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Analysis on embodied energy of China's export trade and the energy consumption trends of key industries

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ABSTRACT

In order to solve the contradictions that the static input-output table can't be used for dynamic analysis, this paper unified the 2002, 2005 and 2007 input-output tables into 25 industries, full energy intensity and embodied energy of China's export trade can be calculated quantitatively based on Input-Output analysis approach, we can get the time series data of 2001-2009 through the corrections of energy consumption per unit of GDP, consumer price index and exchange rate, and then analyze the trends of energy consumption of key industries. The results show that full energy intensity of China's 25 industries takes on downward trend generally and the embodied energy of China's export trade is increased firstly and then has a downward trend. Processing trade had great impact on full energy intensity and embodied energy, after deducting the processing trade; full energy intensity and embodied energy had decreased greatly. Smelting and Pressing of Metals, Manufacture of Chemicals, Manufacture of Communication Equipment, Computers and Other Electronic Equipment, Manufacture of Textile are the largest energy-consuming industries of export trade in China. The trends of energy consumption in these four industries are similar to the total energy consumption, changes in export trade is the main reason for this result, full energy intensity has a certain influence on the trend of energy consumption, but the effect is limited.

Key Words: Export Trade; Input-Output analysis; Embodied Energy

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1. INTRODUCTION

Since reform and opening, with the rapid development of China's economy, export trade has increased rapidly. At the same time, China's energy consumption has grown greatly, which has brought enormous pressure to energy supply and renders the energy production fail to support economic development. Therefore, domestic and foreign scholars show great enthusiasm at the relationship between energy consumption and export trade. T.owen[1] studied the relationship between energy consumption and export trade in Brazil, Peru and other Latin American countries from 1960s to 1970s, he thought that the rapid expansion of the export trade in these countries was an important reason caused the energy supply shortage; Jose, Goldemberg[2] studied the relationship between energy consumption structure and international trade from the perspective of supply and demand in Latin American countries, the results showed that the import and export trade of Latin American countries had a major impact on energy consumption structure; Zhifang Su, Jinghan Cai[3] used Granger causality test to study the relationship between energy consumption and export trade in China, the results showed that there was a one-way Granger causality relationship between export trade and energy consumption; Chuanguo Zhang, Weijuan Chen[4]took use of Granger causality test, impulse response and variance decomposition to study the causal and dynamic relationship between energy consumption and export trade in China, and found that there was a one-way Granger causality relationship between energy consumption and export trade, export trade had great impact on energy consumption Continuously. These studies indicated that the rapid development of export trade was the primary reason for the growth of energy consumption, but the indirect energy consumption in goods of export trade can't be taken into account, so it wouldn't reveal the energy flow of export goods scientifically.

"Embodied energy" solved this problem well, which refers to the full energy consumed by processing, manufacturing, transporting the upstream product. As long as this concept put forward, scholars at home and abroad got the attention of "Embodied Energy". Since the 1990s, studies on the "embodied energy" were active, due to data limitations, these studies were based on the national level and from the static perspective. Wyckoff and Roop[5] studied energy embodied in goods of import trade in six major OECD countries such as Britain, France, Germany, Japan, the United States, Canada during 1984-1986, the conclusion shown that the domestic policies about reduction could be compromised for the domestic consumption accounted for a large proportion of import goods. Shui and Harriss[6] found that US emissions in the period 1997–2003 would have been 3–6% higher if goods imported from China had been produced in the US, Vice versa, 7–14% of China's emissions of CO2 in 2003 were a result of producing exports for US consumers; Frank Ackermana, Masanobu Ishikawa, Mikio Suga [7]applied input-output analysis approach to estimate greenhouse gas emissions embodied in the Japan-US bilateral trade, the results found that in 1995 the U.S. reduced emissions of

