Relationship Between Energy Consumption and Industrial Structure

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Abstract — **This paper analyses the differences in energy consumption by industry and studies the relationship between industrial structure and energy consumption in China. The findings of the study indicate that energy consumption is mostly concentrated in the sector Industry. Energy consumption for most Chinese provinces is greatly affected by the share of tertiary industry. In some provinces, however, the energy consumption tends to be influenced by the share of secondary industry. Depending on the specific situation, appropriate recommendations are proposed to each province.**

Index Terms: **Energy consumption; industrial structure; energy structure; grey relational analysis; energy sustainability.**

I. Introduction

The aim of sustainable development makes the optimization and upgrading of industrial structure the main means of national macroeconomic regulation and control. The adjustment of industrial structure will effectively accelerate economic development and stimulate potential. However, since energy consumption differs among industries, the adjustment of industrial structure inevitably influences regional energy consumption. Scholars in China and other countries discuss the relationship between energy consumption and industrial structure. According to the studies, industrial restructuring has a significant effect on energy consumption. The influence of industrial structure on energy consumption varies among regions because of the disparities in the economic development and the resource endowment. However, there is still a lack of research on the specific impact of industrial structure on regional energy consumption in China. This study examines the differences in energy consumption among industries and the effect of industrial structure on energy consumption in China based on the recent data. The paper provides reasonable and effective suggestions to achieve sustainable economic growth in each region in China.

II. Inter-Industry Differences in Energy Consumption

The economic development in China is currently in the late stage of industrialization, where the heavy industry dominates. The sector Industry has a great demand for energy. According to the statistics of 2019, the sector Industry accounts for 66.16% of the total energy consumption, while the other sectors have significantly lower proportions: Agriculture, Forestry, Animal Husbandry and Fishery (1.85%), Construction (1.88%), Transport, Storage and Post (9.01%), Wholesale and Retail Trades, Hotels and Catering Services (2.79%), Residential (12.66%), and Others (5.66%).

In addition, in the sector Industry, some industries are characterized by unbalanced energy consumption. These are Smelting and Pressing of Ferrous Metals (13.41%), Manufacture of Raw Chemical Materials and Chemical Products (10.93%), Processing of Petroleum, Manufacture of Non-metallic Mineral Products (6.84%), Coal and Other Fuels (6.68%), and Production and Supply of Electric Power and Heat Power (6.51%). These industries belong to the category of heavy industry of China with high demand for energy and capital.

The data in Tables 1 and 2 indicate that major consumer of primary energy sources such as coal (96.36%), crude oil (99.99%), natural gas (68.37%) and electricity (67.72%) is also the sector Industry. Within the sector Industry, coal and crude oil are mainly consumed by the industries related to mining, processing and conversion of energy. While natural gas and electricity are used in part for energy conversion and basic supply, the rest of the energy demand is concentrated in the manufacture of metals or minerals and the manufacture of chemical raw materials and chemical products. These industries belong to the category of heavy industry and have a great demand for resources and capital.

The main coal consumer within the sector Industry is Production and Supply of Electric Power and Heat Power (50.21%), which accounts for more than half of

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Table 1. Energy Consumption by Sector

Sector	Coal	Coke	Crude Oil	Gasoline	Kerosene	Diesel Oil	Fuel Oil	Natural Gas	Electricity
Agriculture, Forestry, Animal Husbandry and Fishery	0.55%	0.13%		1.86%	0.28%	9.89%	0.03%	0.04%	1.78%
Industry	96.36%	99.77%	99.99%	1.92%	0.28%	8.65%	55.70%	68.37%	67.72%
Construction	0.16%	0.02%		3.67%	0.41%	3.55%	0.68%	0.09%	1.32%
Transport, Storage and Post	0.07%		0.01%	45.82%	93.39%	66.14%	43.18%	11.16%	2.34%
Wholesale and Retail Trades, Hotels and Catering Services	0.59%	0.04%		2.11%	0.39%	1.37%	0.22%	2.04%	4.26%
Others	0.65%	0.01%		16.44%	4.66%	6.40%	0.20%	1.87%	8.37%
Residential	1.63%	0.03%		28.17%	0.59%	4.00%		16.42%	14.21%

