# Prediction of Inter-Provincial Carbon Dioxide Emissions in China:

## Based on Logistic Model

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***Abstract*—Under the assumption that carbon emissions are proportional to energy consumption, we collect some data on energy consumption and cement production to calculate the gross carbon emissions of 30 provincial administrative regions in China from 2002 to 2011. A logistic model is built to estimate the carbon emissions. Based on this, the carbon emissions of 30 provincial administrative regions in China from 2012 to 2020 are estimated, and the carbon intensity that can be reduced is also calculated. The conclusion is that China may achieve the goal to cut the $CO_2$ emissions per unit of GDP by 40~45% by 2020 off 2005 level when the economic growth is over 8%. At the end, we put forward some comprehensive suggestions on mitigation and prospected the outlook of carbon emissions.**

***Keywords-low-carbon economy; inter-provincial; carbon emissions; adjustment of industrial structure***

### I. Introduction

As early as 1968, American economist J. H. Dales put forward the concept of emissions trading, to make the activities of the enterprises discharging pollutants from using fossil fuel a kind of right, and guarantee it in the form of license. This idea is to adapt to society where the commodity economy is highly developed, and the purpose of which is to better balance the relationship among the environment, society and economy, letting the enterprises undertake the due obligations when they make external cost.

In the context of global warming, the Kyoto Protocol was proposed and enforced so that the reduction of carbon emissions became a common problem faced by every country. For our country, developing a low carbon economy is both the requirement in the global development trend and the inevitable result of the increase in domestic economic activity. However, to achieve the goal of low-carbon, there is a necessity to study the relationship between current rate of economic growth and carbon emissions in China.

A large body of literature reveals the different influence that various factors make on the changes in carbon dioxide emissions. Parikh J K and Panda M K (1997) [1] used an input-output model to estimate the $CO_2$ emissions both in urban and rural areas of India during 1990 to 2010, which indicates the positive correlation between income and $CO_2$ emissions. Munksgaard (2001) [2] also used an input-output model, from the perspective of income level, to estimate the $CO_2$ emissions in Denmark, the results of which show that the growth of the energy consumption causes the increase of $CO_2$ emissions. Schmalensee R (1998) [3] found an "inverse U" relation with a within-sample peak between carbon dioxide emissions (or energy use) per capita and per-capita income.

At present, there are quite a lot of studies on carbon emissions generated from the energy consumption, and most of the scholars choose to use the following two estimating methods recommended by IPCC, one is based on the classification of fuel, and the other is based on the classification of technologies. In addition, the domestic scholars also use other methods to estimate China's carbon emissions, the most representative ones are as follows. Wenying Chen and Pengfei Gao (2004)[4] built China's MARKAL-MACRO model, an integrated energy environment and economy dynamic non-linear programming model and then predict the energy consumption as well as carbon emissions in China, and describes the possible effect of carbon emissions on China's energy system; Xuena Wang (2006) [5] built a model based on the concept of System Dynamic, and analyses the carbon dioxide emissions for energy consumption from the perspective of both social energy and transportation; Sen Bao and Lixin Tian (2010) [6] built a two-component energy structure model, the correlation coefficient of energy production and consumption model could be estimated by statistical test estimation methods; Zaipu Tao (2011) [7] applied the method combined with factorization and system dynamics to get China's $CO_2$ emissions per head in baseline scenario, mitigation scenario and Limited scenario respectively.

To make the calculated data stay close to reality as far as possible, this paper uses the default method recommended by IPCC National greenhouse gas emissions listing guidelines. Firstly, we aggregate the emissions of various kinds of fuel, and then add up the $CO_2$ discharged in cement industry, and finally calculate the total carbon dioxide emissions of each province.

### II. Estimation Method of Carbon Dioxide Emissions

To determine the carbon dioxide emissions in each province much more comprehensively and accurately, this paper calculates the total emissions of carbon dioxide including that discharged from burning of fossil fuels.