14.6Mt, Vice versa, Japan increased 6.7Mt, which was 7.9Mt net reduction of greenhouse gas emissions from a global view, in addition, there was less significant positive correlation between carbon intensity and net exports, the carbon tax policies had a positive effect on reducing carbon emissions. Hae-Chun Rhee, Hyun-Sik Chung[8] studied the CO2 emissions between China and South Korea and thought average annual growth rate of South Korea's CO2 emissions was about 8.9% during the period 1990-1995, which this growth rate was only 1.6% in Japan, the rapid growth of exports in energy-intensive industries was the main reason leading to the growth of emissions. In addition, there were a lot of analyses on embodied energy from the perspective of a single country [9-15] Domestic scholars studied embodied energy later than the counterparts at abroad, mostly for qualitative research. Xiangdong Chen, Na Wang[16] discussed the relationship between international trade and energy consumption, environmental impact in the paper, and thought that all products and services produced by an economic system were directly or indirectly associated with energy consumption; Later some scholars calculated energy embodied in goods of China's international trade, Lisheng Shen[17] used input-output analysis approach to estimate the impact of China's import and export on energy consumption in 2002-2005, which demonstrates that China's foreign trade had a positive impact on the economy from the overall view, energy consumed by import is more than exports, which was contributed to reduce domestic energy consumption; Ying Chen, Jiahua Pan[18]estimated energy embodied in goods of China's import and export in 2002, after deducting the impact of imported intermediate goods, the results shown that the full amount of energy embodied in export was about 410 million tce, the data was 170 million tce, net export of embodied energy was about 240 million tce, which occupied about 16 % of primary energy consumption; Siping Luo, Can Wang, Jining Chen[19]analyzed energy embodied in goods of international trade in China during the period 1997-2006, the results shown that the full amount of energy embodied in export is much larger than energy embodied in import, China was a net exporter of embodied energy through international goods trade; Allen Gu [20]estimated the energy embodied in goods of international trade in 2002, 2005 and 2007. The result showed that China was a net exporter of embodied energy and emissions, and the volume was becoming larger and larger.

In summary, we had achieved some results in the studies of energy content, but some shortages were existed when
studying embodied energy in international trade: Firstly there was a lack of dynamic research on embodied energy; Scholars seldom studied the trends of energy consumption in the key export sectors; In order to reveal energy flows of export trade in China scientifically, this paper is regardless of import trade, because it doesn't consume domestic energy. We take use of input-output analysis approach and improve calculation methods with fully affirming our previous research results and accounting for shortages in research, then studying the dynamic characteristics of embodied energy, and on this basis, analyzing the trends of energy consumption of key export industries in China, we can put forward some recommendations to adjust export structure based on results of analysis to effectively control energy consumption and

ease the pressure on energy supply.

2. METHODOLOGY AND DATA

2.1 Input-Output analysis approach

In this study, the input-output analysis, founded by the American economist Leontief, is the well-established method internationally which can be used to calculated energy embodied in goods of international trade. Let y be a vector (n×1) of final demand from industry sectors i=1,…,n and Xij be the elements of a matrix (n×n) of intermediate demand of industries j=1,…,n from industries i=1,…,n. The full (intermediate plus final) demand xi from industry i is then

$$x_i = \sum_{j=1}^{n} X_{ij} + y_i \qquad (1)$$

Let A be a matrix (n×n) of technological or direct requirement coefficients A_{ij}, which relates the output x_j of industry j to its inputs from industries i by

$$X_{ij} = A_{ij} \cdot x_j \qquad (2)$$

So that in matrix notation equation (1) becomes x=Ax+y (3), solving for x yields x= $(I-A)^{-1}y$, （4）, $(I-A)^{-1}$ is the Leontief inverse matrix, Let EI is direct energy intensity of per unit of full product, EI=E/x(5), E means energy consumption, equation (5) becomes $E=EI*x=EI*(I-A)^{-1}y=EEI*y$ (6), EEI is the full energy intensity.

