Far Eastern Studies *Vol. 10* *March 2011*
Center for Far Eastern Studies, University of Toyama

Evaluation System of Low-carbonization of Industrial Structure in China

Maozhang Hou*

Abstract

Low-carbonization has become a vital goal of the economic development of many countries. As the by-product of economic development, carbon emission is highly correlated to industrial structure, which deeply influences the consumption structure, environment protection, and energy structure. Viewed from the history of developed countries, the fundamental way to develop a low-carbon economy is low-carbonization of industrial structure. This paper conducts a system with five different dimensions that includes economic, industrial structure, environment, energy, and social indicators to evaluate the low-carbonization of industrial structure. Furthermore, the paper does an empirical analysis on the industrial structure's low-carbonization of China and five of its provinces.

Keywords: *Low-carbonization, carbon emission, industrial structure, economic development*

---

* Vice professor, School of Economics, Economics Research Center for Agriculture and Forestry, Central South University of Forestry and Technology, Changsha 410004, China. E-mail: ruiruihou@163.com
This work was supported by the Soft Science Plan of Hunan Province (Key Item, 2010ZK2030), Scientific Research Project of Hunan Provincial Education Department (Key Item, 10A133) and Social Science Fund Project of Hunan Province (2010YBB349). I greatly appreciate the advice given by the experts of the 2010 International Conference of the Asia-Pacific Low Carbon Economy & the 9th Northeast Asia Academic Network.

Economic development and carbon emission have become serious global topics, especially the past decade. Many developing countries have addressed carbon emissions in the new era of low carbon. But because of their low level of economic development, developing countries have been striving for their own carbon emission rights from the UNFCCC to the conference in Copenhagen (2009). José Miguez, Brazil's top climate negotiator, claimed that Brazil wanted historic emissions of rich and poor nations rather than "carbon intensity" proposals linked to GDP to be the basis for new greenhouse-gas pollution targets[1]. As the biggest developing country in the world, China also faces the challenge of balancing its economic development goals and international commitments to reduce carbon emissions.

1. Low-carbon Economy and Low-carbonization of Industrial Structure

1.1 Low-carbon Economy

Ann P. Kinzig and Daniel M. Kammen (1998) introduced the concept of a low-carbon economy and developed a framework for analyzing carbon dioxide emissions trajectories from energy and industrial sectors. They also analyzed and presented a proposal on carbon reduction and energy innovation. A low-carbon economy is usually defined as a new economic, technological, and social system of production and consumption that conserves energy and reduces GHG emissions compared with the traditional economic system and simultaneously maintaining momentum toward economic and social development[2]. A low-carbon economy is also recognized as a global revolution involving changes of production patterns, lifestyles, values and norms, and national interests (Zhou Shengxian 2008).

More and more countries are heeding the development of low-carbon economies. In 2003, the British government was the first to use the concept of a low-carbon economy in its official documents and advocated a plan to reduce carbon dioxide emissions some 60% from 1990 levels by about 2050 and to create a low-carbon economy that will ensure that energy, the environment, and economic growth are properly and sustainably

[1] "Brazil opposes carbon-intensity plan". http://www.chinadialogue.net/blog/show/single/en/3144-Brazil-opposes-carbon-intensity-plan. Accessed Jun. 20, 2010.
[2] "China's Pathway towards a Low Carbon Economy". CCICED Policy Research Report 2009. http://www.cciced.net/encciced/policyr/Taskforces/phase4/tflce/200911/P020091124512243707328.pdf. Accessed June 18, 2010.

integrated[3]. Prime Minister Gordon Brown (2007) advocated a "greener Britain where a new green economy provides greater prosperity and high quality jobs even as it protects the environment and provides a better quality of life for all"[4].

1.2 Economic Growth, Industrial Structure, and Carbon Emission

Since the Industrial Revolution except for the two world wars and the Great Depression, the world's economy has achieved positive growth rate in most years, especially fueled by the new economy at the beginning of the 21st century (Table 1).

Table 1 China and Other Countries' Growth Rate of GDP

Country or Area	Average Annual Real Growth Rate		1990	2000	2002	2003	2004	2005	2006
	1991-2000	2001-2006							
World ①	3.3	4.2	2.9	4.8	4.6	3.0	5.3	4.8	5.4
China	10.4	9.8	3.8	8.4	8.0	8.3	10.1	10.4	11.1
France	2.0	1.7	2.6	3.9	2.1	4.2	1.1	2.5	1.7
Germany	2.1	0.9	5.7	3.1	2.9	0.1	1.1	0.8	2.9
Japan	1.3	1.4	5.2	2.9	2.4	-0.3	2.7	1.9	2.2
United Kingdom	2.4	2.5	0.8	3.8	2.1	3.9	1.8	3.3	1.8
United States	3.3	2.4	1.9	3.7	3.7	1.9	3.6	3.1	2.9

Note: refers to the 180 countries and areas listed in the *IMF World Economic Outlook* database.
Source: *International Statistical Yearbook 2008*, China Statistical Press, 2009.

