Study on the Relationship between Energy Consumption and Economic Growth in the Guangdong-Hong Kong-Macao Greater Bay Area

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Abstract. Energy consumption acts as a catalyst for economic growth, as it provides the necessary power for industrial production, transportation, heating, and cooling. A reliable and affordable energy supply is essential for businesses to function efficiently and effectively. In this context, a steady and sufficient supply of energy contributes to increased productivity, job creation, and enhanced economic output. Traditional energy sources, such as fossil fuels, have significant environmental impacts, including greenhouse gas emissions, air pollution, and climate change. With the growth of the economy, the demand for energy increases, underscoring the importance of transitioning to cleaner and sustainable energy systems. Energy is the driving force of national economic development, which has a certain impact on the scale and speed of economic growth. This paper selects data such as GDP, total energy consumption, electricity consumption, natural gas consumption and coal consumption (the data is sourced from statistical yearbooks of various regions), Based on the analysis of the chart and the VAR model, an empirical analysis was made on the relationship between energy consumption and economic growth in the Guangdong-Hong Kong-Macao Greater Bay Area from 2010 to 2021. Through empirical test, it is found that energy consumption has a certain synergistic trend on economic growth and has a causal relationship. The two influence and promote each other. In addition, the efficiency of energy utilization is increasing, and the type of energy consumption is developing towards green energy.

Keywords: VAR model, Energy consumption, Economic growth.

1 Introduction

Climate change is one of the biggest threats facing humanity at present. The massive emissions of greenhouse gases have led to global warming and ecological damage, and sea level rise and glacier melting have brought negative impacts on human production and living environment. They have posed huge challenges to sustainable economic development and become obstacles to sustainable economic and social development in various countries. The Guangdong Hong Kong Macao Greater Bay Area is one of the

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regions with the highest degree of openness and strongest economic vitality in China and even the world. It holds an important strategic position in the overall development of the country and is another world-class bay area after the New York Bay Area, San Francisco Bay Area, and Tokyo Bay Area. Therefore, the Guangdong Hong Kong Macao Greater Bay Area has become a key focus area for low-carbon emission reduction and green low-carbon development[1]. The space for energy conservation and emission reduction in the Greater Bay Area is enormous. China has set the goal of achieving carbon neutrality by 2060. As a leading demonstration zone for China's modernization construction, the Guangdong Hong Kong Macao Greater Bay Area should lead the country in energy transformation, institutional construction, and technological innovation. According to relevant data, Hong Kong's carbon emissions peaked as early as 2014. In terms of carbon reduction, coal consumption in Hong Kong continues to decline, while clean energy sources such as natural gas and electricity continue to increase. However, there is still much work to be done to achieve the 2060 carbon neutrality goal[2].

This article uses the VAR model to analyze the relationship between energy consumption and economic growth, The VAR model is an econometric model used to analyze the interrelationships between multiple time series variables. It can help us understand the causal relationships between variables, impact transmission, and predict future values. The basic idea of the VAR model is to model multiple variables within a unified framework, considering their interdependence. An important feature of the VAR model is its ability to perform shock response analysis, which involves applying shocks to a variable and observing the reactions of other variables. This helps us understand the overall impact of a variable on the system, rather than just focusing on the impact of individual variables.

Therefore, studying the relationship between various factors of energy consumption and economic growth in the Guangdong Hong Kong Macao Greater Bay Area can provide data reference for predicting carbon emission peaks and data support for the country's carbon peaking and carbon neutrality strategies.

2 Literature review

Li and Yao studied the relationship between energy consumption, industrial structure, and economic growth through panel data model testing, and found that there is a stable equilibrium relationship between industrial structure and energy consumption[1]. The optimization and upgrading of industrial structure is conducive to suppressing the rapid growth of energy consumption, and there is also a stable equilibrium relationship between economic growth and energy consumption. Economic growth has a positive impact on energy consumption, The elasticity coefficient of industrial structure on energy consumption remains unchanged in different regions, but due to differences in economic development levels and growth patterns in different regions, there are significant regional differences in the elasticity coefficient of economic growth on energy consumption. Li used the Panel Vector Autoregressive Model (PVAR) and the System Generalized Moment Estimation (GMM) method to predict the model coefficients[2].

