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ВЗАИМОСВЯЗЬ МЕЖДУ УРОВНЕМ ЭНЕРГОПОТРЕБЛЕНИЯ И СТРУКТУРОЙ ПРОМЫШЛЕННОСТИ В ПРОВИНЦИЯХ КИТАЯ

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Исследуются уровень и структура энергопотребления, а также структура промышленности в провинциях Китая. Проводится серый реляционный анализ для изучения взаимосвязи между уровнем энергопотребления и структурой промышленности, и определяется величина влияния различных отраслей промышленности на энергопотребление в регионе. Предлагаются соответствующие меры по оптимизации энергопотребления для каждого типа провинций.

Ключевые слова: энергопотребление; промышленная структура; структура энергопотребления; серый реляционный анализ; рационализация структуры.

THE RELATIONSHIP BETWEEN ENERGY CONSUMPTION AND INDUSTRIAL STRUCTURE IN CHINESE PROVINCES

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This paper analyses the situation of Chinese provinces in terms of energy consumption, industrial structure, and energy consumption structure. With the data of China and its various provinces, we apply grey relational analysis to study the relationship between energy consumption and industrial structure, and identify the magnitude of the impact of the different industries on energy consumption in each region. Corresponding optimisation measures are also proposed to each type of provinces.

Keywords: energy consumption; industrial structure; energy consumption structure; grey relational analysis; structure rationalisation.

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Introduction

Under the goal of sustainable economic development pursued by all countries, the optimisation and upgrading of industrial structure has become the main means of national macroeconomic regulation and control for realising a healthy, stable and sustainable development. The adjustment of industrial structure will effectively promote the speed and potential of economic development. The industrial structure of a region is also a way to evaluate the development. However, the adjustment of industrial structure inevitably affects regional energy consumption. The relationship between energy consumption and industrial structure has been discussing by scholars in China and abroad.

In 1999, Lu Zhengnan studied the relationship between industrial structure and energy consumption with regression method and confirmed that changes in industrial structure would affect energy demand [1]. In 2014, Shi Xiuhua and Liu Lun studied the impact of different industries on energy consumption with the method of comparative analysis and grey relational analysis. They believe that industrial restructuring has an important impact on energy consumption [2]. In 2019, Xuan Zou and Pan Wang argued and analysed the effect of industrial structure on energy consumption with the spatial Durbin model. And they discussed the differences in the effect of energy consumption caused by industrial structure in Chinese provinces where various energy endowments exist [3]. In 2002, F. Krausmann and H. Haberl, in their study of industrialisation and structural changes in energy consumption in Australia, confirmed that energy consumption is strongly correlated with changes in industrial structure brought about by industrialisation in both aggregate and structural terms [4]. In 2014, K. Narayanan and S. K. Sahu, in the study of energy consumption response to climate change, pointed out that the most important reason for the decrease in energy consumption is the change in the economic structure [5].

According to the research results of domestic and foreign scholars, we can know that industrial restructuring has an important impact on energy consumption. Because of the different economic levels and resource endowments, the impact of industrial structure on energy consumption varies among regions. China is a vast country. The economic level, social development, and resource endowment of each province are all different. Therefore, a study on the relationship between energy consumption and industrial structure in each province of China will show reasonable and effective way to achieve sustainable economic growth in each region.

Methodology

This paper uses total energy consumption and output value of industries in each region of China from 2015 to 2019 as the original data. And the grey relational analysis is applied to study the relationship between energy consumption and industrial structure in each region of China. Grey relational analysis is one of the most widely used models of grey system theory. It uses a specific concept of information. It defines situations with no information as black, and those with perfect information as white. However, neither of these idealised situations ever occurs in real world problems. And situations between these extremes, which contain partial information, are described as being grey. Therefore, this paper will apply grey relational analysis to study the practical problems on the relationship between energy consumption and industrial structure in each region of China, which could be with imperfect information.

Suppose the reference sequence is denoted as

$$X_0 = \{x_0(1), x_0(2), \ldots, x_0(n)\},$$

where X_0 is energy consumption in each region; x_0 is energy consumption in each region in one studied year; n is different studied years.

And the comparison sequence is denoted as

$$X_i = \{x_i(1), x_i(2), \ldots, x_i(n)\},$$

where X_i is the share of the three sectors; i – primary, secondary or tertiary sectors; x_i – the share of the i sectors in each region in one studied year.