Seen from the world's economic development history, the global industrial structure underwent a process dominated by Primary Industry, Secondary Industry, and Tertiary Industry in turns. The industrial structure of developed countries is dominated by Tertiary Industry, which accounts for nearly 70% of GDP, while Primary Industry accounts for less than 5%. Such low and middle income countries as China and India experienced a rapid economic growth rate in the past decade due to increases of the proportion of Secondary and Tertiary Industries, which is the rapid declining of the proportion of Primary Industry in GDP. These countries' GDP composition by industry was greatly different from those of the world, which was 3.4:27.6:69.0 in 2004 (Table 2).

Kuznets' research showed that an inverted "U" type curve exists between economic growth and environmental degradation and indicates that the environment deteriorates in the early stage of economic development. When economic development achieves a certain stage, environmental degradation is halted and environment is improved (Grossman & Krueger 1991).

3 "Energy White Paper. Our energy future — creating a low carbon economy". http://webarchive.nationalarchives.gov.uk/tna/+/http://www.dti.gov.uk/files/file10719.pdf/. Accessed May 22, 2010.

4 "Gordon Brown's speech in full" (on the environment to the Foreign Press Association, Nov. 19, 2007). http://www.politics.co.uk/news/health/environment-and-rural-affairs/gordon-browns-speech-in-full-$481751.htm. Accessed May 28, 2010.

This is proved by the experiences of most developed countries over the past three decades. Zhuang Guiyang (2008) studied the relationship between global GHG emissions per capita and GDP per capita and found a near-fitting inverted "U" curve trend between them. His research also showed that the developments of developed and developing countries were not synchronized, and the former's path represented the direction of world economic development. GHG emissions per capita could satisfy the EKC hypothesis. Furthermore, Stern (2000) validated that energy significantly affected the interpretation of GDP, arguing that cointegration existed among GDP, capital, labor, and energy.

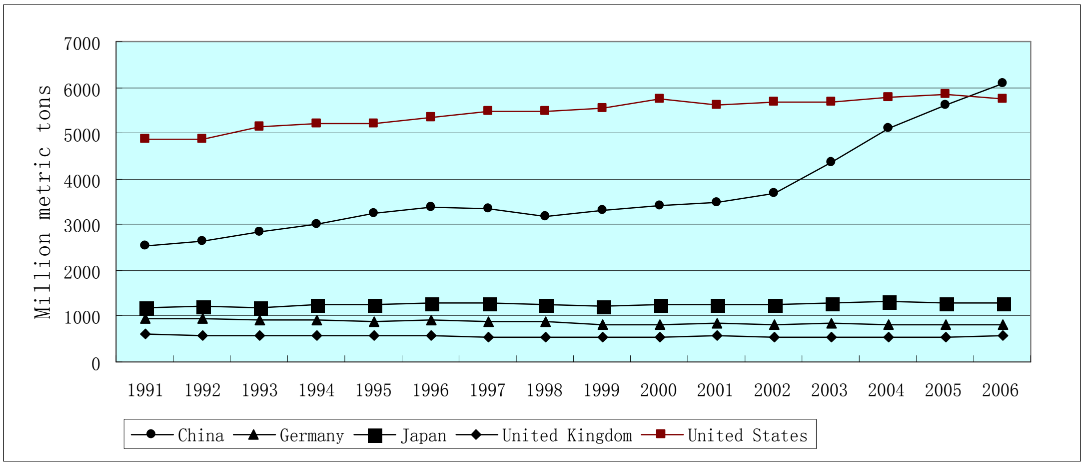
Table 2 Composition of GDP by Industries (%)

Country or Area	Primary Industry		Secondary Industry		Tertiary Industry	
	2000	2006	2000	2006	2000	2006
World	3.7	3.4①	29.2	27.6①	67.1	69.0①
Low Income	26.4	20.4	26.3	28.4	47.2	51.1
Middle Income	9.7	8.7	36.3	36.1	54.0	55.3
Low and Mid Income	12.1	10.5	34.9	34.9	53.0	54.6
High Income	1.9	1.7①	28.0	25.9①	70.1	72.4①
China	14.8	11.9	45.9	47.0	39.3	41.1
United States	1.2	1.3①	24.2	22.0①	74.6	76.7①
Japan	1.8	1.7①	32.4	30.2①	65.8	68.1①
United Kingdom	1.0	1.0②	28.3	26.2②	70.6	72.8②

Note: ①data refer to 2004. ②data refer to 2005.
Source: *International Statistical Yearbook 2008*, China Statistical Press, 2009.

From the perspective of industrial structure upgrading and industrialization of the past two decades, most developed countries show a steady downward trend in carbon emissions, but most developing countries show a continually increasing trend. Carbon emissions in developing countries will inevitably increase to meet the needs of human development, and the trend in developed countries is projected to stabilize or even decline as a result of demographic changes, behavioral adjustments, and technological improvements (Pan 2003). Harald Winkler and Andrew Marquand (2009) studied South Africa's changing development paths from an energy-intensive to a low-carbon economy and found that industrial energy use was the main driver for the high energy intensity of the economy. Dramatically changing this situation would take decades because the minerals-energy complex is so important to the economy. Zhuang Guiyang (2007) pointed out that the phases of global transition to low-carbon economies have characteristics. Developed countries, such as Germany and the UK, maintained a steady declining trend of carbon emission over the past few decades. China's emissions continue to increase due to its industrial structure with a high proportion of Secondary Industry (highest in Table 2) and its coal-fueled energy structure (Fig. 1).