2.2 Embodied energy in export

EEI is a vector (n×1) of full energy intensity from industries sectors i=1,…,n, EX is a vector (n×1) of export from industries i=1,…,n, from the equation (6), the total embodied energy EXEE is then

$$EXEE = \sum_{i=1}^{n} EXEE_i = \sum_{i=1}^{n} EEI_i \cdot EX_i = \sum_{i=1}^{n} EI_i \cdot (I-A)^{-1} \cdot EX_i \qquad (7) \qquad (7)$$

Embodied energy that we estimate from the equation (7) does not deduct the impact of processing trade; the results are somewhat unrealistically high because the direct requirements matrix A contains domestically produced and imported products. In order to deduct the impact of processing trade on embodied energy, imported products should be removed. Thus it is common to derive new requirements matrices Ad,mi=IMi/(xi+IMi-EXi),i=1,…,n,(8)Ad=diag(1-mi)*A (9)
Where mi is the share of imports in the supply of products and services to each sector i. This method removes imported goods, IM, from the direct requirements matrix

$$EXEE' = \sum_{i=1}^{n} EXEE_i' = \sum_{i=1}^{n} EEI_i' \cdot EX_i = \sum_{i=1}^{n} EI_i \cdot [I-Ad]^{-1} \cdot EX_i$$

A.So the equation (7)becomes

(10)

2.3 Data sources

2.3.1. Input-Output tables

We obtained the input-output tables (IOU) from the Chinese National Bureau of Statistics (NBS) for 2002 with 122 sectors, 2005 with 42 sectors and 2007 with 135 sectors, all at current prices. In order to measure more accurately, we divide all sectors in these three input-output tables into 25 sectors uniformly.

2.3.2 Energy and trade data

Energy consumption by industry are available, we can get the energy data from China Statistical Yearbook for 2002(China Statistical Yearbook 2004), 2005(China Statistical Yearbook 2007), 2007(China Statistical Yearbook 2009). All data has the same industry categories: industry, construction, Transportation, Storage, Post and Telecommunications, Wholesale and Retail Trade, Consumption and other industries. Export data comes from the website of China Customs.

3. RESULTS AND DISCUSSION

3.1 .Full energy intensity and embodied energy in 2002, 2005, 2007

Using the formula (2) to input data have been collected, we can get the complete energy consumption intensity of 2002,2005 and 2007, to more directly reflect the change of the full energy intensity in industries from an intuitive point of view, drawn as shown in Figure 1.The number 1 to 25 represents every industry respectively.

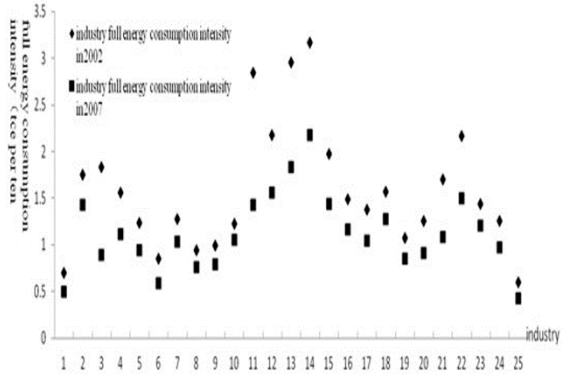

Fig.1.Full energy intensity of 25 industries in China

It can be seen from Figure 1 that the full energy consumption intensity of 25 sectors had emerged as a downward trend during 2002-2007, which revealed that production technologies and energy efficiency in China were gradually improving. We can see from the calculation results that the amount of the average full energy intensity were 1.571 and 1.113 tons of coal equivalent (tce) per ten thousand yuan, respectively, in 2002 and 2007, the amount of embodied energy in exports are 3.78 and 9.86 billion tons of coal equivalent, respectively, after deducting the processing trade, the average full energy intensity decreased by 16.04% and 22.64%, respectively, gross embodied energy decreased by 22.22% and 29.61%, respectively, as can be shown in Fig.2. and Fig.3.