The formula is carried out to reduce values of each indicator to a uniform range:

$$x_0' = \frac{x_0 - x_{\min}}{x_{\max} - x_{\min}},$$

$$x_i' = \frac{x_i - x_{\min}}{x_{\max} - x_{\min}},$$

where x_0' and x_i' are the normalised value of indicators x_0 and x_i, respectively; $x_{\min}$ is the minimum value of certain indicator among basic data; $x_{\max}$ is the maximum value of certain indicator among basic data.

The associated sequence is calculated with the formula

$$\xi_i(k) = \frac{\min_i \min_k \left|x_0'(k) - x_i'(k)\right| + \rho \max_i \max_k \left|x_0'(k) - x_i'(k)\right|}{\left|x_0'(k) - x_i'(k)\right| + \rho \max_i \max_k \left|x_0'(k) - x_i'(k)\right|},$$

$$\rho \in [0, 1], \text{ generally } \rho = 0.5,$$

where $\xi_i(k)$ is the correlation coefficient of i sector in the year k; $\min_i$ is the minimum value of three sectors; $\min_k$ is the minimum value in all studied years; $x_0'(k)$ is the normalised value of energy consumption in each region in the year k; $x_i'(k)$ is the normalised value of the share of the i sectors in each region in the year k; ρ is the dynamic distinguishing coefficient; $\max_i$ is the maximum value of three sectors; $\max_k$ is the maximum value in all studied years.

Grey relational grade would be calculated with the formula

$$r_i = \sum_{k=i}^{n} w_j \xi_i(k),$$

where r_i is the grey relational grade of i sector; w_j – the weight of the elements of the data sets.

Energy consumption and industrial structure by region

Energy consumption. Total energy consumption in China has been increasing during the period examined in the study. In 2015, total energy consumption in China is 4341.13 mln t. While this figure has grown to 4874.88 mln t in 2019. The growth rate over five years is 12.30 %. Due to the vast territory of China and the differences in economic development, social construction, resource endowment, and industrial structure, there are significant inter-regional differences in energy consumption among Chinese provinces. The data on energy consumption by region in 2015, 2017 and 2019 are selected to make a line graph (fig. 1).

As we can see from the fig. 1, the energy consumption in different provinces of China shows significant differences during the period under study. Some of the economically developed regions located in the centre of China or coastal regions with larger populations consume significantly more energy than others, such as Guangdong, Hebei, Jiangsu, Shandong. And the remote regions with small population consume less energy, such as Hainan, Ningxia, and Qinghai. Due to the unbalanced economy, industrial structure, resource endowment, geographic location and population, energy consumption fluctuates widely among regions. Comparing the data in each year, we can notice that the variation of energy consumption in certain province is not significant, although it has been rising year by year in some provinces. China is currently in a period of steady development, with no leapfrog development in all aspect in each province. And there is no more economic advancement at the expense of overused resource and environment.