the total coal consumption in the sector Industry. It is followed by Processing of Petroleum, Coal and Other Fuels (13.43%), Smelting and Pressing of Ferrous Metals (6.96%), Manufacture of Non-metallic Mineral Products (5.63%), Mining Products (5.63%), Mining and Washing of Coal (5.51%), Manufacture of Raw Chemical Materials and Chemical Products (5.48%), Smelting and Pressing of Non-metallic Mineral Products (5.63%), Smelting and Pressing of Non-ferrous metals (5.17%). They all account for a relatively large share of coal consumption. Similarly, almost all of China's crude oil consumption comes from the sector Industry. Within the sector Industry, Processing of Petroleum, Coal and Other Fuels consumes 93.99% of crude oil consumed in the entire sector. It is evident that most of the crude oil is used for conversion to other types of fuels. In addition, the sector Industry accounts for 68.37% of the total natural gas consumption, with the Manufacture of Raw Chemical Materials and Chemical Products (13.39% of total sectoral consumption), Production and Supply of Electric Power and Heat Power (16.11%), Extraction of Petroleum and Natural Gas (5.06%), Processing of Petroleum, Coal and Other Fuels (5.61%), and Manufacture of Non-metallic Mineral Products (5.83%) consuming a large proportion of natural gas within the sector. From the perspective of electricity consumption within the sector Industry, it is significantly higher in Production and Supply of Electric Power and Heat Power (12.07%), Smelting and Pressing of Non-ferrous Metals (8.91%), Smelting and Pressing of Ferrous Metals (8.63%), Manufacture of Raw Chemical Materials and Chemical Products (7.25%), Manufacture of Non-metallic Mineral Products (5.02%), whereas in the other industries, it is relatively balanced.

As for the other energy sources, energy consumption structures are sector- and industry-specific. Energy demand in the sector Industry is mostly concentrated in the heavy industries, except for the condition where the sector Industry does not have a significant demand for a certain energy. The heavy industries absorb large amounts of resources and capital and are generally the pillar. However, these industries tend to have problems such as energy waste and excessive pollution. And due to various factors like industrial structure, it is difficult for these industries to transform their existing production patterns to reduce their energy input and pollution output.

The sector Industry consumes almost all energy coke available with the share of 99.77% of the total coke consumption. Most of the coke consumption within the sector Industry (84.54%) falls on the Smelting and Pressing of Ferrous Metals, which also belongs to the heavy industry category. However, gasoline consumption in the sector Industry only accounts for 1.92% of the total consumption, which is much lower compared to the consumption in all other sectors. The sector Industry shows relatively balanced consumption of gasoline for various industries with a quite low share of total gasoline consumption in the sector. Moreover, there is not any significant difference in gasoline consumption between the industries. Kerosene consumption in the sector Industry accounts for only 0.28% of its total consumption. The sector Transport, Storage and Post is the largest kerosene consumer, which accounts for 93.39%. Similarly, due to the low total consumption of kerosene in the sector Industry, it is clear that there is no significant demand for this resource, thus, the kerosene consumption is relatively balanced within the sector Industry and there is no significant difference in its consumption between the industries. The consumption of diesel oil by the sector Industry is also insignificant, with 8.65% of the total diesel oil consumption, which is significantly lower than 66.14% of diesel oil consumption in the sector Transport, Storage and Post. In the sector Industry, diesel oil is mainly used in the Manufacture of Non-metallic Mineral Products (2.11%), Mining and Washing of Coal (1.02%), and Professional and Support Activities for Mining (1.03%), which also belong to the heavy industry category having a great demand for resources and capital. Fuel oil consumption is concentrated in the sector Industry (55.70%) and in the sector Transport, Storage and Post (43.18%). Within the sector Industry, there are significant inter-industry differences in fuel oil consumption, with 40.40% of fuel oil consumed in Processing of Petroleum, Coal and Other Fuels and 11.99% in Manufacture of Raw Chemical Materials and Chemical Products. The demand for fuel oil in the other industries is significantly lower.

III. The Relationship Between Energy Consumption and Industrial Structure

The above analysis indicates that there are obvious differences in energy consumption among different industries. The regional disparities in industrial structure will result in differences in regional energy consumption, which could affect the sustainable energy development. In this context, based on the data on total energy consumption and industry output value from 2015 to 2019, the grey relational analysis is applied to calculate the grey relational coefficient for each industry in each province of China to study the relationship between energy consumption and industrial structure.