Here is the equation of carbon dioxide emissions discharged from fossil fuels in each province:

$$CO_2 = \sum_{i=1}^{n} E_i \times NCV_i \times CEF_i \times COF_i \times (44/12) \quad (1)$$

Where i=1,2,3,…,n, which represents coal, coke, crude oil and the other fuel energy respectively, E is the consumption of each fuel, NCV is the average low calorific value offered by Appendix 4 of China Energy Statistical Yearbook in 2007, CEF is the coefficient of carbon emissions(calorific value unit carbon content) offered by IPCC(2006), since the coefficient of carbon emissions of coal is not available, and there is no obvious change in coal production and the proportion of each kind of fuel. The fuel consumption is consisting primarily of bituminous coal, which accounts for about 70~80%; anthracite accounts for about 20%. Hence, the coefficient of carbon emissions is calculated in terms of the weighted average of bituminous coal and anthracitic coal in terms of IPCC (2006). COF is the carbon oxidation factor.

In the last two decades, China's cement production has been in the first place throughout the world. In addition, in recent years, the cement production accounts for more than a half of that of the whole world, while its $CO_2$ emissions also constitute a reasonable amount of the total emissions in China. The carbon emissions in cement industry is mainly consist two parts: one is the consumption of burning coal during the cement clinker procedure, which accounts for the 98% of that of the whole cement producing procedure; the other is the power consumption. The $CO_2$ emissions from fuel burning account for more than 30% of the whole cement producing procedure. One of the cement raw materials is carbonate mineral (which is mainly limestone), the $CO_2$ emissions of which account for 60% of the total emissions [13].

For the $CO_2$ emissions are included in the total cement production, to avoid the repetitive computation so that ensure the accuracy e of calculation, this paper only considers the $CO_2$ emissions decomposed from carbonate minerals in cement raw materials. In terms of the carbon emissions estimation model for the cement industry offered by IPCC (2007), the estimation method of carbon emissions for cement is as follows:

$$CO_2 = R_{ik} \times C \times C_{ckd} \quad (2)$$

Where $CO_2$ is the carbon emissions of cement industry in each province; $R_{ik}$ is the production of cement clinker in each province; $V$ is the discharge coefficient of cement clinker, which is 0.510 by calculation; $c_{ckd}$ is the discharge correction factor of cement kiln dust, taking 2% part of cement clinker. So the equation of $CO_2$ emissions can be written as: $CO_2 = R_{ik} \times V \times C_{ckd} = R_{ik} \times 0.510 \times 1.02 = R_{ik} \times 0.520$. By convention, takes 75% part of the total cement production, and the data of the total cement production is drawn from China cement yearbook.

## III. Prediction of $CO_2$ Emissions under Logistic Model

### A. *Design of Logistic Model*

The logistic curve was suggested by a Dutch mathematician, P. E. Verhulst in 1838 for the prediction and control of population growth. Logistic regressions are used for predicting by analyzing the relationship between discrete variables and a group of explanatory variables. Using that method, we can predict future emissions according to existing data. Based on this, this paper builds a differential equation under a logistic model:

$$\frac{dx}{dt} = rx(1 - \frac{x}{k}) \quad (3)$$

In the previous equation, there's a initial condition that $x_0 = x|t = 0$; $x$ is the emissions of carbon dioxide; k is the scope of carbon emissions; $r$ is the growth of emissions ($r > 0$); $t$ is the year.

$$x = \frac{k}{1 + e^{a - rt}} \quad (4)$$

To avoid the errors when using three-point method and four-point method to select segment point, this paper use bathmometry to make parameter estimation, and then a critical point of (3) is gotten as $x = \frac{k}{2}$, so the estimation equation of $k$ is $k_i = 2x_i$. $(x_i, k_i)$ is the maximum-slope point on the curve, so $x_i$ is the value of $x$ when $\frac{\Delta x}{\Delta k}$ reaches its maximal value.

Set $Y = a - rt$, and make variable $Y = \ln[(k - x_t)/x_t]$, according to the determined scope of $k$, pick point in the scope one by one, and substitute them in $Y = \ln[(k - x_t)/x_t]$ respectively to calculate $Y_t$, then use the least square method to make $Y_t$ linear fitted, determining $a$ and $r$, so that the sequence prediction $\hat{Y}_t$ is got.

