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Carbon Emission from Modern Coal Chemical Industry and Its Economic Impact in the Rebuilding of Old Industrial Base in Northeast China

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ABSTRACT

In order to study the relationship between economic growth and carbon emissions in Northeast China, Tapio decoupling model can be introduced to help analyse the elastic relationship between energy saving and emission reduction and economic benefits in Northeast China. The results show that in recent years, especially in the past 10 years, the economy of Northeast China has not developed rapidly. However, the carbon emissions remain high, which means energy saving has been achieved, but the effect of emission reduction is not good, and the relationship between economic growth and carbon emissions is weak decoupling. Through the gradual improvement of the influencing factors and the establishment of a complete data model for analysis and comparison, it is found that among a series of influencing factors, large-scale enterprises and enterprises with deep opening-up often achieve the decoupling of economic growth and carbon emissions. The larger the scale of enterprises is, the more obvious the decoupling effect is, which is the most important factor.

INTRODUCTION

In recent years, with the rapid economic development, sustained population expansion, industrialization and urbanization, energy consumption has increased dramatically, and the ecological environment has deteriorated increasingly, especially the climate warming caused by greenhouse gas emissions has seriously threatened the survival and development of human beings. Low-carbon economy has attracted worldwide attention and became the preferred strategy to cope with climate change and achieve sustainable economic development. The old industrial base in Northeast China is a serious disaster area of carbon emission in China. It inevitably becomes the primary target of carbon emission reduction in the whole country, and industry is the main force of energy consumption. Therefore, it is necessary to analyse the influencing factors of the change of industrial carbon emission in the old industrial base in Northeast China and find out the measures to control or reduce the carbon emission. It is of great significance for energy saving and emission reduction and promoting the development of low-carbon economy in the old industrial base in Northeast China. A decoupling model used to analyse the decoupling relationship between economic growth and carbon emissions is built. The specific factors affecting the decoupling relationship between carbon emissions and economic growth through the spatial panel model are further analysed. The purpose is to provide an empirical reference for energy saving and emission reduction in the future of the old industrial base in Northeast China, and accordingly put forward policy recommendations to control carbon emissions, so as to promote the development of low-carbon economy in the old industrial base in Northeast China, and realize the revitalization and long-term sustainable development of the old industrial base in Northeast China.

State of the art: This study concludes that many countries in Asia have higher carbon dioxide emissions which increase with the increase of energy consumption. With the change of economic development stage, there are some differences between the increase of carbon dioxide emissions and economic growth. Global economic development is constantly reaching a new high record, while energy consumption is also increasing, especially fossil fuels. In particular, the use of fossil fuels remains high, which destroys the balance of carbon dioxide in the atmosphere. This cannot and shouldn't be achieved only by reducing energy consumption.

Currently, most of the energy and carbon emissions assessment studies are based on global or national scales. Most of the studies on China's carbon emissions by some scholars focus on the total amount of carbon emissions at the national level (Fan et al. 2015, Kekwaru et al. 2018, Akash et al. 2017, Marwan et al. 2018). Some studies selected Northeast China as the research object and conclude that the per capita carbon emissions and intensity of carbon emissions in Northeast China are higher than the national level. The main reason is the excessive dependence on fossil fuels in Northeast China, which leads to the continuous increase of carbon dioxide emissions (Miao et al. 2016, H'ng et al. 2018, Wafae et al.

2019, Intsar et al. 2019). Some scholars studied the impact of social and economic conditions on carbon emissions from the perspective of urbanization (Knittel et al. 2016, Waqas et al. 2018, Phirdaous et al. 2018, Maryam et al. 2018). Other scholars focus on natural carbon cycle processes such as forest, grassland, farmland, soil and so on.