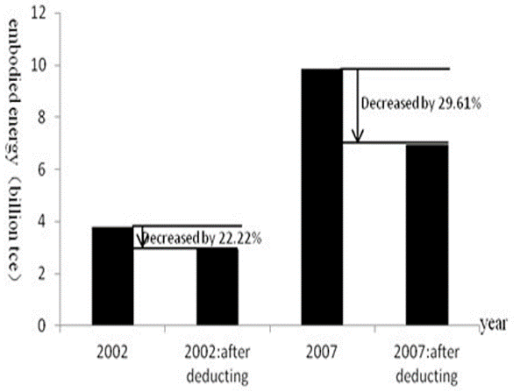

Fig.2. Average full energy intensity and average full energy intensity after deducting the processing trade in 2002, 2007.

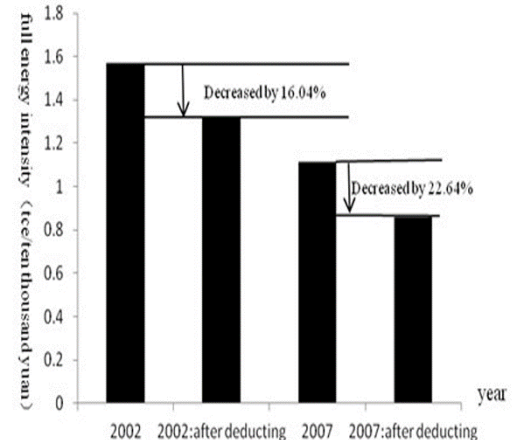

Fig.3. Embodied energy and embodied energy after deducting the processing trade in 2002, 2007.

The data showed that as China joined the World Trade Organization in 2001, the export trade developed fast and the proportion of processing trade in export trade was gradually increasing. The processing trade had a significant impact on the average full energy intensity and embodied energy in China. Besides, the various sectors were affected differently by the processing trade because of their different characteristics, Manufacture of Communication Equipment, Computers and Other Electronic Equipment and Manufacture of Measuring Instruments and Machinery for Cultural Activity and Office Work were affected greatly, the full energy intensity declined by 53.5% and 47.9%, respectively, after deducting the processing trade in 2007. because these two industries commonly regarded processing trading as the main methods of production, so the average energy intensity and gross embodied energy would decline significantly after deducting intermediate products of imports.

3.2. Dynamic analysis of embodied energy in exports.

For dynamic analysis, we need to get the time-series data of energy embodied in export trade, as we all know, the input-output table in China prepared once every five years, so in theory we couldn't obtain the annual input-output table to calculate energy embodied in goods of export trade. If we expanded input-output data to other years by applying technical methods, the amount of data required would be very large, which was not operational. To simplify the calculation, we obtained missing years of the average full energy intensity through corrections of energy consumption per unit of GDP, the consumer price index and exchange rates in the paper (Table 1). Since the annual input-output relations had changed in 2002, 2005 and 2007, respectively, the revised time-series data could reveal the dynamic characteristics of embodied energy in exports scientifically, which had made further improvements based on the previous studies.

We multiplied the average full energy intensity and export trade data; we would obtain embodied energy in exports during the period 2001-2009, as was shown in Table 2.

Figure 4 reflected the change of energy embodied in goods of export trade during the period 2001-2009, this process could be divided into three stages: During the period 2001-2005, export trade and embodied energy were growing rapidly, which had the same degree of tilt. Since 2001, China joined the World Trade Organization, China's exports developed rapidly, the export volume rose from 2.20244 trillion yuan in 2001 to 6.26481 trillion yuan in 2005, which was an increase of 1.84 times; At the same time, embodied energy rose from 251 million tce in 2001 to 680 million tce in 2005, which was an increase of 1.71 times. The growth rate of export trade and embodied energy of exports to foreign countries were consistent. The export trade is the dominant factor that affected the embodied energy. In 2005-2008, China's exports trade remains the first phase of growth. The growth rate of embodied energy is slowing down, which meant that the energy change is due to appear "Eleventh Five-Year Plan" proposed "Eleventh Five-Year" period of China's energy consumption per unit of GDP than in 2005 decreased by 20%, and took a series of effective measures, making China's exports average full energy intensity had been greatly decreased, which rendered the momentum of China's skyrocketing energy content can be checked, the complete energy consumption intensity had the impact on energy, but the impact was less than the export trade. In 2008-2009, China's export of embodied energy and trade worsened had a more significant decline. As the U.S. Subprime mortgage crisis caused the global financial crisis, China's export trade had been hit hard in 2009. The export volume declined from 10.03949 trillion yuan in 2008 to 8.20297 trillion yuan in 2009, which fell by 18.3%, embodied energy had also been decreased greatly due to the influence of exports.