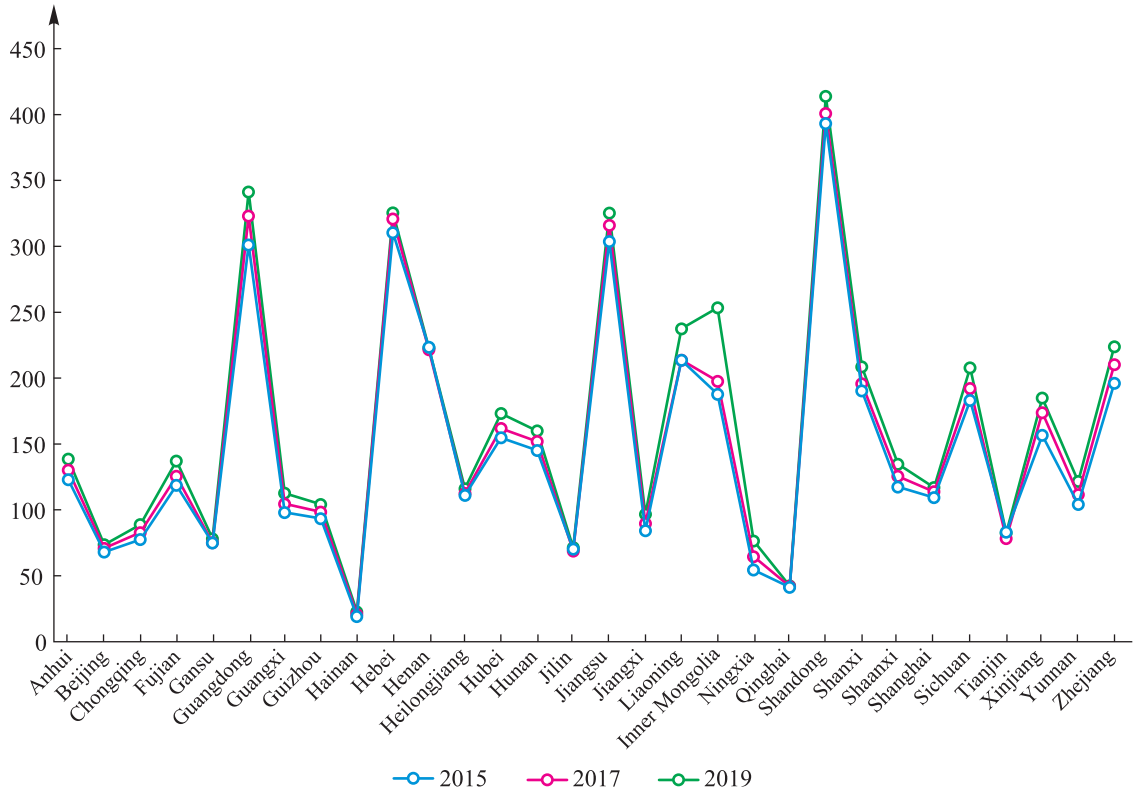

Fig. 1. Energy consumption by China's region in 2015, 2017 and 2019, mln t

Industrial structure. China's economic development is currently in the middle or late stage of industrialisation dominated by heavy industry. A large part of the gross domestic product still comes from the secondary industry, which has a high demand for energy and capital inputs. Especially for some regions with sufficient resource reserves, the secondary industry is still their pillar industry. However, the ratio of tertiary sector will definitely increase as society moves forward. The data on industrial structure by region in 2015 and 2019 are plotted in a bar chart (fig. 2).

