Research of Carbon Emission Mechanism Coupling Model and Empirical Case---A Case Study of Beijing

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***Abstract*—At present, CO_2 emissions in China has been ranking second in the world, 75% of it coming from energy consumption. Effective control of CO_2 emission has become an urgent problem, and analysis on the impact of factors affecting CO_2 emissions will inevitably become the primary solution to this problem. Kaya model is constructed by the product of multiple influencing factors, which associates the CO_2 emission quantity with living standards, economic growth, population size and per capita GDP. This study is based on the coupling of Kaya model and LMDI model which is built to comb Beijing's evolution mechanism of carbon emissions from 2001 and 2010, and respectively builds CO_2 emission factor separation model and energy consumption factor separation and superposition model to comb the evolution mechanism of Beijing's CO_2 emission in different angle of life and production department from 2001 to 2010. The results show that the living standard, economic growth, population size factors have become the main factors affecting the CO_2 emissions, and the effect of energy intensity, industrial structure, energy on CO_2 emissions has reached a bottleneck. Meanwhile the results of this study can provide policy recommendations for other provinces and cities to reduce CO_2 emissions.**

***Index Terms*—CO_2 emission, Kaya model, logarithmic mean Division index model, The Coupling Model, energy consumption,**

I. INTRODUCTION

Nowadays reducing the CO_2 emission is the main measures to mitigate climate warming for CO_2 is the main factor of global climate warming [1]. To make sure the emission reduction being reasonable and effective, we must take the CO_2 emission mechanism as the major study direction. CO_2 emission mechanism studies the process, feature and trend of CO_2 emission as well as effects of various factors on CO_2 emission and on its change. emission mechanism study is in-deep study of CO_2 emission source and level, is key step of CO_2 emission reduction, and directly relate to the set of strategic policies and measures in CO_2 emission reduction, while at the same time is of important significance for the development of low-carbon economy[2].

II. MODEL CONSTRUCTION

Kaya model, which was put forward by Japan scholar Yoichi Kaya and used as one of the main models in CO_2 driving factors analysis, is one of the most widely used model[3]. Using the product of multiple factors to construct Kaya model, the influencing factors such as living standard, economic growth, population scale and Per Capita GDP can be associated with CO_2 emission.

LMDI (logarithmic mean division index) model satisfies the factors reversible, and is able to eliminate residual term, that overcomes the existence of residual term after decomposition and unsuitable decomposition in residual term and make the model more persuasive and widely used[5].

Given this, this article chose the coupling of Kaya model an LMDI model to combs the mechanism of CO_2 emission in Beijing.

A. *The factorization model of CO2 emission*

CO_2 emission factorization model:

$$C = \sum_i C_i = \sum_i ES_i F_i \tag{1}$$

$$\Delta C = \Delta C_E + \Delta C_S + \Delta C_F \tag{2}$$

where,

$$\begin{cases} \Delta C_E = \sum_i \alpha \ln(E_i^t / E_i^0) \\ \Delta C_S = \sum_i \alpha \ln(S_i^t / S_i^0) \\ \Delta C_F = \sum_i \alpha \ln(F_i^t / F_i^0) \end{cases} \tag{3}$$

$$S_i = E_i / E, F_i = C_i / D$$

$$\alpha = (C_i^t - C_i^0) / \ln(C_i^t / C_i^0)$$

ΔC_F —energy carbon emission intensity effect, E —total energy consumption, E_i —the consumption of energy i , S_i —proportion of energy i in total energy, ΔC_S —energy structural effect, D—GDP, i = 1 for coal, i =2 for oil, i =3 for gas, C_i —the carbon dioxide emissions of energy i consumption, t —current time period, 0—basic period, ΔC —the change of the carbon dioxide emissions between current time period and basic period, F_i —carbon emissions intensity, ΔC_E —energy consumption effect.

B. *Energy consumption decomposition model*

The total energy consumption E is divided into production energy consumption E_P and life energy consumption E_R :

$$E = E_P + E_R = \sum_j E_{P,j} + E_R \tag{4}$$

E_P - production energy consumption, E_R - life energy consumption, $E_{p,j}$ - energy consumption of the industrial sector j in production. This build production factors extension model and life extension model, and establish the corresponding relationship with N 、 Q 、 I 、 M 、 P .

