# Research on Carbon Emission in Liaoning Province Based on Kaya Identity

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Abstract. For studying the role of energy structure change in carbon intensity in Liaoning Province, this paper uses the modified model of Kaya identity and the carbon intensity factor decomposition model of industrial and energy construction to calculate the contribution of energy structure to carbon intensity change elements and reveal the causes of carbon intensity factors in Liaoning Province. The carbon intensity factor is also affected by the total energy consumption, economic development, industrial structure, population and technological advancement. Therefore, the ridge regression model is established to further clarify the direct, indirect and total effects of the carbon intensity factor of energy construction, and the path analysis is made. According to the outcomes, the direct inhibitory role of energy structure in reducing carbon intensity is relatively small, which is mainly reflected in the indirect inhibitory effect of elements including economic development, industrial structure, technical advancement and population; The proportion of coal and primary power consumption is the main driving force for the decline of carbon intensity, while the proportion of oil and natural gas consumption and energy intensity inhibit it.

Keywords. Kaya identity, ridge regression model, path analysis

#### 1. Introduction

At the 75th UN General Assembly, the general secretary proposed that China's carbon dioxide emissions will peak in 2030 and realize carbon neutralization by 2060. "Carbon neutralization" means the end of an era dominated by fossil energy and the advent of an era of transition to non-fossil energy [1-4]. As a large industrial country, China insists on restricting carbon dioxide emissions under the trend of global warming. As a part of the global village, China will take practical actions to promote the global response to climate variation and make due contributions.

There are three main methods of carbon neutralization, that is, through energy conservation and emission decrease, energy substitution and industrial structure adjustment, the discharged carbon dioxide can be recovered to achieve positive and negative balance, and finally achieve "zero emission". Among them, industrial structure adjustment is the fundamental measure to promote energy conservation and emission reduction, including speeding up the removal of backward manufacturing capacity and improving the energy structure [5-8]. Therefore, in the aspect of energy

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consumption, we investigate the influence of energy structure and industrial structure on the variation of carbon emission intensity in Liaoning Province through the industry energy two-level decomposition method. The reasons for changing carbon emission intensity in Liaoning Province are deeply excavated and relevant models are established, which can effectively predict and control carbon emission and industrial development.

#### 2. Factor Decomposition Model

# 2.1. Analysis on the Contribution of Energy Structure to the Change of Carbon Emission Intensity

(1) Industry based carbon emission intensity decomposition model. Based on the basic principle of Kaya identity of greenhouse gas emissions proposed by Japanese experts [9-10], carbon emissions can be decomposed into the internal relationship of carbon emissions among industries, namely:

$$C = \sum_{i} \frac{C_{i}}{Y_{i}} \times \frac{Y_{i}}{Y} \times Y$$
(1)

Divide both sides of equation (1) by Y to obtain:

$$D = \frac{C}{Y} = \sum_{i} \frac{C_{i}}{Y_{i}} \times \frac{Y_{i}}{Y}$$
(2)

where  $\frac{C_i}{Y_i}$  represents the carbon emission of industry *i*, namely, the carbon intensity of industry *i*, and the industrial carbon intensity can be expressed by *ID*;  $\frac{Y_i}{Y}$  represents the ratio of the output value of the industry *i* in the total output value, namely, the industrial structure, which can be expressed by *S*; Equation (2) can be simplified as:

$$D = \sum_{i} ID_{i}S_{i} \tag{3}$$

(2) Industry based carbon emission energy decomposition model. According to the transformation of Kaya identity, the industrial carbon emission is mainly caused by energy consumption, and the industrial carbon intensity can be decomposed into:

$$ID_{i} = \frac{C_{i}}{Y_{i}} = \sum_{i} \frac{C_{ij}}{Y_{ij}} \times \frac{E_{ij}}{E_{i}} \times \frac{E_{i}}{Y_{i}} = 1, 2, 3$$
(4)

where  $\frac{C_{ij}}{Y_{ij}}$  represents the carbon emission brought by the energy *j* of the industry *i* consumption unit, and  $F_{ij}$  represents it;  $\frac{E_{ij}}{E_i}$  represents the carbon emission brought by the energy *j* of the industry *i*, represented by  $ES_{ij}$ ;  $\frac{E_i}{Y_i}$  represents the energy consumption per unit output value of the industry *i*, expressed by  $I_i$ ; Equation (4) can be simplified as:

$$ID_i = \sum_{ij} F_{ij} ES_{ij} I_i$$
<sup>(5)</sup>

To sum up, Figure 1 displays the decomposition process of carbon intensity in Liaoning Province:



Figure 1. Decomposition process of carbon intensity in Liaoning Province.

#### 2.2. Effect Analysis of Energy Structure on Carbon Intensity

#### 2.2.1 Model Construction and Data Processing

(1) Energy structure impact effect model. On basis of the above analysis, carbon emission intensity is mainly affected by energy consumption structure, total energy consumption, economic growth, industrial structure, technological progress, population, etc. Therefore, the construction model is as follows:

$$D = \delta + \sum_{i=1}^{6} \beta_i X_i \tag{6}$$

among them,  $X_i$  (i=1,2,3,4,5,6) respectively represents six factors: energy consumption structure, total energy consumption, economic development, industrial structure, technological progress and population.  $\beta_i$  represents the coefficients of their respective variables, and  $\delta$  is random error terms.

(2) Energy structure internal proportion effect model. It can be seen from equation (6) that assuming that the carbon emission parameter of various energy sources is constant, the carbon intensity mostly relies on the ratio of coal consumption, the ratio of oil consumption, the ratio of natural gas consumption, the ratio of primary power consumption and energy intensity. Therefore, the following model is established:

$$D = \lambda + \alpha_0 I + \sum_{j=1}^4 \alpha_j E S_j \tag{7}$$

where  $ES_j$  (j = 1, 2, 3, 4) represents the proportion of energy *j* consumption; *I* represents energy intensity;  $\alpha_0, \alpha_j$  are estimated parameters and  $\lambda$  is a random error term.

(3) Path analysis model influence effect. Path discussion is to further decompose the Pearson correlation parameter. Pearson correlation parameter stands for the total impact of every variable on the dependent variable, such as the direct impact of every variable on the dependent variable and the indirect impact of every variable on the dependent variable by other independent variables.

Then there are:

$$r_{iy} = p_{iy} + \sum_{j} r_{ij} p_{jy} (i, j = 1, 2, ..., 6, i \neq j)$$
(8)

## 2.2.2 Path Analysis of Influencing Effect

The dependent variables are normally distributed, which is in line with the premise of regression analysis. Using Python to test the normality of dependent variable y, the results in Table 1 can be obtained. Because the sample number n = 36 is a small sample, the normality test of dependent variable y is carried out based on Shapiro-Wilk method, while the statistics is 0.908 and the significance level is 0.006 > 0.005. Therefore, dependent variable y conforms to normal distribution.

	Table 1. Normality test results.								
		Kolmogorov-Smirnov							
	Statistical magnitude	Degrees of freedom	Significance level						
у	0.199	36	0.001						
	Shapiro-Wilk								
	Statistical magnitude	Degrees of freedom	Significance level						
у	0.908	36	0.006						

	<b>Table 2.</b> Correlation analysis among variables ( $N = 36$ ).								
	Y	X <sub>1</sub>	X <sub>2</sub>	<b>X</b> <sub>3</sub>	X <sub>4</sub>	X5	X <sub>6</sub>		
Y	1	0.428	-0.728	-0.628	-0.856	-0.894	-0.947		
$\mathbf{X}_1$	0.428	1	-0.103	0.111	-0.230	-0.246	-0.294		
$\mathbf{X}_2$	-0.728	-0.103	1	0.965	0.963	0.951	0.896		
<b>X</b> <sub>3</sub>	-0.628	0.111	0.965	1	0.898	0.890	0.831		
<b>X</b> <sub>4</sub>	-0.856	0.230	0.963	0.898	1	0.984	0.960		
<b>X</b> 5	-0.894	-0.246	0.951	0.890	0.984	1	0.986		

**Table 2**. Correlation analysis among variables (N = 36).

(1) The model fitted the effect of energy structure. The results in Table 2 can be obtained by simple correlation analysis of each variable using python. The Pearson correlation coefficients among independent variables  $X_2$ ,  $X_3$ ,  $X_4$ ,  $X_5$  and  $X_6$  are above 0.8, and the significant level (bilateral 0.05) is less than 0.8, indicating a strong correlation between the two.