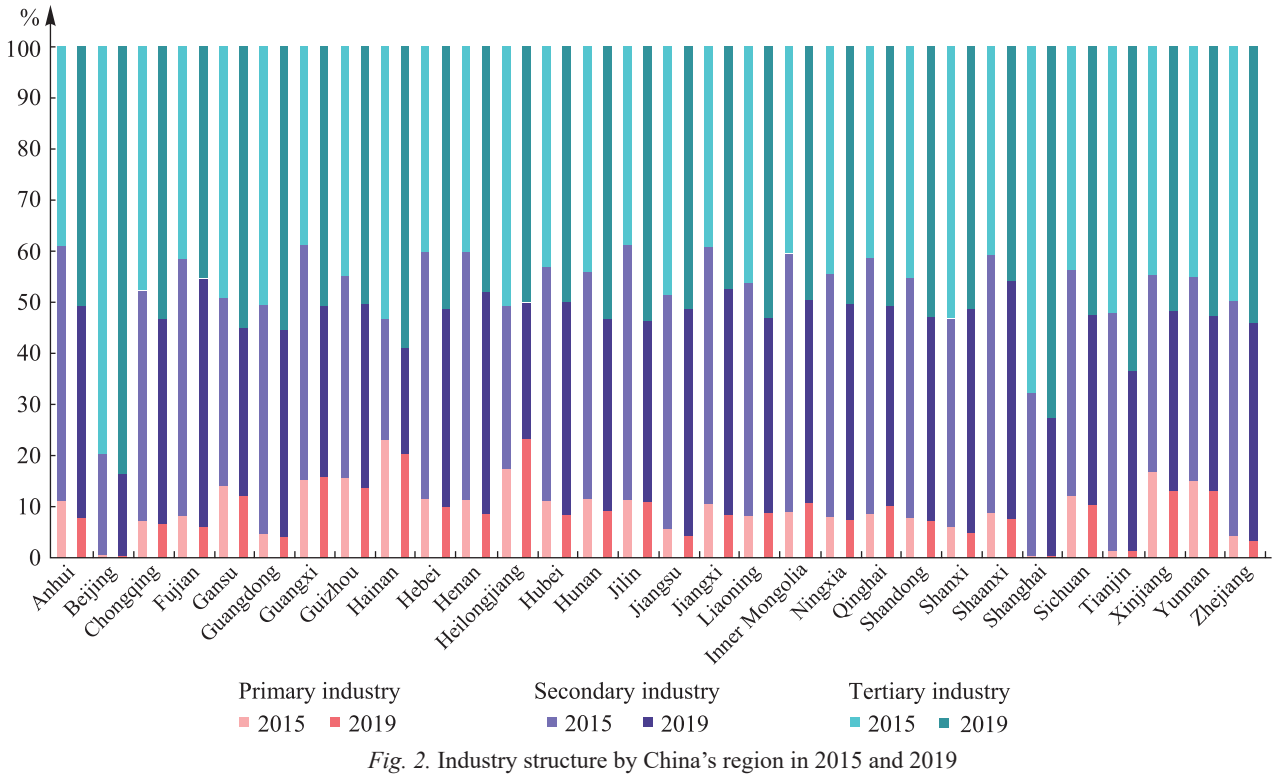

Fig. 2. Industry structure by China's region in 2015 and 2019

From the fig. 2, we can see that all provinces have either secondary or tertiary industries as the main source of the gross regional product. There are obvious differences in the industrial structure among provinces, which can be mainly divided into secondary industry led and tertiary industry led. In 2015, there are 15 provinces belonging to the secondary industry led type, namely Anhui, Fujian, Guangxi, Hebei, Henan, Hubei, Hunan, Jilin, Jiangxi, Inner Mongolia, Ningxia, Qinghai, Shandong, Shaanxi, and Sichuan. The provinces Anhui, Hebei, Henan, Inner Mongolia, Shandong, Shaanxi, and Sichuan, are resource-based regions with large amounts of energy production such as coal and coke. And there are remote provinces with not well-developed economy, such as Guangxi, Jilin, Jiangxi, Ningxia, Qinghai. In 2015, there are 15 provinces belonging to the tertiary industry led type, namely Beijing, Chongqing, Gansu, Guangdong, Guizhou, Hainan, Heilongjiang, Jiangsu, Liaoning, Shanxi, Shanghai, Tianjin, Xinjiang, Yunnan, and Zhejiang. Some provinces are economically developed and located in the centre or coastal regions, such as Beijing, Guangdong, Jiangsu, Shanghai, Zhejiang. And some have huge tourism industry, such as Hainan, Xinjiang, Yunnan. As for the industrial structure by region in 2015, the secondary industry dominated provinces accounted for the same percentage as the tertiary industry dominated provinces.

In 2019, the industrial structure in certain provinces has changed with development. Some secondary industry led provinces have shifted to tertiary industry led provinces. In 2019, only Fujian and Shaanxi are among the secondary industry led provinces. Other 13 provinces which belonged to secondary industry led type in 2015 have changed from secondary industry led to tertiary industry led over five years. It could be seen that the transformation of industrial structure in Chinese provinces develops rapidly, with some provinces having completed their transformation in 2015–2019. The tertiary industries have the largest contribution to gross regional product in the vast majority of provinces of China in 2019. For the primary industry, except for some remote provinces which still maintain a certain proportion of primary industry, the other provinces have been reducing the proportion of primary industry in varying degrees from 2015 to 2019.

Energy consumption structure. China's economic development is currently in the middle or late stage of industrialisation dominated by heavy industry. The sector industry has a huge demand for energy due to a variety of factors, such as industrial structure and social demand. 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 %).

According to fig. 3 and 4 it can be seen that the energy consumption of the various industries is unbalanced. Among them smelting and pressing of ferrous metals (13.41 %), manufacture of raw chemical materials and chemical products (10.93 %), manufacture of non-metallic mineral products (6.84 %), processing of petroleum, coal and other fuels (6.68 %), and production and supply of electric power and heat power (6.51 %) have a higher energy consumption. For primary energy sources such as coal (96.36 %), crude oil (99.99 %), natural gas (68.37 %) and electricity (67.72 %), the sector industry also accounts for a substantial share of the total consumption. Within the sector industry, the consumption of coal and crude oil is concentrated in the industries about 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 consumption is concentrated in the industries related to the manufacture of metals or minerals and the manufacture of chemical raw materials and chemical products. These industries belong to the category of heavy industries, and they have a great demand for resources and capital [6].