Energy consumption decomposition extension model in production department:

$$E_P = \sum_j E_{P,j} = \sum_j NQI_j M_j \tag{5}$$

$$\Delta E_P = \Delta E_{N1} + \Delta E_Q + \Delta E_I + \Delta E_M \tag{6}$$

where,

$$Q = G / N \text{,} I_j = G_j / G \text{,} M_j = E_{P,j} / G_j \text{,}$$

$$\begin{cases} \Delta E_{N1} = \sum_j \beta In(N_i^t / N_i^0) \\ \Delta E_Q = \sum_j \beta In(Q_i^t / Q_i^0) \\ \Delta E_I = \sum_j \beta In(I_i^t / I_i^0) \\ \Delta E_M = \sum_j \beta In(M_i^t / M_i^0) \end{cases} \tag{7}$$

$$\beta = (E_{P,j}^t - E_{P,j}^0) / In(E_{P,j}^t / E_{P,j}^0)$$

where, Q - Per Capita GDP, using $j = 1, 2, 3$ respectively indicate for industrial sector j , G - GDP， G_j -production value of industrial sector j , $E_{p,j}$ -energy consumption of industrial sector j , ΔE_Q , ΔE_{N1} , ΔE_M , ΔE_I respectively indicate economic growth, population scale, energy consumption intensity and industrial structure.

Life factor decomposition extension model：

$$\begin{cases} E_R = NP \\ \Delta E_R = E_R^t - E_R^0 = \Delta E_{N2} + \Delta E_p \end{cases} \tag{8}$$

where,

$$P = E_R / N \tag{9}$$

$$\begin{cases} \Delta E_{N2} = \gamma \ln(N^t / N^0) \\ \Delta E_P = \gamma \ln(p^t / p^0) \end{cases} \tag{10}$$

$$\gamma = (E_R^t - E_R^0) / In(E_R^t / E_R^0)$$

P —per capita consumption, ΔE_R—energy consumption during the relative time， ΔE_{N2}—population size influence factor in life department, ΔE_P—living level influence factor.

C. *CO2 emission factor superposition model*

The superposition of production department and life department influence establishes the factor superposition model:

$$\Delta C = \Delta C_N + \Delta C_Q + \Delta C_I + \Delta C_M + \Delta C_P + \Delta C_S + \Delta C_F \tag{11}$$

where,

$$\Delta C_N = \left[(\Delta E_{N1} + \Delta E_{N2}) / \Delta E \right] / \Delta C_F$$

$$\Delta C_Q = (\Delta E_Q / \Delta E) \Delta C_E$$

$$\Delta C_I = (\Delta E_I / \Delta E)\Delta C_E, \Delta C_P = (\Delta E_P / \Delta E)\Delta C_E$$

In the equations, ΔC is for the current changes in CO_2 emissions relative to the base period, ΔC_N-population factor, ΔC_Q-economic growth factor, ΔC_I - industrial structure factor, ΔC_M -energy consumption intensity factor, ΔC_P -living level factor.

III. CARBON EMISSION MECHANISM ANALYSIS

A. *analysis on results of Beijing CO2 emissions model*

Beijing proposed an energy-supplying system, which is both multilevel complemented and accommodated and harmoniously developed. The system is electric-oriented, assisting with oil, gas, coal and renewable sources. During the ten years from 2001 to 2010, the proportion of coal fells to 73%, the proportion of oil is 9%, and the proportion of natural gas rise to 18%, but coal is still occupies a high proportion among the three. Coal has the highest emission coefficient and the largest proportion among three kinds of energy, followed by oil and gas. In order to reduce the emission of CO_2, we must upgrade the industrial structure[6~7].

From the Fig.1 we can see that in the first five years, the emission of CO_2 in Beijing is in a rapid increase trend. But then it is in a year-by-year decreasing trend from 2005 to 2010. The change of energy consumption and energy structure is positive, that increased the CO_2 emission. And with the upgrade of energy structure, contribution rate is also firstly in increasing trend and then in decreasing trend. ΔC_S is negative and restrains CO_2 emission, while the contribution rate is also negative, that means the energy structure has little effect on CO_2 emissions.