He found that there is a mutually supportive development effect between economic growth and carbon emissions, and this effect weakens over time. From a long-term perspective, energy consumption first hinders economic growth, and then stimulates economic growth. The interaction between energy consumption and carbon emissions fluctuates to some extent, which is related to changes in energy consumption structure. Since studying energy consumption requires further research on the differentiation of impacts on different types of energy. Yang found from a nonlinear perspective that non clean energy in the Beijing, Tianjin, Hebei region has a larger coefficient of effect on economic growth compared to clean energy, and there is a causal relationship. Non clean energy accounts for a larger proportion but shows a downward trend, while clean energy accounts for the opposite[3,4].

The scholar confirmed through a panel ARDL model that energy prices, labor, and capital stocks have a positive and statistically significant long-term impact on economic growth in G7 countries (Canada, France, Germany, the UK, Italy, and the United States). The short-term dynamics of the results indicate that there is a short-term causal relationship between non renewable energy consumption and economic growth, as well as between capital stock and economic growth[4,5]. According to the Environmental Kuznets Curve Hypothesis, there is an inverted U-shaped relationship between per capita GDP and per capita pollutant emissions. Jie He and Patrick Richard used semi parametric and flexible nonlinear parameter modeling methods to conclude that the oil shock of the 1970s had a significant impact on Canada's progress in pollution reduction technology and production[6,7].

Most foreign literature research focuses on the relationship between energy consumption and economic growth[8,9], but there is relatively little research on the consumption of differentiated energy types. However, domestic literature has rich research on the consumption of differentiated energy types. However, the proportion of energy resources in different regions varies, and the research results show significant differences[10,11]. Therefore, surveys in different regions still need to be continuously enriched.

3 Model construction

3.1 Variable Selection

In order to avoid pseudo regression and heteroscedasticity in the data, this article logarithmizes all data, denoted as LNGDP, LNGR, LNTEC, and LNEC, respectively. The specific indicators are shown in Table 1.

Table 1. Selection of variables

Category	Variable	unit	Variable Symbol
Explained Variable	GDP	Billion Yuan	LNGDP
explanatory variable	Total energy consumption	10,000 tons of standard coal	LNTEC
	Electricity consumption	10,000 kWh	LNEC
	natural gas	10,000 m^3	LNNG
	coal	10,000 tons	LNCL

3.2 VAR Model

Vector autoregressive (VAR) models are generally used to analyze or predict the dynamic relationships between multiple variables and the response of system variables to disturbances. By observing the impact of random disturbances on the current and future effects of endogenous variables, the impact of shocks on system variables is explained. Based on this, this article mainly uses the VAR model to examine the dynamic interaction characteristics between regional GDP and total energy consumption, electricity consumption, natural gas, and coal. The mathematical expression of the VAR model is:

$$Yt=A1\,_{yt-1}+...+Ap_{yt-p}+B_{xt}+\varepsilon T\ (t=1, 2, 3,..., T) \tag{1}$$

Among them, Yt is an endogenous variable, xt is an exogenous variable, p is the order of lag, t is the number of samples, A1,...., Ap, and B are the coefficient matrices to be estimated, εT is a random perturbation term.