(1) Determine the reference sequence. Suppose the reference sequence is denoted as: $x_0 = \{x_0(1), x_0(2), ..., x_0(n)\}$, the comparison sequence is denoted as: $x_i = \{x_i(1),$

Table 2. Energy Consumption by Industry part 1

Industry	Coal	Coke	Crude Oil	Gasoline	Kerosene	Diesel Oil	Fuel Oil	Natural Gas	Electricity
Coal Mining and Washing	5.72%	0.11%		1.89%	6.84%	11.83%	0.01%	8.92%	2.03%
Petroleum and Natural Gas Extraction	0.03%		0.95%	2.67%		3.15%	0.23%	1.18%	0.86%
Mining and Processing of Ferrous Metal Ores	0.05%	0.32%		0.31%		3.30%		7.41%	0.83%
Mining and Processing of Non-Ferrous Metal Ores	0.02%	0.01%		0.63%	4.19%	1.69%	0.04%		0.76%
Mining and Processing of Nonmetal Ores	0.19%	0.02%		0.40%	0.18%	4.17%		0.03%	0.51%
Professional and Support Activities for Mining	0.15%			1.46%		11.92%	0.02%	0.08%	0.08%
Mining of Other Ores						0.01%		0.22%	0.42%
Processing of Food from Agricultural Products	0.44%	0.27%		2.71%	0.82%	1.67%	0.06%	67.14%	1.57%
Manufacture of Foods	0.42%			1.61%		0.64%	0.04%	1.51%	0.60%
Manufacture of Liquor, Beverages and Refined Tea	0.16%			1.10%	0.55%	0.37%	0.01%	1.16%	0.34%
Manufacture of Tobacco				0.15%		0.08%		0.80%	0.10%
Manufacture of Textile	0.20%	0.01%		2.13%	0.27%	0.46%	0.13%	0.06%	3.47%
Manufacture of Textile, Wearing Apparel and Accessories	0.01%			1.87%	0.46%	0.42%	0.02%	2.15%	0.46%
Manufacture of Leather, Fur, Feather and Related Products and Footwear	0.01%			1.09%	0.09%	0.15%	0.01%	0.52%	0.31%
Processing of Timber, Manufacture of Wood, Bamboo, Rattan, Palm, and Straw Products	0.02%			0.65%		0.40%	0.01%	0.10%	0.55%
Manufacture of Furniture				0.92%		0.23%	0.01%	0.14%	0.23%
Manufacture of Paper and Paper Products	1.02%			0.96%	0.09%	1.20%	0.31%	0.08%	1.47%
Printing and Reproduction of Recording Media	0.02%			1.37%	0.09%	0.33%	0.02%	1.08%	0.26%
Manufacture of Articles for Culture, Education, Arts and Crafts, Sport and Entertainment Activities				1.26%	1.00%	0.27%	0.02%	0.24%	0.18%
Processing of Petroleum, Coal and Other Fuels	13.94%	0.15%	94.00%	10.64%	1.64%	8.35%	72.54%	0.67%	2.36%
Manufacture of Raw Chemical Materials and Chemical Products	5.68%	8.67%	5.05%	5.40%	17.32%	3.05%	21.53%	8.20%	10.71%
Manufacture of Medicines	0.20%	0.01%		1.50%	0.09%	0.45%	0.10%	19.58%	0.80%
Manufacture of Chemical Fibers	0.34%	0.04%		0.23%	0.18%	0.13%	0.02%	0.72%	0.90%
Manufacture of Rubber and Plastics Products	0.10%			3.61%	0.55%	0.92%	0.13%	0.68%	2.81%
Manufacture of Non-metallic Mineral Products	5.84%	2.89%		5.63%	7.57%	24.35%	3.69%	0.85%	7.42%
Smelting and Pressing of Ferrous Metals	7.23%	84.73%		1.28%	0.18%	4.10%	0.02%	8.53%	12.74%
Smelting and Pressing of Non-ferrous Metals	5.36%	0.88%		1.29%	4.92%	2.62%	0.53%	6.58%	13.16%
Manufacture of Metal Products	0.09%	1.01%		4.43%	4.10%	1.51%	0.06%	2.69%	3.30%
Manufacture of General Purpose Machinery	0.01%	0.53%		5.84%	14.77%	1.65%	0.03%	3.02%	1.99%
Manufacture of Special Purpose Machinery	0.01%	0.02%		4.52%	7.02%	1.12%	0.02%	1.04%	0.99%
Manufacture of Automobiles	0.03%	0.03%		9.44%	2.46%	2.09%	0.01%	0.99%	2.03%
Manufacture of Railway, Ship, Aerospace and Other Transport Equipment	0.01%			1.34%	8.66%	0.87%	0.05%	1.28%	0.33%
Manufacture of Electrical Machinery and Apparatus	0.01%			5.70%	3.83%	0.83%	0.08%	1.05%	1.69%
Manufacture of Computers, Communication, and Other Electronic Equipment	0.11%			3.66%	1.37%	0.50%	0.02%	0.57%	2.96%
Manufacture of Measuring Instruments and Machinery				1.47%	1.09%	0.08%		1.64%	0.15%