MATERIALS AND METHODS

The relationship between carbon footprint and economic growth

***Carbon footprint structure analysis*:** Ecological footprint is used to characterize the impact of human production and consumption activities on the ecological environment, and its indicators are the area of ecologically productive land. The carbon footprint is mainly used to represent the greenhouse gas emissions caused by human production and consumption activities, and its indicators are direct and indirect carbon dioxide emissions equivalent (Long et al. 2017, Ghulam et al. 2018, Ismail et al. 2018, Edgar et al. 2018). Among them, indirect carbon dioxide emissions may be obtained not by direct measurement, but by other means. Relatively speaking, the concept of carbon footprint has a relatively short time to come into being, and its precise meaning is still changing (Younsi et al. 2015, Zhang et al. 2018, Imla et al. 2018, Akingboye et al. 2018, Ememu et al. 2018).

Considering the characteristics of large-scale equipment and facilities needed to form the capability of modern coal chemical products, the carbon generated by fixed assets investment in the third layer of carbon footprint inventory is analysed by constructing a Tapio decoupling model.

***Building decoupling model*:** Tapio model and OECD model are two common decoupling models. Among them, Tapio model has low demand for time base period selection and is not affected by the dimension of indicators. It can clearly reflect the decoupling state of different time and regions. Therefore, Tapio model is selected to study the decoupling relationship between carbon emissions and economic growth.

$$E = \frac{R\Delta CO_2}{R\Delta GDP} \qquad \ldots(1)$$

In formula 1, E is the decoupling elasticity index. $R\Delta GDP$ refers to the growth rate of GDP. $R\Delta CO_2$ is the growth rate of carbon emissions. Tapio divides the decoupling state into eight types, as shown in Table 1.

Energy consumption and industrial gross product are introduced into Tapio model as intermediate variables, so as to construct LYQ analysis framework, decompose the carbon emission effect of economic growth, calculate the decoupling state of decoupling variables, and further analyse the factors affecting decoupling elasticity. The decoupling elasticity of carbon emissions and economic growth is decomposed into three components which are energy conservation elasticity, emission reduction elasticity and value creation elasticity.

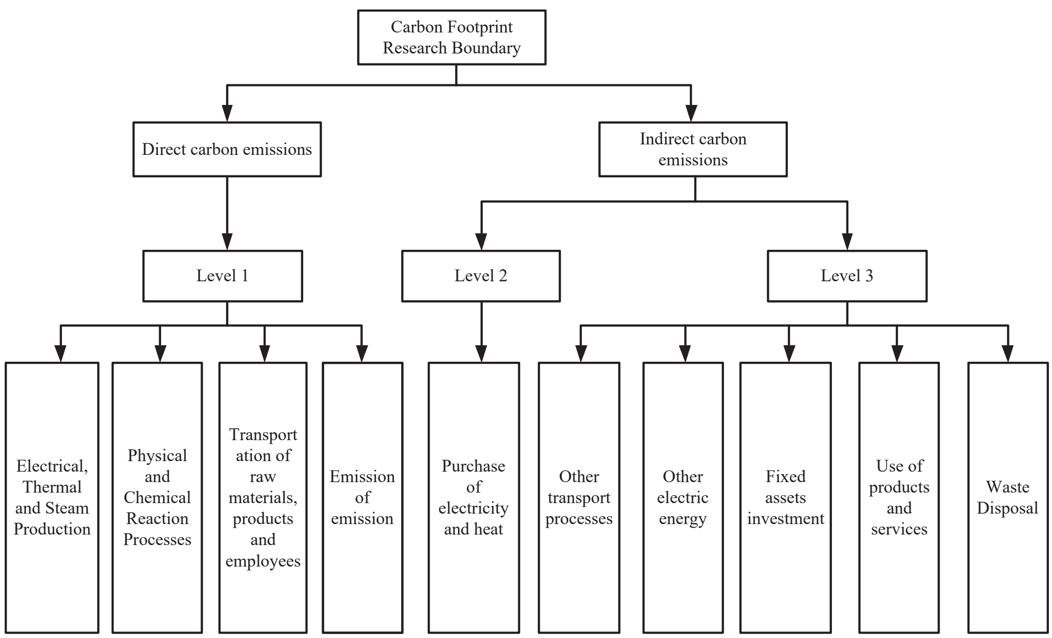

Fig. 1: Carbon footprint boundary map.