4 Empirical analysis

4.1 Stability test

In the process of analyzing time series data, it is necessary to first ensure that the data itself is stationary. To avoid the phenomenon of "pseudo regression" caused by non-stationary time series, it is necessary to first conduct a stationarity test on the data to determine whether it can meet the prerequisite conditions for establishing a VAR model. Using the ADF unit root test method for stationarity testing, if the significance level P-value is greater than 0.1, it indicates that the null hypothesis is not rejected and the sequence has a unit root, indicating a stable trend. Otherwise, the trend is unstable. The unit root test results for each variable are shown in Table 2:

Table 2. ADF unit root test results

Variable	Number of differen-tials	ADF Value	1% Critical Value	5% Critical Value	10% Critical Value	P Value	stability
LNGDP	0	-2.258796	-4.297073	-3.212696	-2.747676	0.2002	Unstable
	1	-3.514476	-4.297073	-3.212696	-2.747676	0.0318**	Stable
LNTEC	0	-0.344076	-4.297073	-3.212696	-2.747676	0.8847	Unstable
	1	-7.107124	-4.297073	-3.212696	-2.747676	0.0003***	Stable
LNEC	0	1.060891	-4.420595	-3.259808	-2.771129	0.9922	Unstable
	1	-3.140143	-4.582648	-3.212696	-2.801384	0.0636*	Stable
LNNG	0	-2.680513	-5.295384	-4.008157	-3.460791	0.2632	Unstable
	1	-2.382913	-2.84725	-1.988198	-1.60014	0.0239**	Stable
LNCL	0	-2.787711	-5.52186	-4.107833	-3.515047	0.2385	Unstable
	1	-4.900496	-2.81674	-1.982344	-1.601144	0.0002***	Stable

Due to the use of differenced data to construct VAR models, the long-term information of the data is often lost, leading to a decrease in the accuracy of the analysis results. According to relevant research results, the time series is unstable, but there is a cointegration relationship, and the original series analysis can be used. Therefore, in order to improve the accuracy of the analysis results, cointegration tests will be conducted on each variable below. If the results indicate the existence of cointegration tests between variables, the original data will be used to construct the VAR model.

4.2 Cointegration test

The EG two-step method is used to test the cointegration relationship. Firstly, perform OLS regression on LNGDP with LNTEC, LNEC, LNNG, and LNCL, and obtain the residual sequences after regression, named E1, E2, E3, and E4 respectively; Then perform a stationarity test on the residual sequence. If the sequence is stationary, there is a cointegration relationship between variables, otherwise it is not. With the help of Eviews 9.0 software, the regression results are shown in Table 3 below.

Table 3. Residual sequence stationarity test results

Variable	Number of differentials	ADF Value	1% Critical Value	5% Critical Value	10% Critical Value	P Value	stability
LNGDP	0	-2.258796	-4.297073	-3.212696	-2.747676	0.2002	Unstable
	1	-3.514476	-4.297073	-3.212696	-2.747676	0.0318**	Stable
LNTEC	0	-0.344076	-4.297073	-3.212696	-2.747676	0.8847	Unstable
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	1	-2.382913	-2.84725	-1.988198	-1.60014	0.0239**	Stable
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	1	-4.900496	-2.81674	-1.982344	-1.601144	0.0002***	Stable

After conducting stationarity tests on residual sequences, it was found that all residual sequences are stationary, indicating a cointegration relationship between variables, i.e. LNGDP has a long-term equilibrium relationship with LNTEC, LNEC, LNNG, and LNCL.

4.3 VAR model stability testing and model estimation

(1) Determination of the optimal lag order for VAR models

Generally speaking, the larger the lag order of a VAR model, the smaller the degree of freedom, and it can better represent the dynamic characteristics of the model. This article uses criteria such as LR, FPE, AIC, SC, HQ to determine the lag order of the VAR model. The test results are shown in Table 4.

Table 4. Maximum lagged order test statistic

Lag	Logl	LR	FPE	AIC	SC	HQ
0	103.1753	NA	1.22e-14	-17.85005	-17.66918	-17.96405
1	170.9578	61.62049*	9.90e-18*	-25.62869*	-24.54352*	-26.31274*

According to the optimal lag order displayed by each statistic in Table 5 above, it can be seen that the optimal lag order displayed by LR, FPE, AIC, SC, and HQ is all lag order 1. Therefore, it can be determined that the optimal lag order of the economic growth model is lag order 1.