Table 2. Energy Consumption by Industry part 2

Industry	Coal	Coke	Crude Oil	Gasoline	Kerosene	Diesel Oil	Fuel Oil	Natural Gas	Electricity
Other types of Manufacture				0.26%	0.73%	0.09%		0.05%	1.14%
Utilization of Waste Resources	0.03%	0.21%		0.12%	0.18%	0.38%	0.05%	0.21%	0.11%
Repair Service of Metal Products, Machinery and Equipment				0.17%	8.48%	0.34%	0.01%	0.92%	0.03%
Electric Power and Heat Power Production and Supply	52.11%	0.09%		8.23%		4.04%	0.15%	23.95%	17.82%
Gas Production and Supply	0.44%			0.97%		0.11%		23.56%	0.37%
Water Production and Supply	0.01%			1.13%		0.15%		0.36%	1.17%

Table 3. Impact Coefficients by Industry in Each Province in China

Region	Primary Industry	Secondary Industry	Tertiary Industry	Industry with the greatest impact on energy consumption
CHINA	**0.587**	**0.566**	**0.814**	**Tertiary Industry**
Anhui	0.548	0.649	0.776	Tertiary Industry
Beijing	0.542	0.768	0.954	Tertiary Industry
Chongqing	0.469	0.485	0.887	Tertiary Industry
Fujian	0.495	0.717	0.869	Tertiary Industry
Gansu	0.436	0.650	0.835	Tertiary Industry
Guangdong	0.462	0.618	0.919	Tertiary Industry
Guangxi	0.817	0.598	0.821	Tertiary Industry
Guizhou	0.618	0.662	0.874	Tertiary Industry
Hainan	0.497	0.619	0.787	Tertiary Industry
Hebei	0.585	0.700	0.752	Tertiary Industry
Henan	0.479	0.709	0.689	Secondary Industry
Heilongjiang	0.716	0.626	0.789	Tertiary Industry
Hubei	0.517	0.709	0.882	Tertiary Industry
Hunan	0.457	0.677	0.847	Tertiary Industry
Jilin	0.458	0.589	0.647	Tertiary Industry
Jiangsu	0.505	0.845	0.952	Tertiary Industry
Jiangxi	0.494	0.631	0.902	Tertiary Industry
Liaoning	0.638	0.692	0.696	Tertiary Industry
Inner Mongolia	0.761	0.521	0.774	Tertiary Industry
Ningxia	0.520	0.543	0.668	Tertiary Industry
Qinghai	0.750	0.531	0.703	Tertiary Industry
Shandong	0.620	0.639	0.766	Tertiary Industry
Shanxi	0.441	0.894	0.776	Secondary Industry
Shaanxi	0.476	0.666	0.861	Tertiary Industry
Shanghai	0.562	0.795	0.977	Tertiary Industry
Sichuan	0.515	0.533	0.832	Tertiary Industry
Tianjin	0.410	0.666	0.643	Secondary Industry
Xinjiang	0.486	0.769	0.870	Tertiary Industry
Yunnan	0.588	0.673	0.864	Tertiary Industry
Zhejiang	0.499	0.620	0.911	Tertiary Industry

$x_i(2), ..., x_i(n)\}$, $i = 1, 2, ..., m$.

