Temporal Evolution and Decoupling Relationship between Carbon Emissions and Economic Growth in Liaoning Province of China

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Abstract. With the development of Northeast traditional industrial base, Liaoning is currently facing a practical contradiction between economic growth and the demand for low-carbon emission reduction. Accelerating the process of a low-carbon economy is effective to break the bottleneck of current economic development. In this paper, we take Liaoning Province as a study area, and carry out the following work by combining theoretical methods and empirical research. First, we estimated the carbon emissions from 1990 to 2021 by using the methods of calculating carbon emissions proposed by the IPCC. Second, we construct the production function model of regression analysis for exploring the correlation between carbon emissions and economic growth, the results show that there is a positive correlation among the variables. Last, the decoupling model can be used to obtain the specific decoupling states and changing trends from 1991 to 2021. The above calculated results can provide a reference to boost the low-carbon economy and achieve a long-term ideal decoupling state in Liaoning Province.

Keywords: Carbon emission, GDP growth, Regression analysis, Decoupling model, Low-Carbon Economy.

1 Introduction

With the continuous expansion of the world population and the rapid development of the economy, human consumption of resources and energy has shown a remarkable increase [1]. As one of the world's largest carbon emission, China attaches great importance to energy utilization efficiency and resource conservation measures while developing its economy. At the 75th session of the United Nations General Assembly, China stressed the importance of environmental protection and proposed a “Dual Carbon” target for global carbon emissions, namely, “carbon peak and carbon neutrality”. It can be seen that the balance between the environment and economy is the key to sustainable development in the future.

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Based on past research, the scholars mainly established production function models to analyze the correlation and causality between the two. At the beginning, foreign scholars proposed the concept of the environmental Kuznets curve and proved that the relationship between economic growth and environmental pollution in some highly developed countries is an inverted U-shape [2]. Following this international research trend, many domestic scholars have carried out extensive theoretical and applied studies. As a heavy industry base in China, Liaoning Province is an undeniable part. Fu et al. explored the correlation between economic growth and carbon emissions in Liaoning Province by building a regression model, and concluded that economic growth has a positive impact on total carbon emissions [3]. Li et al. calculated the carbon emissions and empirically explored the relationship between carbon emissions and economic growth by applying the decoupling theory in Liaoning Province [4]. Therefore, this paper investigates the dynamic relationship between carbon emissions and economic growth in more than 30 years, which is of great significance for improving regional industrial optimization and energy adjustment in Liaoning province.

2 Calculation of carbon emission in Liaoning Province

Based on the unit calorific value, carbon content, and average oxidation rate of fuel combustion of coal, oil, and natural gas, carbon emissions can be calculated after deducting carbon sequestration [5]. According to the investigations, coal, petroleum, and natural gas are selected as the three major energies considering their correlation with carbon emissions. In order to facilitate calculation, this paper refers to the Intergovernmental Panel on Climate Change (IPCC) method to calculate carbon emissions [6]. The calculation formula is as follows:

$$C_i=\sum_1^n E_i \times \alpha_i \tag{1}$$

where C represents the carbon emissions generated by energy consumption, E refers to the physical amount of energy consumption, α represents the carbon emission coefficient, and i is the specific energy type. The data of energy consumption are from the Liaoning Statistical Yearbook (1990-2022). With reference to the U.S. Energy Information Administration (EIA), the carbon emission coefficients of the three types of energy are shown in Table 1.

Table 1. Carbon emission coefficients of different energy types

Energy types	Coal	Petroleum	Natural gas
Carbon emission coefficient	0.702	0.478	0.389