(2) Stability testing of AR characteristic polynomial roots

Further conduct stability tests on the AR feature polynomial roots of the VAR model, and determine whether the model is stable by observing the eigenvalues of the VAR model. The eigenvalues are generally in the form of complex numbers, with the real part a as the horizontal axis and the imaginary part b as the vertical axis in the coordinate plane. The AR feature polynomial roots of this VAR model are obtained as shown in Figure 1. The results show that the reciprocal of all root modes in the model falls within the unit circle, with values less than 1. Therefore, it can be considered that this VAR model is relatively stable, and the obtained results are effective. Further research on impulse response and variance decomposition analysis can be conducted.

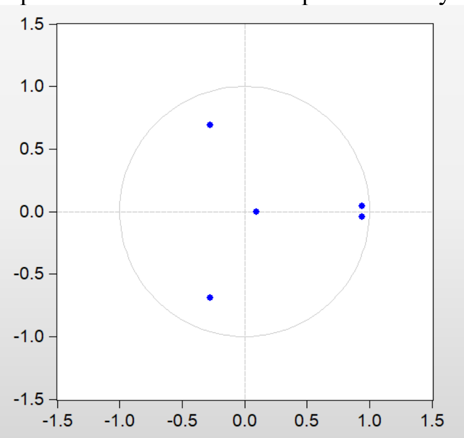

Fig. 1. Test of AR feature polynomial roots

(3) Model estimation

The corresponding model estimation results are as follows:

$$LNGDP=1.2214*LNGDP(-1)-1.7766*LNTEC(-1)-0.1281*LNEC(-1)+0.3877*LNNG(-1)-0.1762*LNCL(-1) + 13.6458 \tag{2}$$

$$R^2 = 0.9984，\overline{R^2} = 0.9969，F= 643.1586$$

According to the regression results, it can be seen that the overall goodness of fit of the VAR model estimation results of LNGDP and LNTEC, LNEC, LNNG, and LNCL reaches 99.69%, with most parameters having t-values greater than 2. The model estimation is relatively accurate, that is, the variables selected in this model can reasonably explain the factors affecting regional GDP.

(4) Granger causality tests

The cointegration test and VAR estimation indicate a long-term equilibrium relationship between energy consumption and regional economic development. However, the causal relationship behind this stable relationship needs further examination. Granger causality test was conducted on the causal relationship between LNGDP, LNTEC, LNEC, LNNG, and LNCL, and the results are shown in Table 5.

Table 5. The Granger causality test results of energy consumption on regional economic development

Null Hypothesis	F Statistics	P Value	Conclusion
LNTEC does not Granger Cause LNGDP	5.19422	0.0211	Reject the null hypothesis
LNGDP does not Granger Cause LNTEC	7.50422	0.0108	Reject the null hypothesis
LNEC does not Granger Cause LNGDP	3.67714	0.0314	Reject the null hypothesis
LNGDP does not Granger Cause LNEC	0.73677	0.4157	Accept the null hypothesis
LNNG does not Granger Cause LNGDP	5.88939	0.0414	Reject the null hypothesis
LNGDP does not Granger Cause LNNG	0.04581	0.8359	Accept the null hypothesis
LNCL does not Granger Cause LNGR	5.58854	0.0457	Reject the null hypothesis
LNGR does not Granger Cause LNCL	13.6724	0.0061	Reject the null hypothesis

From this, it can be seen that LNGDP has a bidirectional causal relationship with LNTEC and LNCL, while LNEC and LNNG are the unidirectional Granger reasons for LNGDP. This also means that there is a significant dependency relationship between regional GDP and total energy consumption, electricity consumption, natural gas, and coal, and any change in variables can cause changes in regional GDP.

(5)Pulse response function analysis

The impulse response function describes the impact of one endogenous change on other endogenous changes in the VAR model. In some aspects, it can directly reflect the dynamic relationship between energy consumption and regional economic development. The analysis of the pulse response results of LNGDP on LNTEC, LNEC, LNNG, and LNCL obtained is shown in Figure 2.