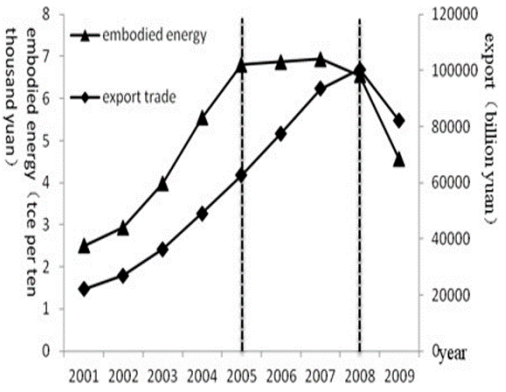

Fig.4. Exports and embodied energy in China during the period 2001-2009

In order to examine the impact of embodied energy on energy consumption, Figure 5 illustrated the proportion of embodied energy in total energy consumption.

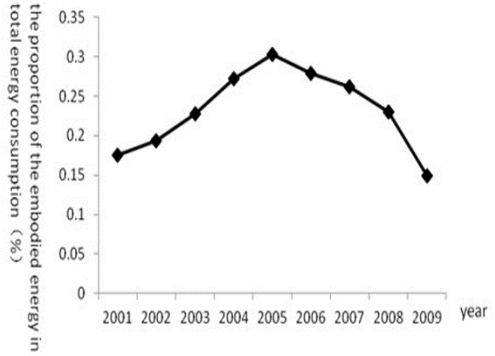

Fig.5 the proportion of embodied energy in total energy consumption.

We can see from the figure 5 that the proportion of embodied energy in the total energy consumption firstly increased and then had a downward trend as the embodied energy was
mainly affected by export trade, which had the same effect on the total energy consumption. Due to the international financial crisis, the embodied energy in exports fell sharply in 2008, which led to a decline in the proportion of embodied energy in total energy consumption. As an export-oriented country, China's export trade will rebound quickly after the financial crisis. China will output a large number of energy to foreign countries by way of export especially for the rapid development of export trade in high energy-consuming industries recently, the proportion of embodied in the total energy consumption will rise.

3.3. Analysis on the trends of energy consumption in keg sectors.

China was undergoing the stage of the rapid development, and we should not rely on restricting the development of export to conserve energy. On the technical level, energy consumption per unit was difficult to obtain a significant decline, so it was hard to reduce energy consumption through introducing foreign technologies. In order to help the government optimize the export structure and make some valuable recommendations, it was necessary to analyze the trends of energy consumption in key industries which wasted a lot of energy in China.

In theory, the full energy intensity of each industry would affect the energy embodied in goods of exports in China, we didn't consider some industries which shared the small proportion of exports and had little impact on embodied energy of exports. In order to facilitate analysis, we selected these eight sectors such as Smelting and Pressing of Metals, Manufacture of Chemicals, Manufacture of Communication Equipment, Computers and Other Electronic Equipment, Manufacture of Textile, Manufacture of Electrical Machinery and Equipment, Manufacture of General and Special Purpose Machinery, Transport, Storage and Post, Manufacture of Wearing Apparel, Leather, Feather and Related Products, the embodied energy of these eight sectors accounted for 72.3% of total embodied energy in all industries in 2007, these selected industries were representative. We obtained the time series data of full energy intensity of these eight industries during the period 2001-2009.