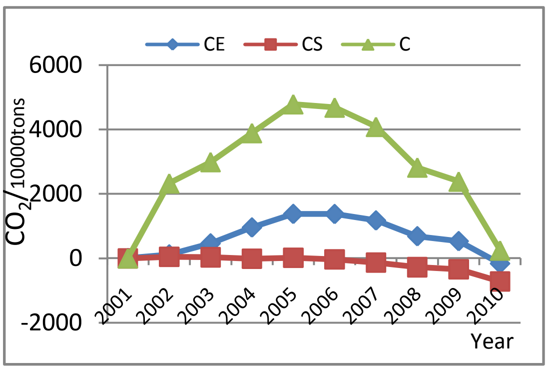

Fig.1. model decomposition results of CO_2 emissions in Beijing from 2001 to 2010

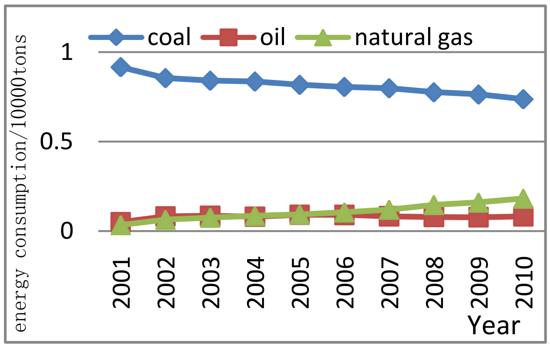

Fig.2. the change trend of Beijing's energy structure during 2001~2010

B. *Analysis on the result of energy consumption separation model*

According to Fig.3, the total consumption of energy is in increasing trend during the ten years from 2001 to 2010, and the living energy consumption factor has less effect in CO_2. E_P and E_R all increased, but the amplification of E_R is relatively small for its lower influence, while the growth rate of E_P is in fleetness increasing tendency for its larger influence on E, especially before 2007. The growth rate slowed down after 2007 under the influence of the policy on energy white paper which released by the state council in December 2007.

Among the changes of E form 2001 to 2010, the contribution of change E_P is about 82%~86%, and is 13%~17% for change E_R. This is related to the respectively proportion of E_P and E_R in Beijing. From 2001 to 2010, E_P keep sharing above 80% in E, though there is decreasing in every years, and the sharing rate of E_R is keeping slow increasing.

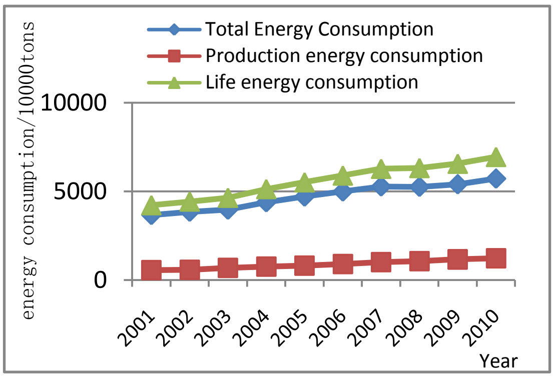

Fig.3. Results of Beijing energy consumption separation model form 2001 to 2010

TABLE.1. Results of Beijing energy consumption separation model form 2001 to 2010

Year	Consumption contribution of production	Consumption contribution of life
2001	0.867343	0.132657
2002	0.868355	0.131645
2003	0.853572	0.146428
2004	0.853736	0.146264
2005	0.852519	0.147481
2006	0.845966	0.154034
2007	0.840053	0.159947
2008	0.831009	0.168991
2009	0.822412	0.177588
2010	0.823169	0.176831

In Fig.4, we can find that among the numerous factors, the per capita energy consumption factor occupies a large proportion in the production department, and the proportion of other factors is relatively smaller. And M take a negative effect on CO_2 emission while other factors take a positive effect.