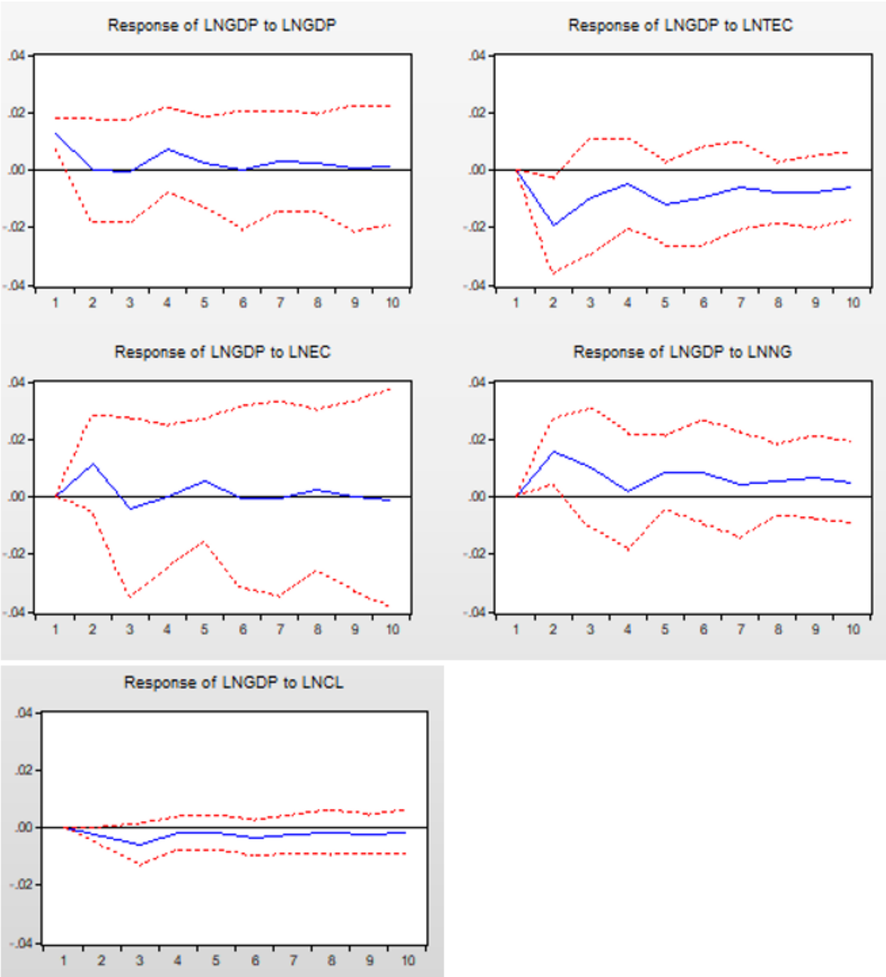

Fig. 2. Pulse response diagram of LNGDP to LNTEC, LNEC, LNNG, LNCL

As shown in Figure 2, Gross Domestic Product (LNGDP) has a positive effect on itself. The total energy consumption (LNTEC) has a negative impact on regional GDP. Both electricity consumption (LNEC) and natural gas (LNNG) have a short-term positive impact on regional GDP. Coal consumption (LNCL) has a negative impact on regional GDP. But the impact is not significant.

(6)variance decomposition

In order to further analyze the impact of different structural shocks on endogenous variables in the VAR model, variance decomposition was performed. The variance decomposition results of regional GDP are shown in Figure 3, where the horizontal axis represents the number of response periods and the vertical axis represents the variance contribution rate, expressed in percentage.