Among them, energy-saving elasticity refers to the percentage increase of energy consumption per 1% increase in industrial gross output value, expressed by the growth rate of energy consumption and industrial gross output value. Emission reduction elasticity refers to the percentage increase of carbon emissions per 1% increase in energy consumption, expressed by the ratio of carbon emission growth rate to the growth rate of energy consumption. Value creation elasticity refers to the increase of industrial gross output per 1% increase in GDP. Percentage is expressed by the ratio of the growth rate of industrial gross product to the growth rate of regional gross product.

The decoupling elasticity formula of carbon emissions is as follows:

$$E = \frac{R\Delta CO_2}{R\Delta GDP} = \frac{R\Delta EC}{R\Delta GIO} \times \frac{R\Delta CO_2}{R\Delta EC} \times \frac{R\Delta GIO}{R\Delta GDP} \qquad \ldots(2)$$

In formula 2, $R\Delta EC$ refers to the growth rate of final energy consumption. $R\Delta GIO$ represents the growth rate of gross industrial output. When energy-saving elasticity is decoupled, it shows that the growth rate of energy consumption is less than the growth rate of industrial gross output. In addition, it also indicates that energy-saving effect is obvious and emission reduction elasticity is the effect of measuring emission reduction behaviour. When emission reduction elasticity is decoupled, it shows that emission reduction effect is obvious. Value creation elasticity is a variable to measure the ability of scarce elements such as energy to create value in economic production. When it is in the state of growth connection and negative decoupling of expansion, it shows that the growth rate of industrial output is equal to or higher than that of economic growth, which means the ability of energy to create value in economic production is enhanced.

***Variable selection*:** Yang Qian's method is used to calculate carbon dioxide emissions. Carbon dioxide emissions are estimated from the consumption of seven major fossil energy sources. The calculation formula is as follows:

$$CO_2 = \sum_{i=1}^{7} EC_i \times NCV_i \times CEF_i \qquad \ldots(3)$$

Among them, EC is the final consumption of seven main fossil energy sources (coal, coke, gasoline, kerosene, diesel, fuel oil and natural gas) in the three north-eastern provinces; NCV is the average low calorific value (kJ/kg or kJ/m^3), which is derived from the China Energy Statistics Yearbook in 2013, CEF is the carbon emission factor (kg/TJ or m^3/TJ), and the data is derived from IPCC. Table 2 shows the reference values of CEF and NCV.

The energy consumption is selected as the final energy consumption of the three provinces in the Middle East and North China in the Energy Statistics Yearbook from 2005 to 2014, which are converted into standard coal. The data used are from the Energy Statistics Yearbook, China Urban Statistics Yearbook and the website of the National Bureau of Statistics from 2005 to 2014 (Table 3).

Building a spatial panel model:

Model selection: Spatial panel model includes spatial autoregression model and spatial error correction model. The spatial autoregression model is used to test the spatial spill over effect of the explained variables, and its spill over effect is judged by the lag term. The specific model is:

$$Y_{it} = rW_i + InY_{it} + bX_{it} + m_{it} + g_t + x_{it} \qquad \ldots(4)$$

Y_{it} is the decoupling elasticity index of carbon emissions and economic growth; W_i is the spatial weight matrix of geographical proximity; $W_i InY_{it} = \sum_{i \neq j} W_{ijt} InY_{it}$ is the spatial lag term of the decoupling elasticity index of carbon emissions; X_{it} is the explanatory variable; β is the coefficient to be estimated; μ_i and γ_t are the individual effect and time effect respectively; ξ_{it} is the random error.

Table 1: Classification of Tapio decoupling elasticity.