Fig. 1 Carbon Emission of China and Several Developed Countries



Source: http://www.un.org/en/databases/.

1.3 Low-carbonization of Industrial Structure

The global climate change is mainly caused by carbon emission, which is the by-product of economic development. Xu Yugao (1997) analyzed the impact of various factors on carbon emissions from 1970-1994 in China and concluded that economic growth was the most important factor, accounting for more than 94% of the total carbon emission. The CCICED Report (2009) wrote that a major obstacle China faced in the transition to a low-carbon economy was industrial structure: "A large share of China's economy is in a stage of industrialization marked by heavy chemical industries,. . . all of which require a large volume of materials and energy." The Report adds that "there is a dramatic variation among regions in China in terms of economic development level and industrialization stage"[5]. The history of developed countries shows that a low-carbon economy is the best way to reduce emissions, and the low-carbonization of industrial structure is the core of low-carbon economies. Lin Boqiang (2003) argued that improving the economic efficiency of economic reforms and industrial restructuring could save energy and that adopting energy conservation measures and improving energy utilization efficiency would promote long-term sustainable economic growth.

[5] "China's Pathway Towards a Low Carbon Economy". CCICED Policy Research Report 2009. http://www.cciced.net/encciced/policyr/Taskforces/phase4/tflce/200911/P020091124512243707328.pdf. Accessed June 18, 2010.

Harald Winkler and Andrew Marquand (2009) believe that to achieve a low-carbon economy in South Africa, the most transformative change should be in the economic structure by building new, climate-friendly industries to develop low-carbon economies. They advocate a paradigm shift in industrial policy, sustain employment, and investment.

The concept of the low-carbonization of industrial structure argues that every possible measures and policies must be utilized so that the industrial structure provides more effective output with low energy consumption, low emission, and low pollution, all of which comply with the trends of the world's industrial development.

Fig. 2 Process of Low-carbonization of Industrial Structure

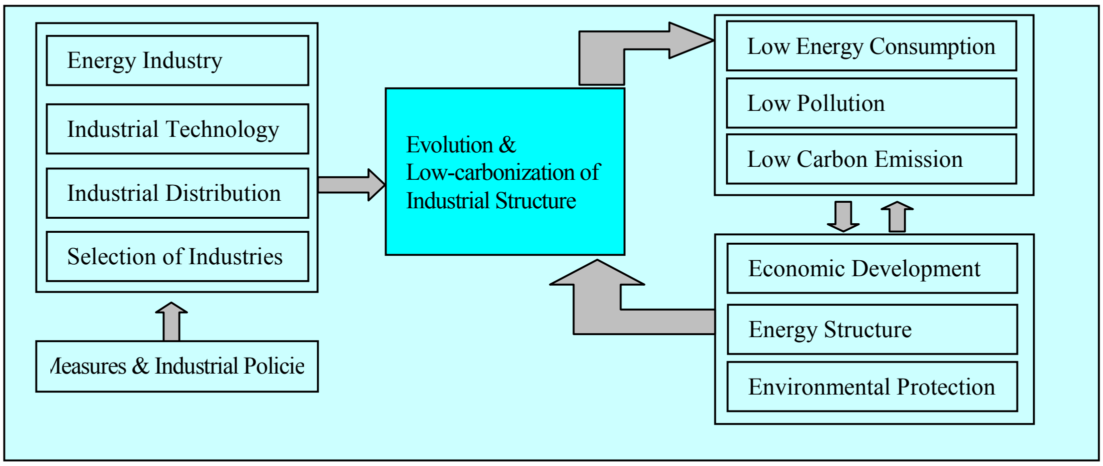


Figure 2 shows that the low-carbonization of industrial structure lies in the core link of the long-term goal of low-carbon economies. During the industrial structure evolution, measures and industrial policies, which should be adopted to affect the selection of industries, industrial technology, industrial distribution, and energy industry, are necessary to improve the low-carbonization of industrial structure and to make output more effective with low energy consumption, low pollution, and low emissions. Achieving the ultimate goal of economic development and environmental protection would further influence the low-carbonization process of industrial structure. Finally, the economic and ecological system would become a virtuous circle.

Research on the low-carbonization of industrial structure weighs a country's or a region's low-carbonization level from the perspective of industrial structure in different periods, countries, or regions for the same period. We can identify the status and the factors of the industrial structure's low-carbonization and provide possible policy options to achieve a low-carbon economy.