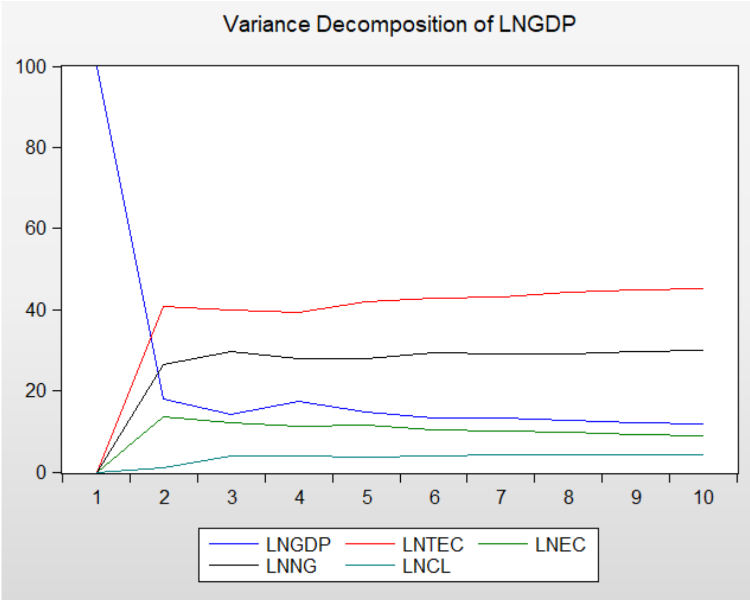

Fig. 3. Variance decomposition diagram

The variance decomposition diagram can be seen from Figure 3. The analysis of variance results show that the regional GDP has the greatest impact on itself, and this level of performance shows a decreasing trend year by year.

4.4 Empirical analysis results

This article establishes a VAR econometric model based on sample data related to energy consumption and economic growth from 2010 to 2021. The relationship between energy consumption and economic growth is analyzed using methods such as stationarity test, cointegration test, model estimation, impulse response, and variance decomposition. The results indicate that:

Firstly, from the perspective of model stationarity, all characteristic roots of the VAR model are less than 1, indicating that the entire tribe is within the unit circle. This indicates that the VAR model system is stable, meets the prerequisite for operation, can be used for subsequent analysis, and the subsequent analysis results are reasonable.

Secondly, from a causal perspective, the growth rate of regional gross domestic product and regional gross domestic product are mutually causal, while regional gross domestic product is mutually causal with total energy consumption and coal consumption. Natural gas consumption and electricity consumption are one-way causal relationships of regional gross domestic product. This also means that there is a significant impact between regional GDP, total energy consumption, natural gas consumption, electricity consumption, and coal consumption.

Thirdly, from the perspective of pulse response results and cycles, regional gross domestic product has a positive impact on its own in the initial stage, and the impact gradually weakens in the later stage; The total energy consumption has a negative effect on the rapid growth of regional GDP in the first two years, but this negative effect is not sustainable; Electricity consumption and natural gas have a short-term positive impact on regional GDP; The impact of coal consumption on regional GDP is not significant.

Fourthly, in terms of contribution, without considering the impact of LNGDP fluctuations, the total energy consumption has the greatest contribution to regional GDP, followed by natural gas consumption, electricity consumption, and coal consumption. Energy consumption has been increasing year by year with the development of the economy and the passage of time. Among them, the contribution of regional GDP to it has shown a downward trend, which may be related to factors such as optimizing the energy consumption structure and improving energy efficiency.

5 Conclusion

In summary, through charts and var model tests, we can conclude that energy consumption does have a significant impact on economic growth, and clean energy, such as electricity and natural gas, has a more significant promoting effect on economic growth. This indicates that the energy consumption type of the Guangdong Hong Kong Macao Greater Bay Area urban agglomeration is constantly shifting towards the development of clean energy and has achieved good results, with coal The economic model driven mainly by traditional energy consumption such as oil is shifting towards a healthier development mode. The energy structure reform driven by the 13th Five Year Plan has achieved significant results, and the energy utilization rate is constantly improving. The driving effect of energy consumption on economic growth is decreasing. Clean energy, mainly electricity and natural gas, is gradually playing a leading role in promoting economic growth, but natural gas is a non renewable energy source, The status of electricity consumption is bound to gradually rise, and the energy transformation of the Guangdong Hong Kong Macao Greater Bay Area urban agglomeration is gradually achieving initial results. In the future, we should continue to promote healthy and sustainable economic development.

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