The Relationship Between Energy Structure and Energy Efficiency in China

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Abstract

In order to control carbon emissions， energy efficiency is an important issue that the Chinese government has to deal with. In China, the energy structure is dominated by coal, which makes the conflict of economy-energy-environment more serious. Accordingly, the energy structure adjustment is increasingly meaningful. However，the influence of energy structure adjustment on energy efficiency has not been studied sufficiently. This paper, firstly, introduces the status quo of energy structure and energy efficiency and analyzes the energy structure adjustment environment from economic, energy conservation, emission reduction and related policy. Then, the relationship between energy structure and energy efficiency by using regression analysis and Granger causality test is studied. The results show that the coal consumption has a negative correlation with energy efficiency whereas a positive correlation with the oil, gas, electricity exists. Thirdly, a series of energy structure adjustments to improve energy efficiency is discussed.

Keywords

Energy structure; energy efficiency; linear regression; mechanism design; energy policy.

1. Introduction

1.1 Background

Energy efficiency is the term to measure the economic output produced by a certain amount of energy input. It reflects the ability of creating social value through a certain amount of energy consumption. As one of major energy consumers, China has an energy consumption structure dominated by coal, oil and natural gas, which leads to China's significant lower energy efficiency than developed countries'. According to the International The rapid development of economy has driven the rising of total energy consumption. Low energy utilization efficiency makes the economic growth closer to the constrained boundaries of resources and environment[3]. In order to control and change the contradictory relationship of economy-energy-environment and improve energy efficiency, the restructuring of energy consumption with a lower proportion of non-fossil energy has been put on the agenda.

1.2 Literature Reviews

The existing studies on the relationship between energy structure and energy efficiency of Chinese scholars have more focused on policy planning, development model and technology model[4-7].

The Policy Planning. At present, the energy structure in China is in transition from coal to renewable energy, but the dominant position of coal in the consumption structure will not change, the structural adjustment needs to strengthen legislation and management, improve the economic incentive policies, expand the financing channels and promote production technology internationalization[10]. The energy policies of structural adjustment have been playing a role, but there are still many problems.

For example, there is no long-term strategy policy in energy adjustment, the policy to encourage renewable energy industry development is not perfect, differential electricity pricing policy implementation is not in place[11]. In order to push for the energy structure adjustment and optimize the energy structure, China needs to improve the existing coal pricing mechanism, make full utilization of natural gas resources, develop alternative technologies.

The Development Model. Energy structure optimization is the inevitable trend of social economic development. China will have to optimize her economic structure and industrial structure, promote energy diversification, establish a reasonable consumption pattern, vigorously promote energy-saving emission reduction and improve energy utilization efficiency combine with the national conditions and the energy reality[12]. By increasing the energy saving and deducing carbon emission, these actions will promote energy efficiency through energy alternatives, building electric power as a center, coal as basis and other energies as auxiliary[13,14]. In China, the energy structure strategy adjustment should be achieved through increasing the proportion of renewable energy in the energy consumption structure[15]. Subject to the constraints of total energy consumption control, environmental protection, energy efficiency improvement, energy supply security and other factors, energy structure adjustment depends on a variety of instruments, including raising the relative energy price, energy price adjustment and vigorously developing renewable energy[16].

The Technology Model. In order to optimize energy structure, China should carry out technology innovation, achieve the fundamental transformation on the energy production and consumption mode [17-19]. For example, Chu Wei used the data envelopment analysis (DEA) method to construct the index of energy technical efficiency and divided the structure into five kinds of elements: industrial structure, ownership structure, elements of structure and energy structure. It was found that optimizing the energy consumption structure and developing efficient and clean energy can not only significantly improve the energy efficiency, but also reduce pollution emissions[20].Chunyou Wu established an energy efficiency evaluation model and analyzed the influencing factors of energy efficiency by using the DEA method combined with the characteristics of the energy system in the total factor framework of energy efficiency[21]. Cointegration techniques and Markov chain model are used to forecast the energy efficiency trends from 2011 to 2020[22,23], which found energy structure adjustments could improve energy efficiency.

2. Status quo of energy structure and energy efficiency in China

2.1 Energy consumption structure in China

Energy resource endowment conditions determine the long-term sustainability of coal-dominated primary energy structure. The structure evolution has undergone five major development stages:

(1)In the early days of new China. China was short of oil and there was strong resistance again importing oil. It had to rely on its own abundant coal resources, focusing on the development of coal-dominated energy economic models. The main energy structure is coal-dominated at this stage.

(2)During 1960s to 1970s. With the continuous development of oil resources in the Daqing Oilfield, Shengli Oilfield, etc, the proportion of oil in primary energy consumption continues to increase. But since China was still in the early stages of industrialization, the coal consumption ratio remained high.