For $R^2 = 1 - \frac{\sum e_t^2}{\sum (Y_t - \hat{Y}_t)^2}$, $e_t = Y_t - \hat{Y}_t$ and $\hat{Y}_t = \sum Y_t / n$, the optimal $k$ as well as corresponding variable $a$, $r$ could be determined by $\max_k R^2$.

As the initial year is 2002, it could be denoted as t(2002)=1, t(2003)=2,…, t(2011)=10.

We determine the value of $k$ with $x_i$ given, and select points next to that value, then make the regression analyzation with different points respectively, after that substitute r and a under $k$ with the maximum $R^2$ into original equation to solve.

In terms of this principle, the carbon dioxide emissions of 30 provincial administrative regions could be predicted.

Next, we make a comparison between the carbon dioxide emissions predicted under the logistic growth model and the real carbon dioxide emissions in 30 provincial administrative regions from 2002 to 2011. According to the results shown in table 1, the average error rate is calculated to be 4.07%, which is a number with rather high accuracy, therefore the carbon dioxide emissions could be fitted with rather high fitting degree. Similarly, we could get the carbon dioxide emissions from 2012 to 2020, and find the carbon dioxide emissions show a trend of increased year by year, the average growth of which is around 3.8%.

TABLE I. RATE OF DEVIATION BETWEEN ACTUAL VALUES AND PREDICTED VALUES IN 30 PROVINCIAL ADMINISTRATIVE REGIONS, 2002~2011 (UNIT:%)

| **Province** | **BJ**[a] | **TJ** | **HE** | **SX** | **NM** |
|---|---|---|---|---|---|
| Error Rate | 1.81 | 3.26 | 4.54 | 3.25 | 4.26 |
| **Province** | **LN** | **JL** | **HLJ** | **SH** | **JS** |
| Error Rate | 3.76 | 3.83 | 2.22 | 1.06 | 3.49 |
| **Province** | **ZJ** | **AH** | **FJ** | **JX** | **SD** |
| Error Rate | 3.49 | 2.45 | 4.2 | 4.42 | 3.05 |
| **Province** | **HA** | **HB** | **HN** | **GD** | **GX** |
| Error Rate | 3.52 | 3.01 | 4.02 | 2.19 | 2.61 |
| **Province** | **HI** | **CQ** | **SC** | **GZ** | **YN** |
| Error Rate | 3.89 | 3.96 | 3.63 | 5.53 | 3.53 |
| **Province** | **SN** | **GS** | **QH** | **NX** | **XJ** |
| Error Rate | 2.08 | 3.59 | 5.19 | 7.4 | 5.52 |

a. BJ-Beijing; TJ-Tianjin; HE-Hebei; SX-Shanxi; NM-Neimenggu; LN-Liaoning; JL-Jilin; HLJ-Heilongjiang; SH-Shanghai; JS-Jiangsu; ZJ-Zhejiang; AH-Anhui; FJ-Fujian; JX-Jiangxi; SD-Shandong; HA-Henan; HB-Hubei; HN-Hunan; GD-Guangdong; GX-Guangxi; HI-Hainan; CQ-Chongqing; SC-Sichuan; GZ-Guizhou; YN-Yunnan; SN-Shaanxi; GS-Gansu; QH-Qinghai; NX-Ningxia; XJ-Xinjiang.

### B. *Economic Growth and Carbon Intensity*

December 25, 2009, the Chinese Government made a commitment to cut the $CO_2$ emissions per unit of GDP by 40~45% by 2020 off 2005 level.

Zhongli Ding, an academician of Chinese Academy of Science, once put forward two points to better understand this commitment：Firstly, the emissions refer in particular to the emissions for using fossil fuel and producing cement, the emissions for land utilization are not included, nor the negative emissions for ecological construction(activities of carbon sequestration); Secondly, the measure of GDP should be the constant price in2005, instead of nominal GDP(adjusted for inflation) [8].