Using Python software, ridge plots  $X_1(k)$ ,  $X_2(k)$ ,  $X_3(k)$ ,  $X_4(k)$ ,  $X_5(k)$ , and  $X_6(k)$  of  $X_1$ ,  $X_2$ ,  $X_3$ ,  $X_4$ ,  $X_5$ ,  $X_6$  and other variables can be obtained respectively. As shown in Figure 2, when k = 0.15, the ridge plots of various variables begin to flatten; As shown in Figure 3,  $X_4$ ,  $X_3$  and  $X_2$  begin to stabilize at 0.15. When k = 0.15, the standardized ridge regression equation is obtained as follows:

$$\hat{Y} = 0.1220X_1 + 0.1097\hat{X}_2 + 0.1422\hat{X}_3 - 0.1987\hat{X}_4 - 0.3181\hat{X}_5 - 0.5418\hat{X}_6$$
(9)

The determination coefficient of  $R^2 = 0.9226$  in the equation shows that the explanatory power of each variable to the dependent variable is strong;  $F = 57.6086 > F_{0.05}$  (6,29) = 2.43, the absolute values of t values of respective variables were 2.6566, 2.7504, 3.2057, 4.9442, 11.4088 and 11.4269, respectively, which were greater than

 $t_{0.05/2}(29) = 2.045$ , which passed the significance test; It is shown that the fitting effect of the equation is good.



Figure 2. Ridge trace diagram of respective variables. Figure 3. Change of determination coefficient.

(2) The fitting problem of the internal proportion effect model of energy structure. Using Python software, the ridge trace diagrams of  $ES_1$ ,  $ES_2$ ,  $ES_3$ ,  $ES_4$ , I and other variables  $ES_1(k)$ ,  $ES_2(k)$ ,  $ES_3(k)$ ,  $ES_4(k)$ , I(k) and the trend diagram of determination parameter after change can be obtained respectively. As shown in Figures 4 and 5, when k = 0.2, the ridge trace diagram of respective variables and the deceleration of determination coefficient begin to stabilize. When k = 0.2, the normalized ridge regression equation is

$$\hat{Y} = -0.0444E\hat{S}_1 + 0.0767E\hat{S}_2 + 0.0855E\hat{S}_3 - 0.1276E\hat{S}_4 + 0.7382\hat{I}$$
(10)

The determination parameter  $R^2$  of the equation is 0.9672, showing that the explanatory ability of every variable to the dependent variable is strong; At the level of significance 0.01,  $F = 176.7434 > F_{0.01}$  (5,30) = 3.70, and the absolute values of t of regression coefficients of respective variables are 2.9201, 3.4615, 3.2116, 4.9204 and 24.7766 respectively, which are greater than  $t_{0.01/2}$  (30) = 2.75, which are greater than the significance test; It can be seen that the fitting of the equation is ideal.



Figure 4. Ridge trace diagram of respective variables. Figure 5. Change of determination coefficient.

## 3. Conclusion

In order to find the relationship between the indicators affecting carbon emissions and the final carbon emissions, we proceeded from the actual situation of Liaoning Province, using the correction model of the Kaya identity, respectively established a decomposition model of carbon emissions based on the industrial structure and energy structure. The influence of energy structure and industrial structure on its carbon emission change law was analyzed, and a path analysis model of energy structure in Liaoning Province was established by using the comprehensive regression model. Finally, the influence degree of five driving factors on the total carbon emission is obtained.

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