Decoupling state		CO	ΔGDP	Elastic level E
Negative decoupling	Strong negative decoupling	>0	<0	<0
	Weakly negative decoupling	<0	<0	0<t<0.8
	Expansion negative decoupling	>0	>0	t>1.2
Decoupling	Strong decoupling	<0	>0	<0
	Weak decoupling	>0	>0	0<t<0.8
	Recessive decoupling	<0	<0	t>1.2
Connect	Growth link	>0	>0	0<t<0.8
	Fading connection	<0	<0	0<t<0.8

Table 2: Average low calorific value and carbon emission coefficient of various energy sources.

Fuel type	Coal	Coke	Gasoline	Kerosene	Diesel oil	Fuel oil	Natural gas
NCV	20908	28435	43070	43070	42652	41816	38931
CEF	95333	107000	69300	71500	74100	77400	56100

Table 3: Elasticity and decoupling of carbon emission and economic growth in the old industrial base of northeast China from 2005 to 2014.

Particular year	Energy saving elasticity	State	Emission reduction elasticity	State	Value Creation Elasticity	State	Decoupling elasticity	State
2005	0.36621	Weak decoupling	2.03093	Expansion negative decoupling	1.28000	Expansion negative decoupling	0.95201	Growth link
2006	0.48303	Weak decoupling	1.05945	Growth link	1.15366	Growth link	0.59038	Weak decoupling
2007	0.43992	Weak decoupling	0.88419	Growth link	1.07065	Growth link	0.41646	Weak decoupling
2008	0.09082	Weak decoupling	2.04394	Expansion negative decoupling	1.29839	Expansion negative decoupling	0.24103	Weak decoupling
2009	0.62276	Weak decoupling	0.60732	Weak decoupling	0.92442	Growth link	0.34963	Weak decoupling
2010	0.32790	Weak decoupling	1.13028	Growth link	1.22775	Expansion negative decoupling	0.45503	Weak decoupling
2011	0.39158	Weak decoupling	1.11982	Growth link	1.06763	Growth link	0.46818	Weak decoupling
2012	0.45991	Weak decoupling	0.66797	Weak decoupling	0.75287	Weak decoupling	0.23127	Weak decoupling
2013	1.38384	Strong decoupling	0.67160	Negative weak decoupling	0.58191	Weak decoupling	-0.5408	Strong decoupling
2014	0.07783	Weak decoupling	2.21759	Expansion negative decoupling	0.58007	Weak decoupling	0.10012	Weak decoupling

Because the spatial spill over effect of decoupling elasticity of carbon emissions may be influenced by the interference term, which means the spatial correlation is caused by the lag term of the error term, and the spatial error model just solves this problem.

$$Y_{it} = bX_{it} + m_i + g_t + x_{it}$$
$$x_{it} = 1W_i x_t + u_{it} \quad \ldots(5)$$

λ is the coefficient of the spatial lag term of the explanatory variable, which indicates the impact of the decoupling elasticity of carbon emissions and economic growth in adjacent regions on the decoupling elasticity of the region.

RESULTS AND DISCUSSION

By comparing the above two models, it is found that the resolvable coefficient of the spatial error correction model (0.7045) is higher than that of the spatial autoregressive model (0.3027). Therefore, the spatial error correction model is chosen. At the same time, according to Husman test, the P value is 0.9927, so the stochastic utility model is chosen. The regression results are shown in Table 4.

Table 3 shows that the energy-saving decoupling in Northeast China in recent 10 years is mainly weak decoupling, and the decoupling value mainly concentrates between 0.3 and 0.5. The growth rate of energy consumption is less than the growth rate of industrial output, which indicates that the energy consumption per unit output of the old industrial base in Northeast China has been decreasing in recent 10 years, and the energy-saving effect is obvious. The emission reduction elasticity in recent 10 years has been negative decoupling by growth and expansion. The growth rate of

Table 4: Result of spatial error regression model.