2. China's Industrial Structure and Carbon Emission

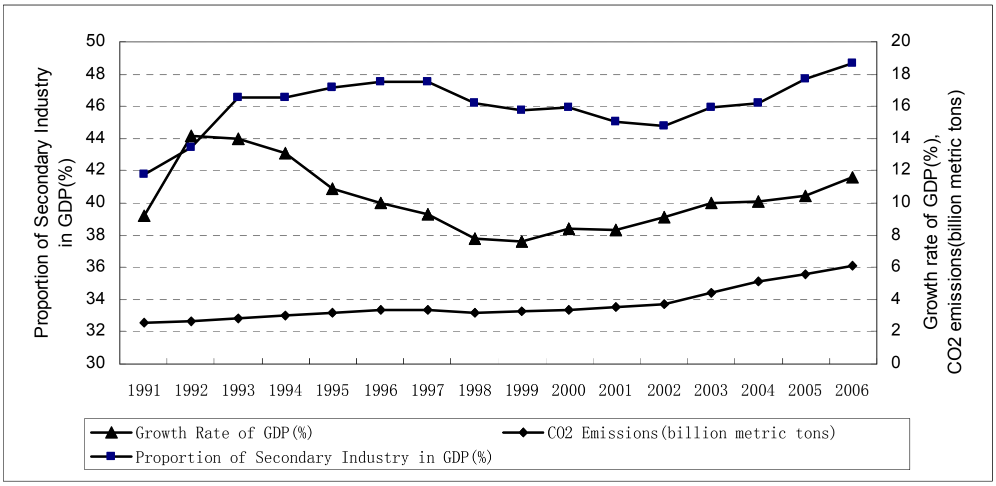
2.1 Industrial Structure and Carbon Emission

Some research addressed the relationship between industrial development and energy intensity, because the latter is closely related to carbon emission. Garbaccio et al. (1999) found that the change of industrial structure increased energy consumption in China from 1978 to 1995. Shi Dan (2002) analyzed industrial structure's effect on China's energy intensity and showed that the change of China's industrial structure, particularly the decline of the proportion of Secondary Industry, reduced energy intensity before 1990. But industrial structure enhanced energy intensity because of the re-rise of the proportion of industry in 1990-1995. Although the changes of industrial structure enhanced energy intensity, that role has greatly reduced since 1995. Ma and Stern (2008) pointed out that China's structural changes in industries and sectors improved the country's energy intensity from 1980 to 2003, but the structural changes within the industry sector reduced her energy intensity from 1994 to 2003.

Wang Zhongying and Wang Limao (2006) analyzed the relationship between GDP growth and carbon emission in China for the years 1980-2000 and concluded that GDP growth was significantly correlated to carbon emission (R^2=0.9581). They concluded that China's economic development pattern mainly depended on the investment and expansion of Secondary Industry, which strongly impacts carbon emission. Since 1978, China has experienced industrialization with an average annual economic growth rate of nearly 10%, which has ushered in tremendous development of its heavy industries with increasing energy consumption, leading to a higher proportion (about 45%) of Secondary Industry in GDP. So the economic growth and industrial structure transforming also increases carbon emissions in the past three decades in China.

As shown in Fig. 3 and Table 2, Secondary Industry, which greatly contributed to China's industrialization process, kept its GDP share at about 45%. China's carbon emissions also show an increasing trend. A significant correlation was found among economic growth, Secondary Industry, and carbon emission from 1999 to 2006. Jiang Kejun (2009) predicted that the increasing trend of carbon emission would continue for the next two decades until China completed its industrialization and that China's carbon emission would achieve its zenith in the 2030s and decline to its 1990 levels by the 2060s[6].

Fig. 3 China's Growth Rate of GDP, Secondary Industry and CO_2 emission



Source: *China Statistical Yearbook 2008*, China Statistical Press, 2008. *International Statistical Yearbook 2008*, China Statistical Press, 2009.

2.2 Domestic and International Pressure

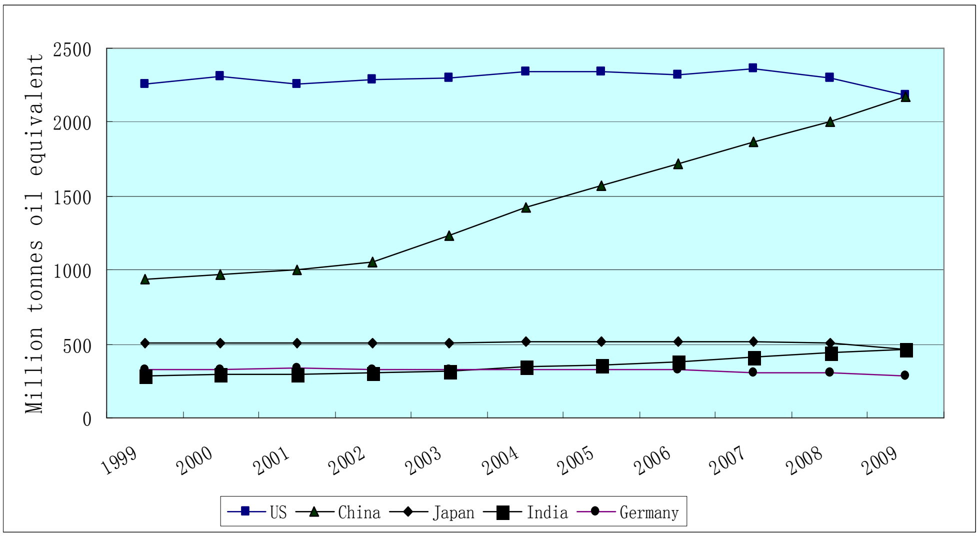
China's energy consumption has sharply increased the past decade (Fig. 4)[7]. Lin Boqiang (2003) tested whether China's electricity consumption and economic growth were endogenous and found that the two variables are interrelated. Liu Xing (2006) identified cointegration between energy consumption and GDP in China. Liu emphasized energy's effect on the economic development model and making long-term plans to guide the structural adjustment of the economy and the energy industry. Since it is greatly pressured by economic development, citizen living levels, employment, taxes, and social stability, China has to maintain its former growth form and industrial structure in the near future. The Netherlands Environmental Assessment Agency estimated that China's CO_2 emissions jumped by 9% to 8.1 billion tonnes in 2009, becoming the world's biggest producer. Unfortunately, China and India are "offsetting"