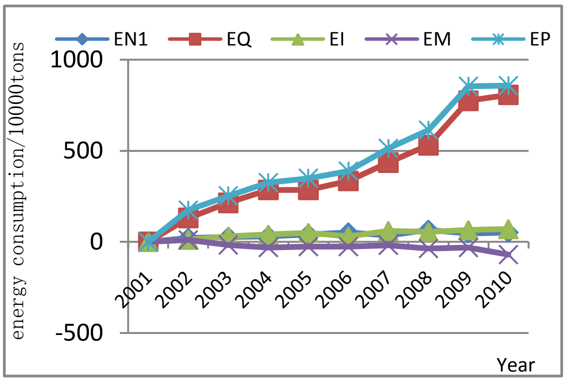

Fig.4. Accumulation of consumption separation model's results from 2001 to 2010

Fig.5 is the Beijing energy intensity change trend chart. From this chart we can see that the energy intensity of first industry and third industry all in decreasing tendency, but in a low rate, and decline in second industry is larger than the other two industries, so changes in industry structure make the E_P reduced. During the ten years from 2001 to2010 present in Fig.6, the output ratio of the first and second industry is in decreasing tendency, while the third industry's output ratio is in increasing tendency. Fig.5 presents the changing trend of Beijing's energy intensity in each industry from 2001 to 2010. We can see that the influence degree of industry structure and CDP on CO_2 emission is decreasing year by year, especially ine policies during this ten years. So, during the period of 2001~2010, the industry structure changes make E_P reduced. From the Fig.4, we can find that the population scale in living department continued increasing since 2001. Beijing is the political and economic center of our country and Beijing's pouring into employment makes the living energy consumption increasing, that turn out to be the increasing of CO_2 emission.

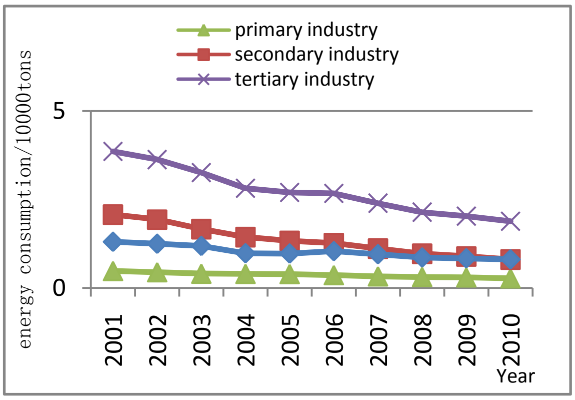

Fig.5. Changing trend of Beijing's energy intensity in each industry from 2001 to 2010

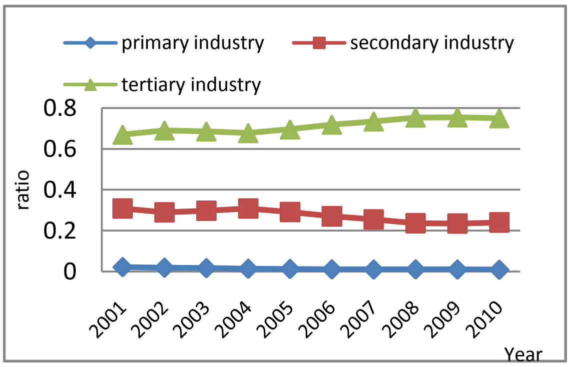

Fig.6. the proportion change tendency of industrial structure of Beijing form 2001 to 2010

Form Fig.7 we can see that the population scale factor in production department occupies a steady contribution to energy consumption which is in positive increasing trend. And the influence degree is gradually increased with the rapid growth of contribute rate after 2008. Changes in living level have made a great influence in energy consumption, and have led the total energy consumption to in a significant growth trend. Though the contribution of it in 2005 and 2010 has some ups-and-downs, it still occupies a relatively larger proportion on the whole.

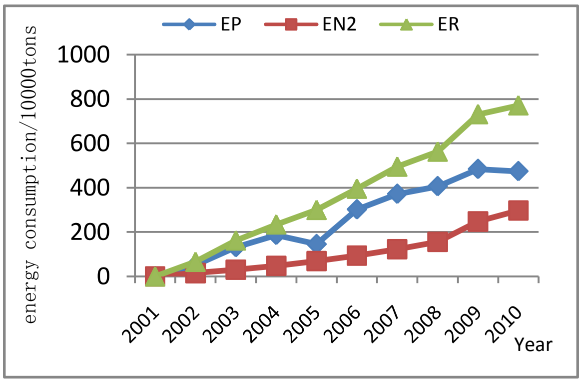

Fig.7. Accumulation of life energy consumption model decomposition from 2001~2010