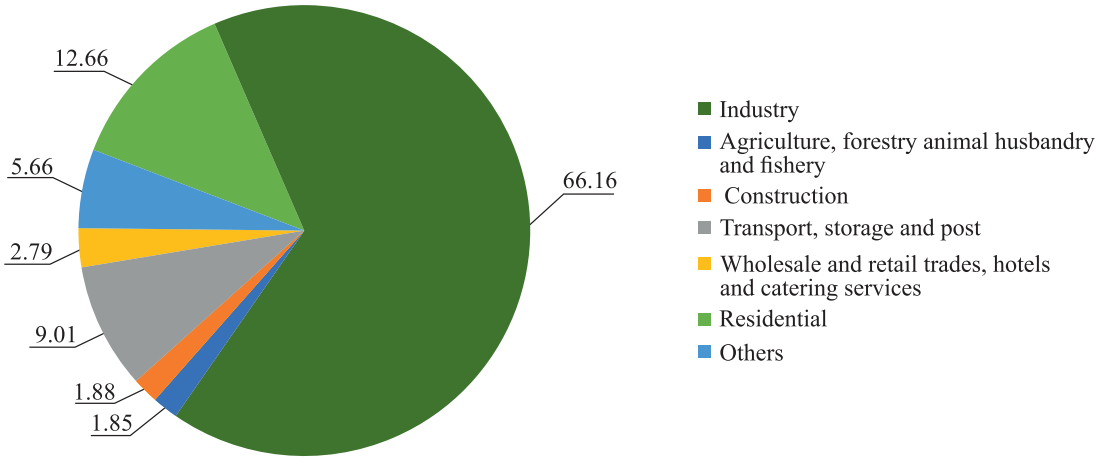

Fig. 3. Energy consumption by sector in 2019

At the national level, the secondary industry which includes the industry sector consumes most of the coal, coke, and electricity. Although the consumption of petroleum products and natural gas in the secondary industry is not as much as that in the tertiary industry, the secondary industry still accounts for a larger share of the total consumption. At the regional level, the consumption of coal mainly comes from the secondary industry in most of provinces in China, with only some provinces consuming significantly less coal in the secondary industry. As for these provinces, the consumption of coal would be more possible from the industry residential which are tertiary industry. As the capital of China, Beijing has a huge population and a well-developed society. And its energy demand generated by the operation of the city is unparalleled to other regions. As for Guizhou whose largest consumption of coal is also in the tertiary industry, the industry wholesale and retail trades, hotels and catering service shows an outstanding energy demand for coal. While as for Heilongjiang, the reason of its relatively small consumption of coal is prominent share of coal consumption in the primary industry. Besides, the consumption of coke comes mostly from the secondary industry in all provinces of China. And there are huge differences in the consumption of petroleum products among industries and among regions. There exist two possible situations. The one is that the consumption of petroleum products in the tertiary industry is significantly higher than that in the primary or secondary industry. The majority of provinces in China are in this kind of situation. The other is that the primary sector consumes less petroleum products, and the secondary and tertiary industry consume equal amount of petroleum products. The raw data shows that the provinces in this situation usually have a huge demand for petroleum products due to industrial characteristics. As for natural gas, there are obvious differences in the consumption among provinces. All provinces could be divided into two types, the secondary industry as the main consumer or the tertiary industry as the main consumer. The consumption of natural gas tends to come from the production and manufacturing industries that belong to the secondary industry. From the table 1, we can see that the provinces where the consumption of natural gas in the secondary industry occupies a larger share are generally the regions with more developed manufacturing industries, such as Chongqing, Fujian, Guangdong, etc. The same situation occurs in the consumption of electricity. There are obvious differences in the consumption of electricity among industries and among regions. The two types of the consumption of electricity in Chinese provinces are also the secondary industry as the main consumer and the tertiary industry as the main consumer. However, electricity has a wide range of industrial uses, and each province has a different pattern of electricity consumption.