[6] http://www.cleanairnet.org/caiasia/1412/articles-73574_energy2a.pdf. Accessed June 10, 2010.
[7] Some politicians and economists said that China has already been the world's highest emitter of carbon dioxide, the major greenhouse gas. Just as Paul Krugman said that the growth of emissions from China — already the world's largest producer of carbon dioxide — is one main reason for this new pessimism. http://www.nytimes.com/2009/05/15/opinion/15krugman.html, accessed Sep. 15, 2009.

the efforts of developed economies to reduce emissions[8]. The situation also reflects the other main developing countries. Without China and the other main developing countries' active participation, there can be no solution to the world's climate change.

To facilitate the carbon emission reduction of developing countries, such developed countries as US and some European countries are restricting imports from developing countries by levying carbon tariffs. As the biggest developing country in the world, China has been adopting an export-oriented economy since the reforms and opening-up in 1978, her increasing export resulted in more and more international trade conflicts. Under internal and external pressures, China proposed three actions under the 2009 Copenhagen Accord: (1) To lower CO_2 emissions per unit of GDP by 40 to 45% by 2020 from 2005 levels; (2) To increase the share of non-fossil fuels in primary energy consumption to around 15% by 2020; (3) To increase forest coverage by 40 million ha and forest stock volume by 1.3 billion m^3 by 2020 based on 2005 levels[9].

Fig. 4 Primary Energy Consumption (million tonnes of oil equivalent)



Notes: Oil consumption is measured in million tonnes; other fuels in million tonnes of oil equivalent.
Source: *BP Statistical Review of World Energy*, June 2010.

[8] J.G.J. Olivier, J.A.H.W. Peters. "No growth in total global CO_2 emissions in 2009". http://www.rivm.nl/bibliotheek/rapporten/500212001.pdf. (Acessed July 10, 2010). Dutchman also admitted that China's per capita emissions only account for a quarter of those of the United States in 2009.

[9] "From Copenhagen Accord to Climate Action: Tracking National Commitments to Curb Global Warming". http://www.nrdc.org/international/copenhagenaccords/. Accessed June 22, 2010.

However, achieving these targets won't be easy for China. First, China's accelerating industrialization process will enlarge its industrial body, which relies on such high energy-consuming industries as iron and steel, automobiles, shipbuilding, and mechanical engineering. These energy-intensive industries, which cause more carbon emission, are the pillar industries of the national economy. China's less energy-intensive industries, such as Tertiary Industry, lag significantly behind the world average level (Table 2). Second, China's abundant coal resources account for 70% of its primary energy production and consumption, which is much higher than the world level of 33%. A coal-based energy structure constrains the industrial structure's adjustment and imposes tremendous pressure on carbon emissions. Third, the ever increasing urbanization ratio and population will also impose pressure on reaching the targets.

Under such circumstances, the Chinese government has adopted many measures to achieve its reduction commitments. The Chinese Renewable Energy Law was enacted in 2006 to increase the share of renewable energy within the country's total primary energy consumption. The National Development and Reform Commission of China (NDRC) will promote modern biomass, geothermal energy, hydro and solar power, and tidal and wind energy. Zhang Guobao, the director of the National Energy Administration, said in 2010 that "the government puts great stock in seeking harmonious development between cities and the environment, and is readjusting the energy structure by giving priority to the development of clean and low-carbon energies, including hydroelectric, nuclear, wind and solar power."

But the fundamental way to achieve the carbon reduction goals is to make industrial structure low-carbonization by industrial adjustment and upgrading, as described in Fig. 2, to satisfy the developing trend of the world's industrial structure and global industrial competition.

3. Indicators of Evaluation System

This evaluation system is based on the concept that a low-carbon economy is a new pattern of economic development that concerns economy, society, and environment. Many aspects must be considered to erect an evaluation system of industrial structure's low-carbonization (Table 3).

Table 3 Indictor System for Low-carbonization of Industrial Structure

Indicators	Code	Sub-indicators	Code
Economic indicators	α_1	Energy intensity	β_1
		Carbon intensity	β_2
		Elasticity ratio of energy production	β_3
		Elasticity ratio of energy consumption	β_4
		R&D intensity	β_5
Industrial structure indicators	α_2	Secondary Industry's ratio of GDP	β_6
		Ratio of high-tech industries' gross production of GDP	β_7
		Growth rate of high-tech industries' gross production	β_8
		Ratio of high-tech industries' export of total exports	β_9
		Ratio of new energies' gross product of GDP	β_{10}
Environmental indicators	α_3	Carbon emission per capita	β_{11}
		Ratio of carbon caption and storage in carbon emission	β_{12}
		Certification ratio of ISO14000	β_{13}
Energy indicators	α_4	Supply ratio of clean energy in primary energy	β_{14}
		Ratio of clean energy consumption of total energy consumption	β_{15}
		Subsidy intensity of new energy	β_{16}
Social indicators	α_5	Housing area per capita	β_{17}
		Ratio of urbanization	β_{18}
		Vehicle quantity per households	β_{19}