(3)During 1976 to 1995. The focus on the economic construction led to a sharp increase in energy consumption and a substantial increase in coal consumption. But the energy consumption structure evolution was not obvious and still coal-dominated.

(4)During 1995 to 2002.The tension of energy supply and demand had been appeased, the pace of energy consumption structure optimization was faster and primary energy consumption structure transited from coal-dominated to coal and oil-dominated. However, the proportion of oil in the overall energy consumption was still low.

(5)From 2002 to now, the Chinese economy has entered a new round of rapid growth. The economic structure of heavy-duty was exacerbated and domestic energy demand has continued to grow rapidly, while international oil prices have continued to rise, leading to a severe shortfall in domestic energy supply. The energy structure has also shown a reversal trend with the proportion of coal in energy consumption rising once again. But with the trend of clean energy development setting off in the world, the proportion of coal consumption has declined. The primary energy structure is transforming from coal and oil-dominated to coal, oil, natural gas and so on. The energy consumption structure has been optimized progressively.

Table1 Primary energy consumption structure in China during2005-2018

Year	Total	Percentage in total energy consumption (%)			
	(Mtoe)	Coal	Oil	Natural gas	Others
2005	1566.7	70.8	19.8	2.6	6.8
2006	1729.8	71.1	19.3	2.9	6.7
2007	1862.8	71.1	18.8	3.3	6.8
2008	2002.5	70.3	18.3	3.7	7.7
2009	2187.7	70.4	17.9	3.9	7.8
2010	2432.2	68	19	4.4	8.6
2011	2613.2	68.7	18	4.5	8.8
2012	2735.2	68.2	17.8	4.9	9.1
2013	2852.4	67.5	17.8	5.1	9.6
2014	2972.1	66.0	17.1	5.7	11.2
2015	3014.0	63.7	18.6	5.9	11.8
2016	3053.0	61.8	19.0	6.2	13.0
2017	4400.0	60.0	14.3	6.8	18.9
2018E	4534.6	59.0	13.1	7.0	20.9

2.1.3 End Energy Consumption Structure

China’s coal-dominated primary energy consumption structure determines the coal-dominated end energy consumption structure. The end-use energy consumption reached 4.4 billion tons standard coal in 2017. The development of the end energy consumption structure can be summarized as:

(1)The proportion of coal has continued to decline in the end energy consumption. With the development and utilization of oil, gas and other resources.

(2)The proportion of oil in the end energy consumption structure has evolved in an inverted “U” shape. Besides increasing in the primary energy consumption, the proportion of oil also gradually increased from 1991 to 2002. Affected by oil’s supply capacity and high price, the proportion of oil in the end energy consumption decreased during 2002-2017.

(3)The proportion of natural gas in the end energy consumption has continued to increase. With the advancement of natural gas extraction technologies and the increase of natural gas production, the proportion of natural gas consumption is increasing but still relatively low due to the constraint of the natural gas reserves.

(4)The proportion of power resources in terminal energy consumption continues to increase. With the consumption structure of primary energy transited to coal, oil, natural gas and electricity gradually, the proportion of gas and electricity resources in final energy consumption continues to grow.

2.2 Energy Efficiency in China

At present, China has crossed the apex of the U-shaped curve of energy efficiency. Energy efficiency is at the rising stage, but the total energy consumption is also increasing year by year. The government still needs to improve energy efficiency and control the growth rate of energy consumption. In recent years, energy efficiency trends can be divided into three stages:

(1)From the early days to the reform and opening-up. China gave priority to develop energy-intensive industries and the energy efficiency was following a downward trend.

(2)From 2003 to 2004. China entered a new round of economic expansion cycle. Accordingly the rapid expansion of high energy-intensive industries led to rapid growth in energy demand, which exceeded the growth rate of GDP. Energy efficiency declined for two consecutive years, dropped to 7,400 yuan per ton standard coal.

(3)After 2005, energy efficiency again returned to the rising trend with the efforts to encourage energy conservation and restrict the expansion of high energy-consuming industries. After a fluctuation caused by the financial crisis in 2008, the energy efficiency started growing in 2009.

3. Drivers for China's energy structure adjustments

3.1 Economic Drivers

Energy consumption is mainly affected by the industrial structure and energy structure. At present, the national development stage determines the secondary industry-dominated industrial structure, so the economic development mainly depends on energy. The secondary industry output value in GDP accounted for 45.3%, far higher than the industrialized countries. The proportion of the secondary industrial energy consumption in total energy consumption reached 55.5% in 2017. As a developing country, the rapid economic development will continue to be the main objective and it will take a long time to adjust the industrial structure. Therefore, the energy structure adjustment has become the main way to alleviate the growing trend of energy demand.