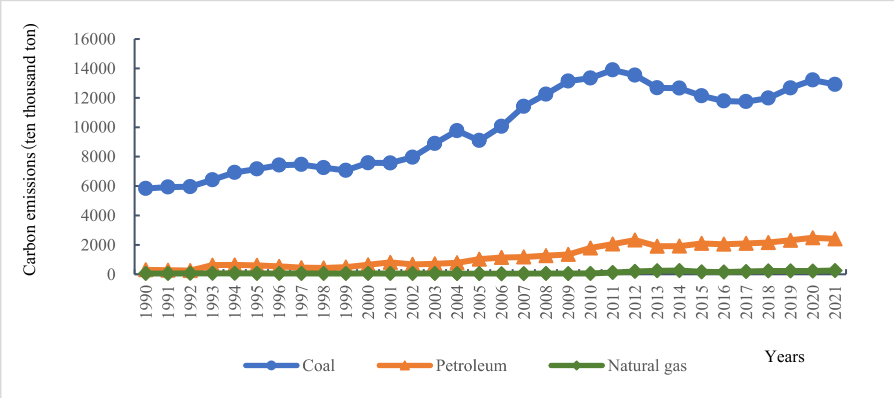

Fig. 1. The changing trends of carbon emissions by three energy sources

By using formula (1), the carbon emission of main energy consumption is calculated and analyzed from 1990 to 2021 in Liaoning Province. The changing trend of carbon emissions is shown in Figure 1. It can be seen that carbon emissions from coal are the largest, followed by petroleum products, and those from natural gas are the least.

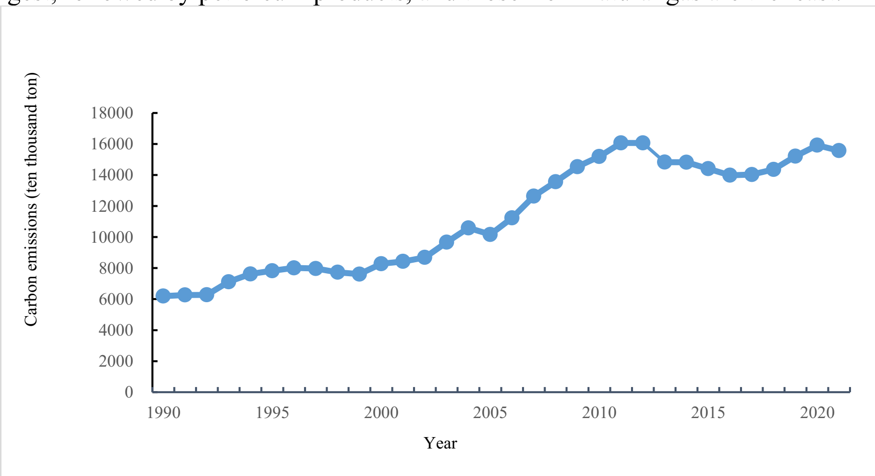

Fig. 2. The changing trend of total carbon emissions in Liaoning Province

According to the calculated carbon emissions generated by three energy consumption, the total carbon emissions of Liaoning Province can be summed up from 1990 to 2021, as shown in Figure 2. In Figure 2, the change curve of total carbon emissions in Liaoning Province in recent 32 years showed an overall upward trend. Figure 2, the change curve of total carbon emissions showed an overall upward trend during the past 32 years in Liaoning Province.

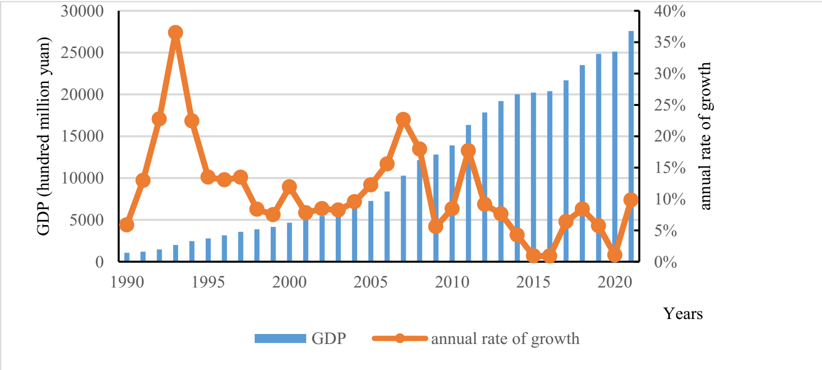

Fig. 3. The changing trend of GDP in Liaoning Province

In addition, the economic growth situation of Liaoning Province can be observed in the changing trend of GDP. The GDP data comes from Liaoning Statistical Yearbook (1990-2021), and the changing trend is shown in Figure 3. Figure 3 showed that the total GDP of Liaoning Province generally implied an increasing trend with each passing year, but the growth rate showed a significant downward trend between 1990 and 2021.