3.1 Economic Indicators

(1) Energy intensity, which is calculated as the units of energy per unit of GDP, refers to the energy consumption per unit of GDP in a country or the Gross Regional Product in a region in the same reference period and reflects the energy efficiency of a nation's economy. High energy intensity indicates a high price or cost of converting energy into GDP. (2) Carbon intensity is the ratio of carbon emissions produced to GDP and refers to the carbon emission per unit of GDP. High carbon intensity shows a high negative effect of GDP. (3) Elasticity ratio of energy production shows the relationship between the growth rates of energy production and the national economy. Generally speaking, since the growth rate of energy production should be higher than that of the national economy, its value exceeds 1. (4) Elasticity ratio of energy consumption indicates the relationship between the growth rates of energy consumption and the national economy. (5) R&D intensity is the ratio of expenditures on R&D to GDP. High R&D intensity indicates a high payout in GDP, which will benefit technological improvement, energy consumption efficiency, and production efficiency.

3.2 Industrial Structure Indicators

(1) The Secondary Industry's ratio of GDP indicates the industrialization stage and degree of a country or a region. (2) The ratio of high-tech industries' gross product in GDP indicates the high-tech sectors' (especially low-carbon emission industries) static proportion of GDP. (3) The growth rate of high-tech industries' gross product refers to

the dynamic growth rate of low-carbon emission industries. (4) The ratio of high-tech industries' exports of total exports indicates the international competitiveness of the low-carbon emission sectors. (5) The ratio of new energies' gross product in GDP shows the importance of new energy industries in industrial structure and the national economy.

3.3 Environmental Indicators

(1) Carbon emission per capita refers to the average carbon emission per capita in a country or a region. (2) The ratio of carbon caption and storage in carbon emission partly indicates the results of the struggles of a country or a region to control carbon emission. (3) The certification ratio of ISO14000 indicates the enterprises' emphasis on environmental protection.

3.4 Energy Indicators

(1) The supply ratio of clean energy in primary energy shows the proportion of clean energy in the energy supply structure, including nuclear energy and such renewable energies as hydro, wind, solar, and biomass, which are considered zero carbon emission resources. (2) This is the ratio of clean energy consumption of the total energy consumption. (3) The subsidy intensity of new energy indicates the degree to which the government supports new energies.

3.5 Social Indicators

(1) Housing area per capita. Generally speaking, based on the factors of construction materials, area, cooling, heating, etc., the larger the per capita housing area is, the higher are carbon emissions. (2) The ratio of urbanization. Energy consumption of urban residents exceeds rural residents, especially in the rapid urbanization phase. (3) Vehicle quantity per household shows resident durable goods consumption that relates to energy consumption and carbon emission.

4. Evaluation Method

This paper adopts the Analytic Hierarchy Process (AHP) and the method of expert consultation to analyze the low-carbonization of industrial structure. As a method with systematic, hierarchical, qualitative, and quantitative analysis, AHP is a simple, flexible, and practical method of multi-criteria decision making that is used comprehensively in many fields.

4.1 Calculation of Weight

First, this paper identifies the major evaluation factors and constructs an evaluation model. Based on statistical analysis and expert consultations, the paper establishes set $\beta = (\beta_1, \beta_2, \beta_3, \ldots, \beta_n)$ of the characterization parameters of the main evaluation factors and gains dimensionless set $\overline{\beta} = (\overline{\beta}_1, \overline{\beta}_2, \overline{\beta}_3, \ldots, \overline{\beta}_n)$. Second, it establishes a set of the weights of the hierarchical sectors in the evaluation system by expert consultation and AHP. The detailed procedures include the following steps (Saaty 1980).

(1) Choose q experts from such relevant fields as economics, ecology, environmental protection, energy, and sociology. (2) Consult by questionnaires with these experts to obtain the degree of importance of one indicator against the other. They rank the relative importance of the indicators by pair-wise comparisons using scales ranging from 1 to 9. (3) Aggregate these judgments by a geometric mean method. Let α_{ij}^r (r = 1, 2, …, q) denote the relative importance of the ith element against the jth element evaluated by rth expert, and use a geometric mean to aggregate all expert opinions: $\alpha_{ij} = (\prod_{r=1}^{q} \alpha_{ij}^r)^{1/q}$, where α_{ij} represents the mean value for expert ratings. (4) Construct judgment matrix $A = (\alpha_{ij})_{n \times n}$, where $\alpha_{ij} = 1/\alpha_{ji}$, $\alpha_{ii} = 1$ and n denotes the number of elements under an attribute. (5) Test the consistency for AHP.

From these five steps, we get evaluation indicator weights $\omega_\alpha = (\omega_1, \omega_2, \omega_3, \omega_4, \omega_5)$, which meets $\sum_{i=1}^{5} \omega_i = 1$. After repeating the same process several times, we can also get the sub-indicator weights $\omega_\beta = (\upsilon_1, \upsilon_2, \ldots, \upsilon_{19})$, which also meets $\sum_{i=1}^{19} \upsilon_i = 1$ (Table 4).

