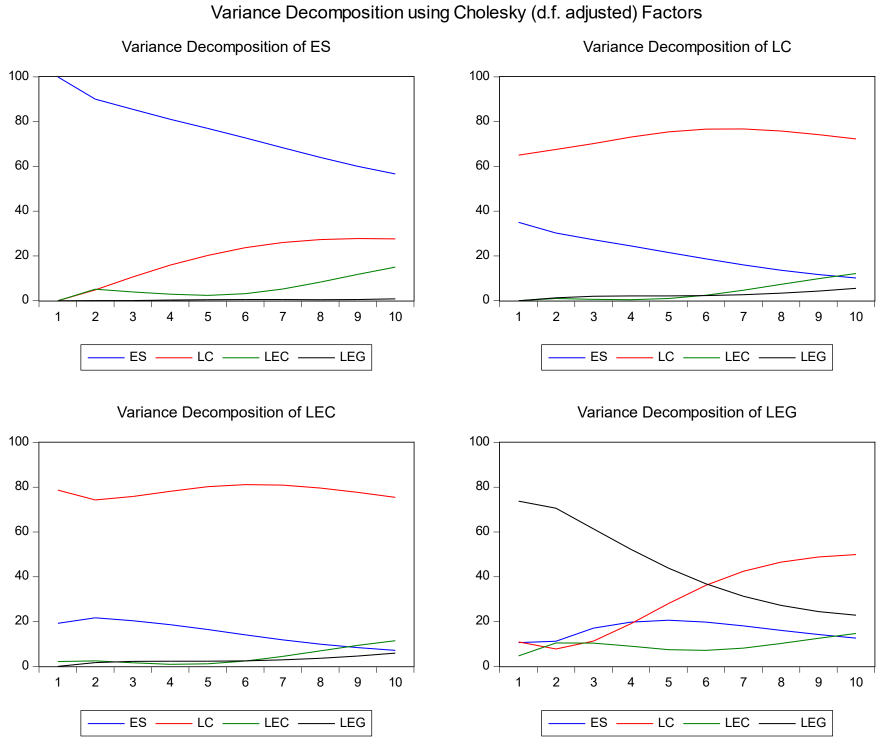


*Figure 7: Variance decomposition diagram.*

As can be seen from Figure 7, the impacts of the four elements of energy structure, carbon emissions, energy consumption, and economic growth on their own changes have relatively large contribution degrees. If the impact strength of these elements on their own changes is not considered, it can be seen that carbon emissions have the largest contribution degree to the change of energy structure and show a gradually increasing trend; the contribution degree of energy structure to carbon emissions is also the largest, but it gradually decreases as the number of periods increases; the contribution degree of energy structure to energy consumption is the largest, which may depend on the reason that the two have a causal relationship with each other; and for the economic growth variable, the contribution degree of carbon emissions shows an increasing trend, and the contribution degrees of other variables are relatively low.

## 5. Conclusions and suggestions

This paper mainly uses the time series data of energy consumption, economic growth, energy structure and carbon emissions from 1980 to 2023 to establish a VAR model, and analyzes the relationship between China's energy consumption, economic growth and carbon emissions through methods such as Granger causality test, impulse response function and variance decomposition. The main conclusions are as follows:

(1) There is a certain long-term equilibrium relationship among several elements of China's energy consumption, economic growth, carbon emissions and energy structure.

(2) From the perspective of causality, there is a two-way causal relationship between energy consumption and energy structure, and there is a two-way causal relationship between carbon emissions and energy structure. These two sets of variables are in a relationship of mutual influence and restraint. The change of any variable will have a certain impact on another variable. Because China's energy consumption is still dominated by coal. However, with the call of the government and national policies, the development and use of clean energy has been continuously put on the agenda, which has certain optimization for the adjustment of energy structure and also affects the carbon emissions generated in the process of coal energy use.

(3) From the perspective of the influencing factors of energy consumption, economic growth and carbon emissions, carbon emissions have the greatest impact on the change of energy structure, showing a gradually increasing trend; the influencing factor of energy structure on carbon emissions is also the largest, but gradually decreases with the increase of periods; the influencing factor of energy

structure on energy consumption is the largest, which may depend on the reason for the causal relationship between the two; for the economic growth variable, the impact of carbon emissions shows an increasing trend, and the impact of other variables is relatively low.

Based on the research results of this paper, we put forward the following countermeasures and suggestions:

(1) Attach great importance to the role of new energy consumption in driving economic growth. Pay attention to promoting the use of clean energy across the country and improving the technical level of energy production, processing and utilization. China's energy consumption structure is still dominated by high-carbon fossil energy. To achieve the sustainable development of China's economy, we should transform the energy consumption structure, promote the low-carbonization of the energy structure, and vigorously develop clean energy such as wind energy, solar energy and nuclear energy. At the same time, pay attention to improving the technical level of energy utilization, strengthen innovative research and development of technologies and rationally utilize data elements in the digital economy to improve energy utilization efficiency, thereby achieving the goal of reducing pollution and carbon emissions and promoting high-quality economic development.