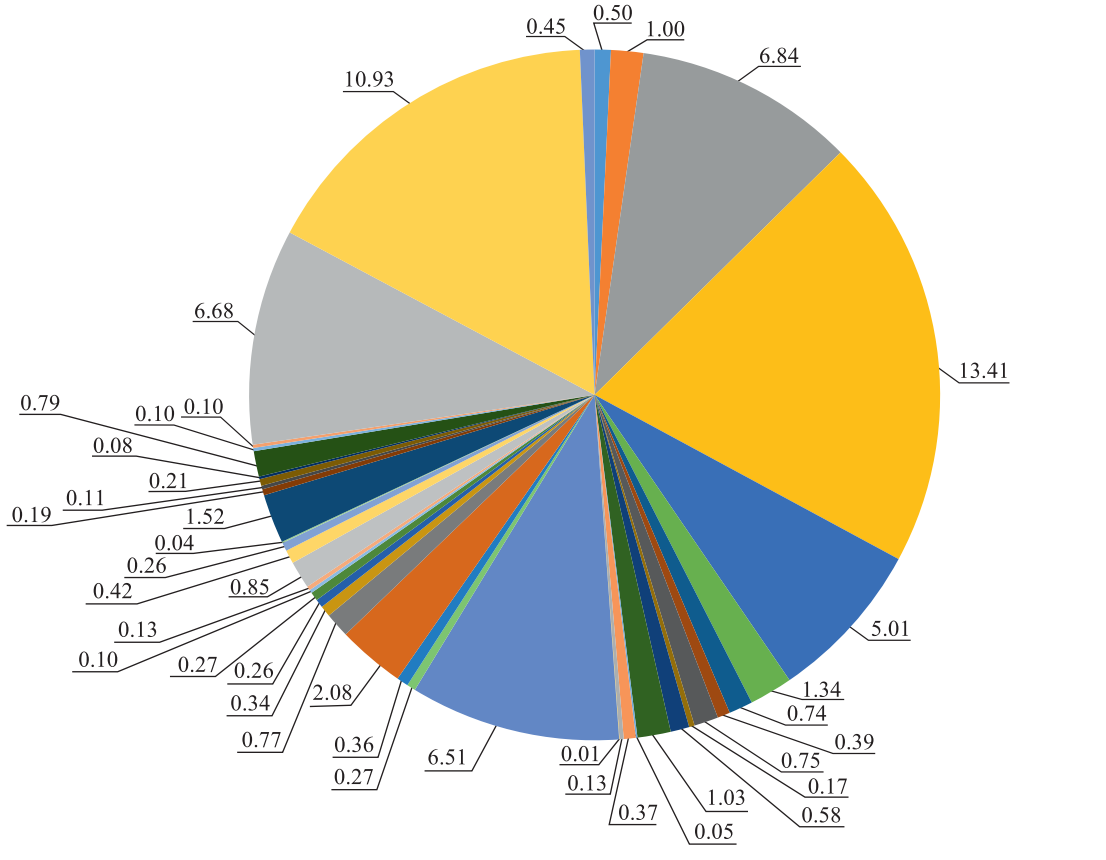

Fig. 4. Energy consumption by industry in industry sector in 2019

Table 1

Energy consumption of various industries by region in China in 2019, %

Region	Coal total			Coke			Petroleum products total			Natural gas			Electricity		
	Primary industry	Secondary industry	Tertiary industry	Primary industry	Secondary industry	Tertiary industry	Primary industry	Secondary industry	Tertiary industry	Primary industry	Secondary industry	Tertiary industry	Primary industry	Secondary industry	Tertiary industry
Anhui	0.64	98.39	0.97	0.00	100.00	0.00	6.39	18.07	75.55	0.00	34.06	65.96	1.53	63.00	35.47
Beijing	2.79	42.65	54.57	0.00	100.00	0.00	0.25	19.88	79.87	0.00	24.02	75.99	1.61	23.56	74.83
Chongqing	2.50	94.27	3.23	0.00	100.00	0.00	3.25	13.41	83.34	1.31	67.36	31.34	0.36	58.98	40.66
Fujian	1.28	97.35	1.37	0.00	100.00	0.00	3.87	43.40	52.73	0.00	85.40	14.60	1.65	62.96	35.39
Gansu	2.63	71.40	25.97	0.00	100.00	0.00	5.62	30.71	63.67	0.00	30.13	69.87	3.66	74.67	21.67
Guangdong	1.09	95.72	3.18	0.00	96.02	3.98	2.49	30.21	67.30	0.00	71.01	28.99	2.01	60.59	37.40
Guangxi	0.00	99.94	0.06	0.00	100.00	0.00	6.62	24.64	68.74	0.00	31.51	68.49	1.86	64.91	33.23
Guizhou	4.20	53.58	42.23	0.00	100.00	0.00	3.59	10.31	86.11	0.00	16.21	83.79	0.75	64.02	35.24
Hainan	0.00	100.00	0.00	0.00	100.00	0.00	8.27	26.60	65.14	0.00	94.39	5.61	5.51	37.71	56.78
Hebei	0.72	77.90	21.37	0.00	100.00	0.00	3.93	25.42	70.64	2.64	43.00	54.36	3.35	67.49	29.16
Henan	1.39	88.88	9.73	0.00	100.00	0.00	7.63	21.59	70.78	0.00	43.80	56.20	2.19	64.27	33.54
Heilongjiang	9.89	55.26	34.85	0.00	100.00	0.00	14.55	28.51	56.94	0.00	64.82	35.18	4.18	60.06	35.75
Hubei	4.12	73.15	22.74	0.00	100.00	0.00	4.16	27.34	68.50	0.00	41.54	58.46	1.81	60.70	37.49
Hunan	8.78	60.31	30.91	3.08	96.92	0.00	1.28	21.44	77.28	0.32	50.29	49.39	1.33	49.49	49.18
Jilin	3.01	77.37	19.62	1.14	98.86	0.00	6.06	47.57	46.37	2.30	46.47	51.24	2.63	57.68	39.69
Jiangsu	1.34	98.56	0.11	0.00	100.00	0.00	7.03	29.29	63.68	0.00	66.48	33.52	1.26	71.21	27.53
Jiangxi	0.72	88.35	10.92	0.00	100.00	0.00	5.43	20.31	74.27	0.00	55.82	44.18	0.94	62.08	36.98