3 Correlation between carbon emission and economic growth in Liaoning Province

3.1 Regression model

In order to investigate the complex relationship among economic growth, energy consumption, the structure of energy consumption and carbon emissions, this paper explores the regression relationship between independent variables and dependent variables by constructing a regression model, selecting three variables as independent variables: the economic scale (*GDP*), energy consumption (*E*), and the percentage of coal accounting for total energy consumption (*P*). Then carbon emission (*C*) is selected as the dependent variable [3]. The following regression model is constructed based on the data of *P* from the Liaoning Statistical Yearbook (2022), combined with the total carbon emissions (*C*) in Fig. 2 and the regional *GDP* in Figure 3:

$$\ln C_t = \alpha_0 + \alpha_1 \ln GDP_t + \alpha_2 \ln E_t + \alpha_3 \ln P_t + \varepsilon_t \tag{2}$$

where α_0 is a constant, α_1, α_2 and α_3 represent the elastic coefficients of influencing factors respectively, ε_t is a random disturbance term, and t represents the time from 1990 to 2021.

3.2 Regression analysis

After substituting the sample data in the above regression model as Formula (2), this paper adopted the ridge regression algorithm to get the regression equation just as Formula (3), and the corresponding parameters are shown in Table 2. The *R*-square is 0.974, indicating excellent fitting performance. The *F*-value is 350.847 and the significance *P*-value based on the *F*-test is 0.000***, which presents a significance level of 1%. Therefore, it can be concluded that there is a regression relationship between independent variables and dependent variable from the results of ridge regression analysis. According to the regression coefficient, it can be seen that the *GDP* of Liaoning Province has a positive impact on *C*. The elasticity coefficient of *E* (0.438) is greater than that of *GDP* (0.137) and *P* (0.059), indicating that *E* has the greatest promoting effect on carbon emissions, the impact of *GDP* is less than *E*, and the impact of *P* is the least.

$$\ln C = 3.619 + 0.137\ln GDP + 0.438\ln E + 0.059\ln P + \varepsilon_t \quad (3)$$

Table 2. Results of Ridge regression analysis

K=0.098	Unstandardized coefficient		Standardized Coefficient	*t*	*P*	R^2	Adjusted R^2	*F*
	B	Standard error	Beta					
Constant	3.619	0.561	-	6.452	0.000***	0.974	0.971	350.847 (0.000***)
ln*GDP*	0.137	0.012	0.405	11.595	0.000***			
ln*E*	0.438	0.025	0.563	17.413	0.000***			
ln*P*	0.059	0.088	0.027	0.678	0.503			

Dependent variable: ln*C*

Note: ***, ** and * represent significance levels of 1%, 5% and 10% respectively.

4 Decoupling analysis between carbon emissions and economic growth in Liaoning Province

4.1 Decoupling model and decoupling index measurement

The concept of decoupling was first proposed in the 1960s, and was introduced in the field of resources and the environment by the Organization for Economic Co-operation and Development [7]. Then the theory is used to study the imbalance between material consumption and economic growth, and the discordance between economic development and environmental problems [8]. Later, the improved Tapio decoupling index is carried out through the decoupling elastic coefficient method. According to decoupling indicators, decoupling states include decoupling state, negative decoupling state, and connection state [9]. Furthermore, the decoupling relationship between economic growth and carbon emissions could be conducted and an in-depth analysis could be explored [10]. This paper selected the Tapio decoupling model, and employed GDP and carbon emissions as the main indicators to measure the decoupling elasticity index [11]. The calculation formula is as follows:

$$N = \frac{\%\Delta C_n}{\%\Delta G_n} = \frac{(C_n - C_{n-1})/C_n}{(G_n - G_{n-1})/G_n} \tag{4}$$

where N is the decoupling elasticity index of two variables C and GDP; n represents the year; $\%\Delta C_n$, $\%\Delta G_n$ represents the change rate of C and G respectively (no dimension, maybe positive or negative). According to $\%\Delta C_n$, $\%\Delta G_n$ and the calculated value N, the decoupling relationship between C and GDP is further subdivided into 8 types, and the decoupling state system is listed in Table 3.