(2) The transformation and upgrading of industrial structure is an important means to change the economic growth mode. In order to achieve the coordinated development of China's economy and environment, we should also optimize the industrial structure, realize industrial upgrading, gradually eliminate highly polluting industries, encourage and maintain the development of green environmental protection industries, directly reduce energy consumption and carbon dioxide emissions, and push China's economy onto a green and low-carbon sustainable development path.

## References

*[1] Guan W, Jin Y. Analysis of the impulse response of China's energy utilization and economic growth to the ecological environment[J]. Economic Geography, 2020, 40(2): 31-40. (in Chinese)*

*[2] Xu B, Chen Y F, Shen X B. Clean energy development, carbon dioxide emission reduction and regional economic growth[J]. Econ. Res. J, 2019, 54(7): 188-202. (in Chinese)*

*[3] Han J. Analysis of Dynamic Relationship between Energy Consumption and Economic Growth Based on PVAR Model[J]. International Transactions on Electrical Energy Systems, 2022, 2022(1): 3945522.*

*[4] Bakirtas T, Akpolat A G. The relationship between energy consumption, urbanization, and economic growth in new emerging-market countries[J]. Energy, 2018, 147: 110-121.*

*[5] Alper A, Oguz O. The role of renewable energy consumption in economic growth: Evidence from asymmetric causality[J]. Renewable and Sustainable Energy Reviews, 2016, 60: 953-959.*

*[6] Jing L. Study on the Relationship between Energy Consumption and High-Quality Economic Development in China and its Impacts[J].Modern Economic Research, 2022,(04):11-20+132. (in Chinese)*

*[7] Alshehry A S, Belloumi M. Energy consumption, carbon dioxide emissions and economic growth: The case of Saudi Arabia[J]. Renewable and Sustainable Energy Reviews, 2015, 41: 237-247.*

*[8] Nguyen K H, Kakinaka M. Renewable energy consumption, carbon emissions, and development stages: Some evidence from panel cointegration analysis[J]. Renewable energy, 2019, 132: 1049-1057.*

*[9] Song F L, Han C F, Teng M M. Analysis of Carbon Emission Driving Factors of Energy Consumption and Optimization Strategies in the Yangtze River Delta Region [J]. Ecological Economy, 2022, 38(04):21-28. (in Chinese)*

*[10] Zhang J, Liu J Y, Dong L. Factors influencing $CO_2$ emissions from energy consumption and scenario analysis in China[J]. Journal of Environmental Engineering Technology, 2023,13(01):71-78. (in Chinese)*

*[11] Chen J. Dynamic relationship between urban carbon dioxide emissions and economic growth[J]. Glob. Nest J, 2020, 22: 632-641.*

*[12] Jin L, Chang Y, Wang M, et al. The dynamics of CO2 emissions, energy consumption, and economic development: evidence from the top 28 greenhouse gas emitters[J]. Environmental Science and Pollution Research, 2022, 29(24): 36565-36574.*

*[13] Niu L, Zhang L X, Xi F M. Carbon Emission Influencing Factors and Scenario Projections for Liaoning Province[J].Chinese Journal of Applied Ecology, 2023,34(02):499-509. (in Chinese)*

*[14] Li X P, Su S P, Zhang Y S. Carbon Emission Forecasting and Carbon Peak Path Analysis in Fujian Province [J].Resource Development & Marke,2023, 39(2):139-147. (in Chinese)*

*[15] Wang Z, Fan J. Characterization of factors influencing carbon emissions from energy*

ISSN 2616-5872 Vol.6, Issue 6: 1-12, DOI: 10.25236/AJEE.2024.060601

*consumption and research outlook [J]. Geographical Research, 2022,41(10):2587-2599. (in Chinese)*
*[16] Lin B Q, Liu Y X. Carbon Emissions at the Stage of Urbanization in China: Influencing Factors and Emission Reduction Strategies[J]. Economic Research Journal, 2010(8):13. (in Chinese)*
*[17] Xv W X, Xv Z X ,Liu C J. Energy structure, ecology and economic development--threshold effect and heterogeneity analysis[J]. Journal of Statistics and Information, 2020, 35(10):81-89. (in Chinese)*
*[18] Li L C. An Empirical Examination of the Relationship between Energy Consumption, Economic Growth, and Energy Structure in China[J]. Statistics & Decision, 2017,(13):140-143. (in Chinese)*