(2) Normalize indicators. The dimensionless method is applied to original data.

(3) Calculate the grey relational coefficient. The normalized sequence $x_0 = \{x_0(1), x_0(2), ..., x_0(n)\}$ is regarded as the reference sequence; $x_i = \{x_i(1), x_i(2), ..., x_i(n)\}$, $i = 1, 2, ..., m$ is regarded as the comparison sequence. The associated sequence is calculated as

$$\xi_i(k) = \frac{\min\limits_i \min\limits_k \left|x_0(k) - x_i(k)\right| + \rho \max\limits_i \max\limits_k \left|x_0(k) - x_i(k)\right|}{\left|x_0(k) - x_i(k)\right| + \rho \max\limits_i \max\limits_k \left|x_0(k) - x_i(k)\right|},$$

where $i = 1, 2, \ldots, m$, $k = 1, 2, \ldots, n$, $\rho \in [0,1]$, generally $\rho = 0.5$.

Relational coefficient matrix is:

$$E = \zeta_{ik} \ (i = 1, 2, \ldots, m, k = 1, 2, \ldots, n).$$

(4) Calculate grey relational grade:

$$r_i = \sum_{k=i}^{n} w_i \xi_i(k).$$

Based on the calculation, we obtain the coefficients of specific impact of industrial structure on the energy consumption in each province in China and the industry with the greatest impact on energy consumption as shown in Table 3.

In general, the tertiary industry produces the greatest effect on energy consumption in China, followed by the secondary industry and the primary industry. Therefore, the energy consumption is largely determined by the share of tertiary industry. A change in the share of tertiary industry would greatly influence the reginal energy consumption. With a decrease in the contribution of primary and secondary industry to gross domestic product from 2015 to 2019, the contribution of tertiary industry increased during that period. The influence of the tertiary industry on energy consumption increased as well.

In most of the provinces in China, the share of tertiary industry influences the energy consumption. For these provinces, the focus should be put on optimising the internal industrial structure, reducing energy intensity, and developing energy-saving technologies. Besides, the energy consumption in three provinces (Henan, Shanxi, and Tianjin) is more affected by the share of secondary industry. For these three provinces, there is a possibility that the growing share of secondary industry will increase energy consumption. For this kind of provinces, certain measures should be taken to limit the growth of secondary industry and reduce the share of secondary industry. It is also necessary to promote the development of tertiary industry and improve its contribution to gross regional product. The economic development should be driven by the tertiary industry.

IV. Conclusion

China's economic development is currently in the late stage of industrialization dominated by heavy industry. The energy consumption of the sector Industry accounts for a large proportion of the total energy consumption. The share of the sector Industry in the consumption of primary energy sources is also large. The consumption of coal and crude oil is concentrated in the industries associated with mining, processing and conversion of energy within the sector Industry. While natural gas and electricity are used in part for energy conversion and basic supply, the rest of the demand is concentrated in the industries related to manufacture of metals or minerals and manufacture of chemical raw materials and chemical products. With regard to the other kinds of energy, for example, coke, the sector Industry consumes almost all of it. The demand for gasoline, kerosene, and diesel oil in the sector Industry is relatively low. The sector Industry and the sector Transport, Storage, and Post are the main consumers of fuel oil. In the sector Industry, energy demand is mostly concentrated in the heavy industries, except for the condition where the sector Industry does not have a significant demand for certain energy.

Since energy consumption obviously differs for different industries, the regional disparities in industrial structure can result in differences in regional energy consumption. The energy consumption in China is most likely to be affected by the tertiary industry followed by the secondary industry and the primary industry. Furthermore, the energy consumption tends to be influenced by a change in the share of tertiary industry. In addition, energy consumption in most of the provinces in China is greatly influenced by the share of tertiary industry. It is crucial to optimize the internal industrial structure, reduce energy intensity, and develop energy-saving technologies in these provinces. Some provinces, however, are affected by the share of secondary industry. Therefore, measures should be taken for this kind of provinces to reduce the share of secondary industry and improve the contribution of tertiary industry to gross regional product.

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