Table 2 shows the contribution rate of each CO_2 emissions factor. What can be seen from the above conclusions is that from 2001 to 2010 there are two adjustable factors affect the CO_2 emission decline in Beijing. They are adjustment of economic growth and per capita energy consumption. Decline in energy intensity can also partly be the reason of the reduction in CO_2 emissions. The contribution rate of it gradually increased from 28.41% in 2001 to 88.20% in 2010. Due to the conflict between Q and CO_2 emission reduction, it is needed to take the per capita energy consumption, industry structure and other factors into consideration for ensuring economic growth while reducing CO_2 emissions. From 2001 to 2010, energy intensity in Beijing play an inhibitory effect on CO_2 emissions. In 2010 the contribution rate of it is about -7.7%. Contribution rate of Beijing's industrial structure is positive. The contribution rate gradually increased from 2.61% in 2001 to 7.76% in 2010, because the impact factor is relatively small, the adjustment of industrial structure has been basically saturated. From 2001 to 2010, what the energy intensity decline restrains in the CO_2 emissions has reached bottleneck, therefore we need to reduce CO_2 emissions from other factors adjustment. The contribution rate of population scale is maintained in the range of 7.74% to 38.08% in the production and living consumption. Population growth will inevitably lead to big margin increasing in energy consumption, so population control became one of the main factors for controlling CO_2 emissions. The optimization of S has reduced CO_2 emissions, but the contribution rate is low because of the obvious change on S. Although the contribution rate of S has ups and downs, it is in a decreasing tendency on the whole which restrains CO_2 emissions. This is mainly associated with Beijing's coal-dominated energy endowment and the further development of new energy and renewable energy policy initiatives. Optimization of S will help a lot in reducing CO_2 emission.

TABLE 2. The contribution of various factors on CO2 emissions %

Year	$\Delta C_Q / \Delta C$	$\Delta C_I / \Delta C$	$\Delta C_M / \Delta C$	$\Delta C_P / \Delta C$	$\Delta C_S / \Delta C$	$\Delta C_N / \Delta C$
2002	28.40905	2.60896	2.360913	37.83144	21.04507	7.744566
2003	37.80993	5.391104	-3.09846	44.64412	5.346109	9.907207
2004	41.33855	5.801082	-4.52014	47.07683	-1.05704	11.36071
2005	36.7675	6.477096	-3.44273	45.07501	0.854089	14.26904
2006	39.30852	3.55886	-3.13045	45.68385	-2.3597	16.93893
2007	42.08083	5.900807	-1.80878	49.65998	-11.2157	15.38289
2008	58.40464	6.060367	-4.06211	67.59418	-52.4072	24.41013
2009	82.92724	7.00418	-3.28576	91.54925	-109.619	31.42432
2010	88.20065	7.7596	-7.6654	93.86104	-77.97604	38.08366

IV. IN CONCLUSION

1) It can be obtained by the above conclusions after analyzing each CO_2 emission affected factors, that the contribution rate of energy intensity, which is an important factor, is in decreasing tendency and restrains the CO_2 emission. However, the contribution rate of economic growth presents an upward trend in every year

and the effect of it grows positively. This is affected by present policy of Beijing, it indicate the impact of Beijing's industry structure upgrade on CO_2 emissions has reached bottleneck. What led to the increase of life energy consumption is the increase in population scale and the improvement of living standards. During the decade from 2001 to 2010, contribution rate of living standard has increased from 37.83% to 93.86%, and the contribution rate of population scale in a decade rose from 7.74% to 38.08%. On the whole, main influence factors on CO_2 emissions in Beijing are ranked as living standards, economic growth and population scale at present. What the energy intensity and industry structure impact on CO_2 emissions has reached a saturation state. Its means Beijing has made great efforts in industry structure upgrading and reached the effect of energy saving and emission reduction. Thus advisory policy recommendations can be formed to be used for other provinces' and cities' industry structure upgrade.

2) Controlling the per capita consumption and the population size has become the current suggested measures of control CO_2 emissions in Beijing in order to guarantee of economic growth at the same time. In the long term, it's awful necessary to take developing new energy and renewable energy instead of coal consumption as a strategic policy to reduce emissions.

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