According to the data from 2010 to 2020 estimated by Yifu Lin, Sanming Xie, Xianchun Xu [9]~[13], this paper makes a prediction under the growth of six to ten percent, combined with $CO_2$ emissions predicted from 2012 to 2020, to study the implementation under different emission intensities of $CO_2$. The specific calculation process is as follows. First, according to GDP and the annual rate of growth in 2005, we could work out the constant price in 2011. Assume that since the year 2011, the average growth of GDP is 6%, 7%, 8%, 9%, 10% respectively, we could reach a conclusion that the constant GDP in 2020 equals that in 2005; then combined with $CO_2$ emissions predicted from 2012 to 2020, the carbon-dioxide intensity could be calculated; compared with which we could get the droop rate of emission reduction intensity (see table 2).

It could be found by the calculation of carbon intensity: theoretically, the carbon intensity under the economic growth of 7% would reduce to around 39.30% by 2020, and more than 40% when the growth is 8%, 9%, 10% respectively, so that the purpose committed could be achieved. But we should notice that the economic growth is the steady growth with no inflation, and it may rise with the increase of energy intensity, thus the real carbon intensity might be lower than estimated.

TABLE II. CARBON INTENSITY THAT COULD BE REDUCED, 2012~2020 (UNIT:%)

| **GDP Growth Rate** | **Carbon Intensity Could be Reduced by** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | ***2012*** | ***2013*** | ***2014*** | ***2015*** | ***2016*** | ***2017*** | ***2018*** | ***2019*** | ***2020*** |
| 6 | 21.8 | 22.1 | 22.8 | 24.0 | 25.5 | 27.3 | 29.3 | 31.5 | 33.9 |
| 7 | 22.6 | 23.6 | 25.0 | 26.8 | 30.6 | 32.1 | 33.9 | 36.5 | 39.3 |
| 8 | 23.3 | 24.9 | 27.0 | 29.4 | 32.1 | 35.0 | 38.0 | 41.0 | 44.1 |
| 9 | 24.0 | 26.3 | 29.0 | 32.0 | 35.2 | 38.5 | 41.8 | 45.2 | 48.6 |
| 10 | 24.7 | 27.6 | 30.9 | 34.4 | 38.1 | 41.8 | 45.4 | 49.1 | 52.6 |

## IV. CONCLUSIONS AND RECOMMENDATIONS

This paper builds a logistic growth model of carbon dioxide emissions to get the predictions of 30 provinces and autonomous regions from 2012 to 2020. By contrasting the predicted and actual emissions from 2002 to 2011 we can work out the average error as 3.63%, so that the results should be trusted. Based on this, we simulate the different implementation of $CO_2$ emissions intensity in China under 6~10% economic growth rate. Finally, by feasibility analysis on China's stated goal by 2020, it is found that we may achieve the goal to cut the $CO_2$ emissions per unit of GDP by 40~45% by year 2020 off the year 2005 level when the economic growth rate is over 8%.

But at the same time, we should fully recognize that, though under 8% economic growth rate nowadays, it's not quite easy to achieve the goal to cut the $CO_2$ emissions per unit of GDP by 40~45% by year 2020 off the year 2005 level. China's carbon dioxide emissions are still increasing, what's more, the driving forces of the growth of carbon emissions are all long-term factors. Firstly, China is in the stage of accelerated development of industrialization currently, while the heavy industry accounts for about 70% of the whole industry, and this stage would last at least two or three decades. Secondly, fastpaced urbanization means a huge demand for urban infrastructure and residential investment, which would definitely exert an influence on China’s total energy demand and result in rapidly increase in demand for energy; while the increase in demand for public service and transformation of the life-style, would create more energy consumption. Thirdly, import and export net values of embodied energy in international trade show an increasing trend, which are 240 million tons of coal by 2001 and 630 million tons of coal by 2006. Fourthly, consumption structure of energy relying mainly on coal (the proportion of coal in China's energy consumption is nearly 70% at present) could not be changed in quite a long time. In addition, the economy starts to recover on a global scale, and the Chinese economy continues to grow, under such circumstances, we should be alert for a rebound in energy demand and carbon emissions as well.

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