Ending table 1

Region	Coal total			Coke			Petroleum products total			Natural gas			Electricity		
	Primary industry	Secondary industry	Tertiary industry	Primary industry	Secondary industry	Tertiary industry	Primary industry	Secondary industry	Tertiary industry	Primary industry	Secondary industry	Tertiary industry	Primary industry	Secondary industry	Tertiary industry
Liaoning	0.62	83.69	15.69	0.00	100.00	0.00	3.63	48.77	47.60	0.00	73.22	26.77	2.02	71.24	26.75
Inner Mongolia	1.74	84.83	13.42	0.79	99.21	0.00	5.96	36.28	57.77	0.00	63.35	36.65	1.58	87.38	11.04
Ningxia	0.14	97.57	2.29	0.00	100.00	0.00	1.58	71.28	27.15	0.00	60.65	39.30	2.03	90.00	7.97
Qinghai	0.41	83.67	15.92	0.00	100.00	0.00	2.87	35.84	61.29	0.00	61.74	38.26	0.36	88.71	10.93
Shandong	0.64	86.38	12.98	0.00	100.00	0.00	3.95	36.92	59.13	0.00	64.28	35.72	2.00	78.19	19.81
Shanxi	2.47	82.64	14.90	0.00	100.00	0.00	6.61	19.66	73.73	0.00	44.78	55.22	2.20	77.01	20.80
Shaanxi	0.53	87.85	11.62	0.00	99.70	0.03	5.57	24.54	69.88	0.00	62.77	37.23	2.01	66.35	31.64
Shanghai	0.06	98.46	1.49	0.00	100.00	0.00	0.81	32.27	66.91	0.19	56.70	43.10	0.39	49.65	49.97
Sichuan	1.31	95.87	2.82	0.05	99.91	0.04	4.43	22.69	72.87	0.28	66.16	33.56	0.76	61.29	37.95
Tianjin	1.51	86.16	12.33	0.00	100.00	0.00	2.19	57.97	39.85	0.00	56.83	43.17	1.96	64.65	33.39
Xinjiang	4.02	77.69	18.29	0.00	100.00	0.00	6.88	40.92	52.20	0.03	70.59	29.39	4.53	83.51	11.96
Yunnan	5.09	82.69	12.23	0.22	99.77	0.02	2.34	17.18	80.48	0.07	88.61	11.32	1.36	69.69	28.94
Zhejiang	0.00	97.28	2.72	0.00	100.00	0.00	9.76	29.88	60.37	0.00	65.80	34.20	0.64	69.75	29.61
China	*3.00*	*80.93*	*16.07*	*0.13*	*99.79*	*0.08*	*2.87*	*42.26*	*54.87*	*0.08*	*41.38*	*58.54*	*1.87*	*67.60*	*30.53*

The relationship between energy consumption and industrial structure

Based on the data of output value of various industries and energy consumption in each province in China from 2015 to 2019, grey relational analysis was applied to study the effect of industrial structure on energy consumption in each region. The specific impact coefficients of each province in China and the industry with the greatest impact on energy consumption are shown in table 2 [7].