Table 4 Indicator Weights

ω_1					ω_2					ω_3			ω_4			ω_5		
0.182					0.352					0.134			0.201			0.131		
υ_1	υ_2	υ_3	υ_4	υ_5	υ_6	υ_7	υ_8	υ_9	υ_{10}	υ_{11}	υ_{12}	υ_{13}	υ_{14}	υ_{15}	υ_{16}	υ_{17}	υ_{18}	υ_{19}
0.038	0.031	0.052	0.046	0.015	0.183	0.049	0.043	0.035	0.042	0.081	0.028	0.025	0.085	0.061	0.055	0.042	0.046	0.043

4.2 Calculation of Indicators

The following formula calculates the value of the indicators:

$$I_x = \overline{\beta} \cdot \omega = \sum_{i=1}^{n} \overline{\beta_i} \cdot \upsilon_i \qquad (1)$$

Here I_x denotes the indicator value, β_i denotes the evaluation factor value, and υ_i denotes the indicator weight. Since the positive and negative effects of the evaluation factors have been taken into account in the choice of these factors, the greater the index value, the greater the contribution to the low-carbonization of industrial structure.

4.3 Calculation of Main Indicators' Coordination Degree

Coordination degree is a quantitative indicator to measure the coordination among system elements. In this paper, it reflects the coordination status between the main indicators in the system of industrial structure's low-carbonization, such as economy, industrial structure, energy, environment, and social indicators. The following is the coordination degree formula:

$$CD_x = 1 - \sqrt{\sum \frac{(\alpha_i - \overline{\gamma})^2}{N}} \qquad (2)$$

Here CD_x denotes the coordination degree of the system, α_i denotes the indictor value of the *i*th sub-system, $\overline{\gamma}$ denotes the mean value of each sub-system, and N denotes the quantity of each sub-system. There are five sub-systems in this paper. The greater the value of CD_x, the better is the coordination of the sub-system.

4.4 Calculation of Industrial Structure's Low-carbonization

Low-carbonization level of industrial structure (I_{lcx}) is the product of I_x and CD_x; its formula is:

$$I_{lcx} = I_x \cdot CD_x \qquad (3)$$

Generally speaking, a greater I_{lcx} shows higher coordination degree between the low-carbonization of industrial structure and economy, industrial structure, energy, environment, and social indicators.

5. Empirical Study on China's and some Provinces' Industrial Structure

5.1 Data Source and Evaluation Results

The paper selected five provinces of China and did a quantitative analysis of China and these provinces' I_{lcx} for 2007. These five provinces include Shanghai City, Zhejiang Province, Hunan Province, Henan Province, and Shanxi Province. Shanghai City and Zhejiang Province, which respectively represent big cities and comparatively developed regions, have higher levels of industrialization, higher ratios of urbanization, higher GDP and income per capita, and a more modern lifestyle. Hunan and Henan Provinces represent agricultural provinces with a general level of industrialization. Shanxi represents provinces that have good traditional energy resources and rapid industrial development. It is just a coincidence that these selected regions are located in China's geographic eastern, central, and western areas. Most of the data were obtained from the following sources: *"China Statistical Yearbook," "China Energy Statistical Yearbook," "International Statistical Yearbook," "China S&T Statistics Data Book,"* and the statistical yearbooks printed by these five provinces. The calculation results are as follows (Table 5).

Table 5 Data of China and Five Provinces for 2007

	China	Shanghai	Zhejiang	Hunan	Henan	Shanxi
β_1	1.102	0.830	0.831	1.312	1.293	2.761
β_2	2.221	1.591	1.591	2.593	2.251	1.448
β_3	0.596	0.462	0.491	1.389	1.201	0.721
β_4	0.603	0.685	0.752	0.822	0.790	0.691
β_5	0.014	0.025	0.016	0.013	0.007	0.014
B_6	0.486	0.466	0.541	0.427	0.550	0.596
B_7	0.201	0.323	0.309	0.295	0.285	0.276
B_8	0.176	0.192	0.203	0.196	0.186	0.174
B_9	0.205	0.273	0.254	0.208	0.213	0.172
B_{10}	0.001	0.001	0.001	0.001	0.001	0.001
β_{11}	3.778	9.102	5.042	3.091	3.003	2.172
B_{12}	0.001	0.002	0.001	0.001	0.001	0.001
B_{13}	0.016	0.035	0.029	0.016	0.015	0.019
B_{14}	0.121	0.135	0.142	0.129	0.126	0.106
B_{15}	0.132	0.139	0.149	0.131	0.129	0.093
B_{16}	0.013	0.019	0.015	0.011	0.012	0.013
β_{17}	28.92	32.21	36.15	34.42	32.31	31.61
B_{18}	0.449	0.868	0.566	0.404	0.343	0.449
B_{19}	0.061	0.182	0.101	0.053	0.055	0.047

5.2 Analysis

The low-carbonization level of the industrial structure (I_{lcx}) in Shanxi Province (0.325) and Shanghai City (0.336) were below those of China (0.334), Zhejiang Province (0.356), Hunan Province (0.354), and Henan Province (0.343). Shanxi scored the lowest among these five regions, mostly reflecting its highest ratio of Secondary Industry and its coal-based energy structure, which acts as an important part of its industrial structure. Shanghai has a high ratio of urbanization and obviously heavy and chemical industries including metallurgy, chemical, and machinery industries, which consumed a large amount of energy and resulted in high carbon emission (Carbon emission per capita in Shanghai was higher than the other four regions). Table 6 also shows that the industrial structure indicators dominated the value of I_{lcx}, because most of the economic, environmental, energy and social indicators are directly or indirectly determined / influenced by the industrial structure indicators.