3.2 Energy Saving Drivers

Energy Saving

The total energy resources in China are abundant, but are short of high-quality energy resources. Energy resources and energy consumption show a reverse distribution. The first characteristic is "rich in coal but less oil", which means the high-quality fossil energy (oil, natural gas) reserve is relative low. The second characteristic is that energy resources are very unevenly distributed. On the energy resource distribution, coal is mainly located in the west (50%) and central (40%), oil and gas in the western (32% and 83%), hydropower in the Southwest (67%), and wind energy in the "three North" area (96%); The eastern region is the main energy consuming are (43%).

Carbon dioxide emissions abatement

In 2009, China promised that carbon dioxide emissions per unit GDP will decrease by around 40% to 45% compared to 2005 by 2020 in the Copenhagen Global Climate Conference. According to the International Energy Agency data, it shows that China "contributed" 103.57 million tons to the world's emissions in 2017, which was the lowest in the past 10 years.

4. Analysis model for the impact of energy structural adjustments on energy efficiency

4.1 Quantitative analysis for the relations between energy structure and energy efficiency

(1) Impact of primary energy consumption structure on energy efficiency

According to the basic form of the Cobb-Douglas production function, the effect of certain energy in primary energy consumption on energy efficiency can be expressed as a formula:

$$\eta=\mu_k A_k\left(t\right) p_k^{\alpha_k} \tag{1}$$

Where, η is energy efficiency; p_k is the proportion of the kth energy in primary energy consumption; $A_k\left(t\right)$ is the comprehensive technical level of the kth energy; μ_k and α_k are constant; They represent the coal, oil, natural gas and electricity with k respectively as c,o,g,e。

Assuming the comprehensive technical level index is growth, taking the logarithm for both sides, we can get:

$$\ln\eta=\ln\mu_k+\beta_k t+\alpha_k \ln p_k \tag{2}$$

This formula is a regression model for the energy efficiency and the proportion of the kth energy in primary energy consumption. Due to a smaller proportion of natural gas in total primary energy consumption, natural gas regresses with energy efficiency separately. That means, it is easily to be interferenced by incidental factors but not significantly influenced. Therefore, we accumulate the proportion of oil and gas, regression fit with energy efficiency, and obtain the regression equation of primary energy consumption and energy efficiency. Details are as follows:

$$\ln\eta=13.57646+0.021052t-3.31403\ln p_c \tag{3}$$

$$\ln\eta=-3.948836+0.025884t+1.075410\ln p_{o,g} \tag{4}$$

$$\ln\eta=-2.120372+0.018739t+0.847329\ln p_e \tag{5}$$

The equations above show a negative correlation between the proportion of coal consumption and energy efficiency and a positive correlation between the proportion of oil, gas, electricity consumption and energy efficiency. That means, the higher the proportion of coal consumption, the lower the energy efficiency, while the higher the proportion of oil, gas and electricity consumption, the higher the energy efficiency. Therefore, it is conductive to promoting the improvement of energy efficiency by reducing coal in primary energy consumption and increasing the proportion of oil, gas and electricity.

(2) Impact of final energy consumption structure on energy efficiency

The impact of final energy consumption structure on energy efficiency can be estimated by analyzing the marginal efficiency of various energies. The marginal efficiency refers to the output or revenue of increasing the use of some sort of unit energy when the other conditions remain unchanged. The capital, labor factor inputs in economic production are mostly determined by the previous year's total economic output. Therefore, this article will use the economic aggregate one year lag instead of capital and labor elements, as shown below:

$$dGDP=c+\beta GDP(-1)+\alpha dE \tag{6}$$

Where, $dGDP$ is economic increment; $GDP(-1)$ is the economic increment of last year; dE is the final energy consumption increment; c is the constant; We can see from the formula, α is marginal efficiency of energy. Calculation with the data in the final energy consumption and GDP during 2005-2017, constructs the regression analysis for the relationship between terminal consumption increment and GDP increment. Details are as follow:

$$dGDP=-999.3865+0.112108GDP(-1)+1023.841dE \tag{7}$$

$$dGDP=-1848.986+0.111737GDP(-1)+5548.517dE \tag{8}$$

$$dGDP=4006.581+0.037295GDP(-1)+9795.364dE \tag{9}$$

$$dGDP=-172.2722+0.070328GDP(-1)+23328.81dE \tag{10}$$

The above equations show the marginal efficiencies of coal, oil, natural gas and power are 10.238, 55.485, 97.954 and 233.288 million yuan per ton standard coal. The marginal efficiency of different energy can be used to estimate the marginal substitution rate of different energy. The marginal substitution rate of coal, oil, natural gas and power is 22.8:9.6:5.4:1. To create the same economic output, one ton standard coal in electricity consumption can replace 5.4 tons standard coal in natural gas, 9.6 tons standard coal in oil, 22.8 tons standard coal.