Table 2

Impact coefficients by China's region and by industry

Region	Industry			Industry with the greatest impact on energy consumption
	Primary	Secondary	Tertiary	
Anhui	0.5484	0.6486	0.7761	Tertiary
Beijing	0.5416	0.7677	0.9541	Tertiary
Chongqing	0.4686	0.4854	0.8873	Tertiary
Fujian	0.4954	0.7173	0.8685	Tertiary
Gansu	0.4356	0.6498	0.8351	Tertiary
Guangdong	0.4623	0.6175	0.9186	Tertiary
Guangxi	0.8170	0.5976	0.8205	Tertiary
Guizhou	0.6181	0.6618	0.8739	Tertiary
Hainan	0.4968	0.6185	0.7872	Tertiary
Hebei	0.5851	0.6999	0.7520	Tertiary
Henan	0.4793	0.7093	0.6894	Secondary
Heilongjiang	0.7158	0.6257	0.7889	Tertiary
Hubei	0.5165	0.7089	0.8823	Tertiary
Hunan	0.4571	0.6774	0.8466	Tertiary
Jilin	0.4577	0.5888	0.6465	Tertiary
Jiangsu	0.5051	0.8451	0.9523	Tertiary
Jiangxi	0.4944	0.6312	0.9017	Tertiary
Liaoning	0.6384	0.6919	0.6963	Tertiary
Inner Mongolia	0.7614	0.5211	0.7742	Tertiary
Ningxia	0.5201	0.5426	0.6682	Tertiary
Qinghai	0.7500	0.5313	0.7029	Tertiary
Shandong	0.6195	0.6386	0.7664	Tertiary
Shanxi	0.4411	0.8944	0.7757	Secondary
Shaanxi	0.4755	0.6663	0.8606	Tertiary
Shanghai	0.5621	0.7951	0.9770	Tertiary
Sichuan	0.5147	0.5326	0.8316	Tertiary
Tianjin	0.4096	0.6655	0.6429	Secondary
Xinjiang	0.4863	0.7693	0.8699	Tertiary
Yunnan	0.5881	0.6727	0.8643	Tertiary
Zhejiang	0.4987	0.6204	0.9105	Tertiary
China	*0.5871*	*0.5663*	*0.8141*	*Tertiary*

At the national level, the tertiary industry has the largest impact on energy consumption in China, followed by the secondary industry and the primary industry the least. Therefore, the energy consumption would be much easier and more obvious to be affected by the variation of the share of tertiary industry. In 2015, the contribution of primary, secondary and tertiary industry to gross domestic product is 4.50; 42.50; 53.0 %, respectively. While in 2019, the contribution of primary, secondary and tertiary industry to gross domestic product change to 3.80; 36.80; 59.40 %, respectively. It can be seen that the share of the primary industry and the secondary industry both decrease over the five years, while that of the tertiary industry increase. Therefore, the influence of the tertiary industry on energy consumption must increase [8].

At the regional level, most regions follow the same ranking as the nationwide situation in terms of the degree of impact of the three industries on energy consumption. Only the three provinces, Henan, Shanxi, and Tianjin, are most affected by the share of the secondary industry in the energy consumption. As for these provinces, there exist the greatest possibility that an increasing share of secondary industry could lead to an increase of energy consumption. And when the share of secondary industry decrease, energy consumption is most likely to decrease. Considering the variation in the industrial structure of these three regions from 2015 to 2019, the share of secondary industry in Henan and Tianjin has decreased. And because of the higher energy demand and greater energy intensity in the secondary industry, the variation of industrial structure tends to realise a lower energy consumption assuming a constant gross domestic product. However, the situation in Shanxi is just the opposite. Its share of secondary industry has been increasing over five years. Thus, its variation in industrial structure tends to achieve a greater energy consumption assuming a constant gross domestic product. For provinces where the secondary industry has the greatest impact on energy consumption, measures should be taken to slow down the growth of the secondary industry and gradually reduce the share of the secondary industry. It should also promote the rapid development of the tertiary industry and amplify its contribution to gross regional product, in an attempt to drive economic growth depending on the tertiary industry. And the energy consumption per unit of output value in secondary industry should be reduced through internal restructuring or the introduction of advanced technology and equipment. In addition, the tertiary industry as a measure to evaluate the economic development and the industrial structure of a region, the contribution of the tertiary industry to gross regional product is bound to increase as society develops. Therefore, for regions where the tertiary industry has the greatest impact on energy consumption, the focus should be on optimising the internal industrial structure, improving energy efficiency, developing energy-saving technologies and reducing energy intensity [9].

Conclusions

From the aspect of various regions, the energy consumption in different provinces of China shows significant differences. And comparing the data in each year of the same province, we can notice that the variation of energy consumption in certain province is not significant. From the aspect of various industries, the secondary industry is resource-intensive and capital-intensive industry and they have high demands for energy. From the aspect of impact of industrial structure on energy consumption, most provinces in China are much easily affected by the share of tertiary industry, which is same as the nationwide situation. For these provinces, the focus should be on optimising the internal industrial structure, improving energy efficiency, developing energy-saving technologies and reducing energy intensity. Besides, only the three provinces, Henan, Shanxi, and Tianjin, are most affected by the share of the secondary industry in the energy consumption. As for these provinces, there exist the greatest possibility that an increasing share of secondary industry could lead to an increase of energy consumption. For these provinces, some measures should be taken to slow down the growth of the secondary industry and gradually reduce the share of the secondary industry. It should also promote the rapid development of the tertiary industry and amplify its contribution to gross regional product, in an attempt to drive economic growth depending on the tertiary industry.

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