Table 6 I_{lcx} of China and Five Provinces for 2007

	China	Shanghai	Zhejiang	Hunan	Henan	Shanxi
I_x	0.366	0.359	0.379	0.382	0.376	0.351
CD_x	0.912	0.935	0.939	0.926	0.913	0.925
I_{lcx}	0.334	0.336	0.356	0.354	0.343	0.325

6. Conclusion

To evaluate the low-carbonization of industrial structure in China, this paper uses AHP and method of expert consultation to conduct a system with five different dimensions that includes economic, industrial structure, environment, energy, and social indicators. Some conclusions are drawn as following. First, the low-carbonization of industrial structure is a fundamental way to achieve a low-carbon economy, which was proved by the developed countries' process of economic development. Second, the tremendous pressure faced by China from home and abroad was represented by the extensive mode of economic development and increasing carbon emission. Third, the establishment of sustainable energy systems in China is urgent. Energy structure stress impacts the low-carbonization of industrial structure, which not only affects such economic indicators as energy intensity but also the industrial structure, because it's an important part of industrial structure. Fourth, the industrial indicators show the most important effects on low-carbon economies; Secondary Industries, especially heavy and chemical industries, are the most important indicators that negatively affect the reduction of carbon emission, while high-tech industries show the positive effects. Furthermore, the R&D level is closely related not only to industrial technology and innovation but also to research, development, and energy use. The core of industrial structure's low-carbonization in China is trying to decrease the proportion of Secondary Industry, heighten the proportion of Tertiary Industry, and accelerate the development of emerging industries of strategic importance.

References:

Ann P. Kinzig and Daniel M. Kammen, 1998. National Trajectories of Carbon Emissions: Analysis of Proposals to Foster the Transition to Low-carbon Economies, *Global Environmental Change*, Vol. 8, No. 3, 183-208.

Harald Winkler and Andrew Marquand, 2009. Changing Development Paths: From an Energy-intensive to Low-carbon Economy in South Africa, *Climate and Development*, (1) 47-65.

Garbaccio, R. F., M. S. Ho, and D. W. Jorgenson, 1999. Why Has the Energy-output Ratio Fallen in China? *Energy Journal*, 20: 63-91.

Grossman, G. M. and A. B. Krueger, 1991. Environmental Impacts of the North American Free Trade Agreement, *NBER Working Paper*, No. 3914.

Lin Boqiang, 2003. Electricity Consumption and Economic Growth in China: based on Production Function, *Management World*, (11):18-27.

Liu Xing, 2006. Analysis for Economic Growth and Energy, *Application of Statistics and Management*, 25(4): 443-447.

Ma, C. and D. Stern, 2008. China's Changing Energy Intensity Trend: a Decomposition Analysis. *Energy Economics*, 30: 1037-1053.

Nation Bureau of Statistics of China ed., 1990~2008. *China Energy Statistical Yearbook,* Beijing: China Statistics Press.

Nation Bureau of Statistics of China ed., 1990~2008. *China Statistical Yearbook,* Beijing: China Statistics Press.

Nation Bureau of Statistics of China ed., 2009. *International Statistical Yearbook 2008*, Beijing: China Statistical Press.

Pan Jiahua, 2003. Commitment to Human Development Goals with Low Emission: An Alternative to Emissions Caps for Post-Kyoto from a Developing Country Perspective, presentation at side event hosted by Research Centre for Sustainable Development, Chinese Academy of Social Sciences, LINFCCC COP9, 1 December, Milano.

Saaty T. L., 1980. *The Analytic Hierarchy Process*, New York: McGraw-Hill Book Companies.

Shi Dan, 2002. The Improvement of Energy Consumption Efficiency in China's Economic Growth, *Economic Research Journal*, 9: 49-56.

Stern, D. I., 2000. A Multivariate Cointegration Analysis of the Role of Energy in the US Macroeconomy, *Energy Economics*, 22, 267-283.

Wang Zhongying and Wang Limao, 2006. Economic Growth and Its Effects on Carbon Emission in China, *Journal of Safety and Environment*, Vol. 6 (5).

Xu Yugao, Guo Yuan, and Wu Zongxin, 1999. Economic Development, Carbon Emission and Economic Evolvement, *Progress in Environmental Science*, 7 (2), 54-64.

Zhang Peng and Ma Xiaohong, 2005. Research on the Relationship of China Economy Development and Circumstance Pollution, *Journal of Hunan University of Science and Engineering*, 5 (5), 264-268.

Zhou Shengxian, 2008. Prelude in the book '*Introduction of Low-carbon Economy,*' Zhang Kunmin, Pan Jiahua, Cui Dapeng, Beijing, China Environmental Science Press.

Zhuang Guiyang, 2007. *Low-carbon Economy: China's Development in the context of Climate Change*, Meteorological Press.

Zhuang Guiyang, 2008. How Will China Move towards Becoming a Low Carbon Economy? *China & World Economy*, Vol. 16, No. 3, 93-105.