Variable	Coefficient	t-stat	z-Prob
Intercept	-0.0027	-0.369242	0.711947
KJ	-0.000914	-0.098751	0.921336
SC	0.013640	1.536094	0.124515
GM	0.020294**	2.091872	0.03645
CE	0.01858***	3.20893	0.001332
KF	0.003596**	2.357296	0.018409
spat.aut.	0.514867***	4.690213	0.000003
teta	0.000003	0.000041	0.999968

carbon emissions is higher than that of energy consumption, and the effect of emission reduction is not obvious. Low-carbon technology and other factors play no significant role in the development of low-carbon economy. Value creation elasticity is mainly growth connection before 2012, and the elasticity value is close to 1, indicating that the growth rate of industrial output is equal to that of economic growth. However, from 2012 to 2014, the growth rate of industrial output is lower than that of the economy, which indicates that the overall development rate of industry has slowed down in the past two years. Overall, in the past 10 years, the old industrial base in Northeast China has been decoupled from economic growth, and the elasticity has a downward trend. In terms of decomposition factors, it is mainly caused by the improvement of energy utilization rate and remarkable energy-saving effect.

The regression results show that, firstly, in addition to the level of science and technology and the degree of market, the scale of industrial enterprises, the proportion of industrial enterprises and the degree of opening to the outside world have significant positive effects on energy saving and emission reduction. Among them, the scale of industrial enterprises has the greatest impact, which shows that large-scale enterprises have played an important role in energy saving and emission reduction effect in the process of transformation of the old industrial base in Northeast China. Secondly, the opening degree of the region also has a positive impact on the energy saving and emission reduction effect of the old industrial base, which shows that giving full play to the role of the market and making full use of the two market resources are conducive to better development of energy saving and emission reduction. At the same time, compared with the scale of enterprises, the effect of opening to the outside world on energy saving and emission reduction is still relatively low, which requires the region to continue to deepen market mechanism reform, play a decisive role in the market, coordinate the relationship between "two hands", improve market competition mechanism, let more competitive enterprises participate in the competition, actively "go out" and participate in the international market competition.

Finally, from the results of spatial spill over effect analysis, there is a strong spill over effect between the three provinces in the region, which means the promotion of energy saving and emission reduction effect in each province will play a positive role in promoting energy saving and emission reduction in other provinces. That is caused by the benign competition among industrial enterprises in the region.

CONCLUSIONS

By calculating the decoupling elasticity index of carbon emissions and economic growth in the three north-eastern provinces, it is found that carbon emissions and economic growth are mainly in a weak decoupling state. Among them, the significant decrease of energy-saving elasticity plays an important role, indicating that the improvement of energy utilization efficiency and the increase of energy intensity are the main factors that decouple carbon emissions from economic growth. However, the decoupling elasticity index of emission reduction is mainly in a growth-related state, which means the growth rate of carbon emissions is faster than that of energy consumption, indicating that the role of emission reduction technology in low-carbon development is still relatively weak. By building a spatial panel model, the specific factors that influence the weak decoupling relationship between carbon emissions and economic growth are analysed. Besides, it is found that the scale of industrial enterprises, the proportion of industrial industries and the degree of opening-up play a positive role in the decoupling index of carbon emissions and economic growth in the three north-eastern provinces. Among them, the scale of industrial enterprises plays the most significant role, which indicates that the adjustment of industrial structure and large-scale production have played a positive role in the energy saving and emission reduction effect in the process of the adjustment of the old industrial bases in Northeast China.

Based on the research conclusion, the following suggestions for energy saving and emission reduction of the old industrial base in Northeast China are put forward. Firstly, it is necessary to play the role of large-scale enterprises, make use of their abundant capital and high level of science and technology, further improve the efficiency of energy utilization, and focus on improving the technology level of emission reduction on the basis of energy saving. Secondly, it is also necessary to speed up industrial restructuring, eliminate backward capacity enterprises, and achieve high-quality production level of industrial enterprises. Finally, enterprises in the region are encouraged to actively go out and participate in market competition and make full use of the two markets and resources, so as to better realize production with high energy utilization and less environmental pollution in international competition.

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