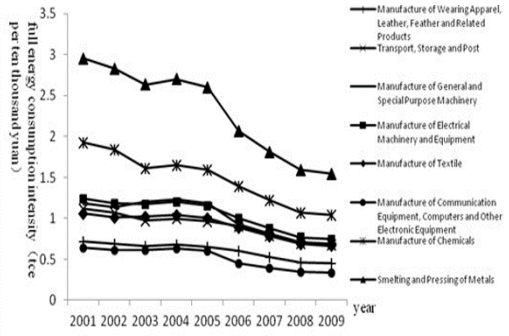

Fig.6. Full energy intensity of these eight industries during the period 2001-2009

We can see from Figure 6 that the full energy intensity of these eight sectors all dropped during the period 2001-2009, with different levels of decreasing in various industries, the full energy intensity of Smelting and Pressing of Metals, Manufacture of Chemicals decreased greatly, which were 46.0% and 47.7%, respectively. It generally had a great potential for saving energy. The full energy intensity of Manufacture of Communication Equipment, Computers and Other Electronic Equipment was the smallest of these eight sectors, but because of its large share of exports, the amount of embodied energy had been among the top three, which consumed a lot of energy in China.We would obtain the time series data of embodied energy for all these eight sectors after calculating during the period 2001-2009, as was shown in Figure 7.

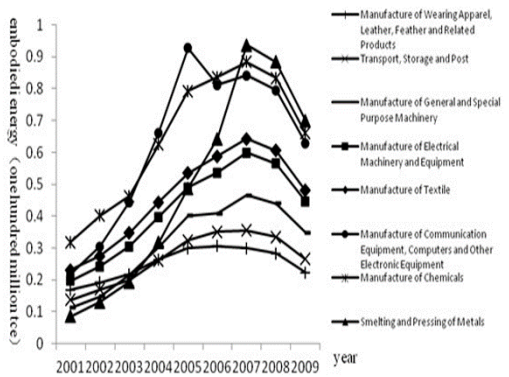

Fig.7. Embodied energy of the eight industries during the period 2001-2009

Overall, embodied energy of the eight industries had increased firstly and then decreased, which is similar to the changing trend of energy embodied in goods of all sectors, indicating that all industries were affected by the economic environment greatly. Exports trade was the leading reason for this situation, and the full energy intensity had certain influence, both of these two factors affected the changes of embodied energy.

From a sectoral point of view, Smelting and Pressing of Metals, Manufacture of Chemicals, Manufacture of Textile and Manufacture of Communication Equipment, Computers and Other Electronic Equipment were the largest energy-consuming sectors. Manufacture of Chemicals, Manufacture of Textile had been dominated by a large proportion of exports that the export volume of them ranked second and third, respectively,. In 2007, the full energy intensity of Manufacture of Chemicals was much higher than Manufacture of Textile, so the embodied energy of Manufacture of Chemicals was more than Manufacture of Textile. We need to focus on Smelting and Pressing of Metals and Manufacture of Communication Equipment, Computers and Other Electronic Equipment. The full energy intensity of Smelting and Pressing of Metals was the largest in all industries, but the embodied energy of it was small because exports of the sector were very small at the beginning of 2001-2009. In recent years, exports developed rapidly, export volume rose from 42120.76 million yuan of 2001 to 515549.05 million yuan of 2007, which was an increase of 10.18 times. Although its export volume ranked only seventh, its full energy intensity ranked first, both of them cause the rapid development of the embodied energy, so the embodied energy curve of Smelting and Pressing of Metals was very steep. The full energy of Manufacture of Communication Equipment, Computers and Other Electronic Equipment was the smallest during the period 2001-2009 in all sectors, because its export trade has been always the top 1, and the annual increase was substantial, so that embodied energy of exports had been in the top three**.**

4. RECOMMENDATIONS

China had output a lot of energy to foreign countries with the rapid development of export trade, which made energy demand continue to rise, the gap between energy supply and demand continued to expand due to the lack of domestic energy production, energy security is threatened. At the same time high energy consumption has led to serious environmental pollution, which made the international community focus on China's energy security and environmental pollution, China's energy saving face enormous pressure. November 2009, China declared that by 2020 carbon dioxide emissions per unit of GDP decreased by 40% -45% compared to 2005, the proportion of non-fossil energy consumption in total primary energy consumption would reach 15% or more. Adjusting and optimizing the export structure to reduce the direct and indirect energy consumption of exports becomes an effective way of reasonably controlling energy consumption, achieving the target of energy-saving and reducing emissions.