Table 3. Tapio decoupling state system

Decoupling state	ΔC_n	ΔG_n	N (C, GDP)	Decoupling subtype (Abbreviate form)
Connection	>0	>0	[0.8, 1.2)	Expansion connection (EC)
	<0	<0	[0.8, 1.2)	Recessionary connection (RC)
Negative Decoupling	>0	>0	≥1.2	Expansion negative decoupling (END)
	>0	<0	<0	Strong negative decoupling (SND)
	<0	<0	[0, 0.8)	Weak negative decoupling (WND)
Decoupling	<0	>0	<0	Strong decoupling (SD)
	>0	>0	[0, 0.8)	Weak decoupling (WD)
	<0	<0	≥1.2	Recessionary decoupling (RD)

4.2 Decoupling state analysis in study area

Using the above-mentioned formula (4), the decoupling elasticity indexes of C and GDP in Liaoning Province from 1991 to 2021 can be calculated and the results are listed in Table 4. Then the decoupling subtypes can be obtained according to the values of N (shown in Table 4).

Table 4. Decoupling analysis results in Liaoning Province from 1991 to 2021

Years	ΔC_n	ΔG_n	$N(C, GDP)$	Decoupling subtype
1991	0.0116	0.129	0.090	WD
1992	0.0021	0.227	0.009	WD
1993	0.1332	0.365	0.365	WD
1994	0.0714	0.224	0.319	WD
1995	0.0268	0.135	0.199	WD
1996	0.0239	0.130	0.183	WD
1997	-0.0053	0.135	-0.039	SD
1998	-0.0304	0.084	-0.364	SD
1999	-0.0152	0.075	-0.203	SD

Years	ΔC_n	ΔG_n	$N(C, GDP)$	Decoupling subtype
2000	0.0880	0.119	0.738	WD
2001	0.0180	0.078	0.231	WD
2002	0.0305	0.084	0.361	WD
2003	0.1126	0.082	1.371	END
2004	0.0957	0.095	1.003	EC
2005	-0.0402	0.122	-0.329	SD
2006	0.1057	0.156	0.680	WD
2007	0.1246	0.227	0.550	WD
2008	0.0735	0.179	0.410	WD
2009	0.0711	0.056	1.274	END
2010	0.0456	0.084	0.541	WD
2011	0.0575	0.177	0.325	WD
2012	-0.0004	0.091	-0.004	SD
2013	-0.0769	0.076	-1.010	SD
2014	-0.0003	0.043	-0.007	SD
2015	-0.0281	0.009	-3.044	SD
2016	-0.0296	0.009	-3.280	SD
2017	0.0036	0.064	0.057	WD
2018	0.0235	0.084	0.280	WD
2019	0.0594	0.057	1.038	EC
2020	0.0463	0.010	4.428	END
2021	-0.0218	0.098	-0.222	SD

As can be seen from Table 4, the decoupling relationships of Liaoning Province are as follows: 16-year weak decoupling type, 10-year strong decoupling type, 3-year expansion negative decoupling type, and only 2-year expansion connection type. In the past 30 years, the strong decoupling and weak decoupling types accounted for more than 80% of the time. In 16 years with weak decoupling, carbon emissions continued to increase with economic growth, energy intensity was reduced and energy efficiency was improved with the development of the economy. It ensures that carbon emissions are effectively controlled along with economic growth, thereby gradually reducing the negative impact of the greenhouse effect. Liaoning Province also had a strong decoupling state in 10 years, which were relatively good states for economic development. At that time, there was a gradual reduction in environmental emissions in the course of economic growth, in line with sustainable development plans.

5 Conclusions

In this paper, Liaoning Province is the research object, and the relationship between carbon emissions and economic growth is calculated and systematically analyzed at the provincial level in the sample space from 1991 to 2021. The research conclusions are as follows. This research estimates the carbon emissions of Liaoning from three major energy consumption and adds them together by referring to the IPCC's carbon emission calculation method. The results show that total carbon emissions presented a trend of fluctuating growth from 1990 to 2021. The regression relationship between carbon emissions and GDP is found by using Ridge regression analysis. According to the results of the positive regression coefficient, there is a positive causal relationship between GDP and carbon emissions in Liaoning Province. Through an in-depth analysis of the decoupling state, it can be seen that most years show weak or strong decoupling, while a few years are in a state of negative decoupling or expansion connection. However, this paper also has limitations, as its time sample is only selected for 30 years. The conclusions obtained from the study also do not apply to other provinces in China. The future research direction is mainly reflected in the prediction of energy consumption and carbon emission in Liaoning Province under the stable economic growth.

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