(1)Without prejudice to the development of export trade, the government should limit the export of these two sectors such as Smelting and Pressing of Metals, Manufacture of Chemicals, and appropriately encourage the development of some sectors such as Manufacture of Wearing Apparel, Leather, Feather and Related Products, Manufacture of Communication Equipment, Computers and Other Electronic Equipment, Manufacture of Textile, Transport, Storage and Post, Manufacture of General and Special Purpose Machinery, Manufacture of Electrical Machinery and Equipment. Smelting and Pressing of Metals, Manufacture of Chemicals are high energy-consuming, high-polluting industries, a large number of exports of these two industries will increase the burden on the domestic environment, causing serious environmental pollution,. These two sectors should be limited as the highly cost for economic development, and the threat to national energy security. Manufacture of Wearing Apparel, Leather, Feather and Related Products, Manufacture of Communication Equipment, Computers and Other Electronic Equipment, Manufacture of Textile are low energy-consuming sectors, with a greater competitive advantage than other industries because of large exports, so the three sectors should be encouraged. Transport, Storage and Post, Manufacture of General and Special Purpose Machinery, Manufacture of Electrical Machinery and Equipment are technical knowledge-intensive and high value-added industries, which are associated with other sectors and had the effect of employment expansion, so these industries should be actively encouraged.

(2) In order to reduce the full energy intensity of some industries and improve energy efficiency such as Smelting and Pressing of Metals, Manufacture of Chemicals, we should take use of clean energy technologies. From the results of the full energy intensity, the full energy intensity of Smelting and Pressing of Metals, Manufacture of Chemicals is largest in
all industries, which shows the largest decline in full energy intensity during the period 2002-2007, with the great potential of energy-saving, advanced clean energy production technology should be introduced to effectively reduce the full energy intensity in these two sectors. Under the dual role of limiting exports and reducing the full energy intensity, we can effectively reduce the embodied energy and control energy consumption.

(3)The Chinese Government should improve the energy pricing formation mechanism and rationally guide self-adjustment of export structure. China's energy market is not perfect, the energy price formation mechanism has not achieved fully market-oriented; the prices of major energy such as electricity, coal have been undervalued. Some energy subsidies policies made production and export of energy-intensive products receive a “false” and low-cost advantage, which would lead to the rapid development of energy-intensive industries and greater demand for energy in China. Energy price distortions are not sufficient to cause the inverse of energy prices, and energy-intensive industries can still obtain energy at a lower price, which makes it difficult to generate spontaneous power of adjusting the export structure. At present, in order to improve the energy price formation mechanism, the government should appropriately use energy subsidies and increase the costs of energy such as

coal, electricity, which determine prices of energy and guide the rational adjustment of the export structure.

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Table 1 the revised index of the average full energy intensity during the period 2001-2009

	2001	2002	2003	2004	2005	2006	2007	2008	2009
consumer price index (2001=100)	100	99.20	100.39	104.30	106.18	107.78	112.95	119.61	118.76
exchange rate (USD/RMB)	8.2770	8.2770	8.2770	8.2768	8.1917	7.9718	7.6040	6.9451	6.8310
energy consumption per unit of GDP (tce/ten thousand yuan)	1.3059	1.2615	1.2884	1.2711	1.2149	1.1385	0.9991	0.9075	0.9006

Table 2 the average full energy intensity and embodied energy in China's exports during the period 2001-2009

	2001	2002	2003	2004	2005	2006	2007	2008	2009
The average full energy intensity(tce/ten thousand yuan)	1.1375	1.08994	1.0993	1.1268	1.0851	0.8465	0.7426	0.6524	0.5554
Embodied energy(billion tce)	2.51	2．94	3.99	5.53	6.80	6.85	6.93	6.55	4.56