In terms of the end-use energy quality, electricity has more advantages than other energy types. By increasing the proportion of electricity in the final energy consumption, the total final energy consumption will be reduced and the energy efficiency will be improved.

4.2 Quantitative analysis of the relationship between the proportion of energy generation and energy efficiency

The proportion of energy generation refers to the proportion of the primary energy generation consumption in total primary energy consumption. The experience of developed countries shows, the improvement of living environment promotes electricity consumption and the proportion of energy generation. Energy efficiency can be decomposed into the product of power efficiency, power generation efficiency and the proportion of energy generation. As the formula (11) shows:

$$\eta = \frac{GDP}{PE} = \frac{GDP}{Elec} \cdot \frac{Elec}{EE} \cdot \frac{EE}{PE} \tag{11}$$

Where, η is energy efficiency; *GDP* is the GDP at constant prices commuted; *PE* is total consumption of primary energy; *Elec* is generation; *EE* is total energy generation. There is a direct quantitative relationship between the proportion of power generation and energy efficiency.

The Engle-Granger two-step method can be the cointegration test for energy efficiency and proportion of energy generation from 2005 to 2017. The result shows, energy efficiency and proportion of energy generation have a cointegration relationship, the cointegration equation is as the formula (12). The results show that the Granger relationship is unidirectional. The proportion of energy generation is the Granger cause of energy efficiency, but energy efficiency is not the Granger cause of the proportion of energy generation.

$$\eta = 3.147808719251ee - 0.323326875572 \tag{12}$$

Therefore, the cointegration relationship shows that there is a long-term stability common trend between energy efficiency and the proportion of energy generation. Improving the proportion of energy generation can effectively improve the energy efficiency.

4.3 Analysis of impact of new energy development on energy efficiency

The quantitative relationship between the proportion of energy generation, energy consumption structure and energy efficiency indicates the energy efficiency can be improved by improving the proportion of power in primary energy consumption and final energy consumption, the proportion of energy generation. The new energy technology development provides more opportunities for nuclear energy, wind, solar and other new energy sources. Most of the new energy is easy to use after being converted to electric energy. Vigorously developing new energy sources is necessary to improve the proportion of power in energy consumption. The energy efficiency will be increased by increasing the proportion of power in the terminal energy consumption and the proportion of primary energy in electricity generation.

5. Mechanism framework

5.1 Energy price mechanism

(1) Coal price reform

The coal price reform in China originated from the planned economy, which fell behind the price reform of other goods for a long time. To meet the need of social development and market resources allocation reform, China speeded up the reform of coal market pricing, which carried out a series of major reforms and initially formed coal resources allocation by the market pricing system.

(2) Renewable energy subsidies

In 2013, the Finance Ministry, the National Development and Reform Commission, the National Energy Bureau jointly issued the 《Interim Measures for additional renewable energy tariff subsidy funds management》, which stipulate that the price policy of renewable energy power generation projects, joint network engineering and the public independent renewable energy power system should be defined by the National Development and Reform Commission based on the characteristics of different types and areas of renewable energy power generation. The price policy should be beneficial to the promotion of renewable energy development and should agree with the Reasonable Economic Principle[27]. Moreover, the price policy should be adjusted upon the development and utilization of renewable energy technology development.

For the investment and operation costs of the renewable energy power generation projection to access the power grids, appropriate subsidies can be used according to the online quantity. The standard is: 1 cent per kWh in 50 km, 2 cents per kWh in 50-100 km, 3 cents per Kwh in 100 km and above.

For the sale price of public renewable energy by independent power system of government investment or subsidies construction, the sale price was implemented as the same area classification, the part of the reasonable operation and management cost higher than the sales price is subsidized by renewable energy electricity additional price, about 4000 yuan per kW per year.

5.2 West to east gas pipeline project

In China, Natural gas resources are distributed in the western region of the Tarim, Qaidam, Shaanxi Gansu and Sichuan Basin, accounting for about 87% of onshore natural gas resources. However, the southeast coastal area is the main energy consumption regions, in order to make full use of natural gas resources and adjust energy structure, the project of “west to east gas pipeline” began in 1998 and officially started construction in July 4, 2002. There are three main line projects in East Gas Pipeline project, all three line projects have completed in 2014 and they have form a foundation natural gas pipeline network from east to west, north to south with West line, West second line, a second line from Shanxi to Beijing and other trunk pipeline network. The “west to east gas pipeline” project has speeded up the process of energy structure optimization, effectively eased the contradiction between supply and demand of energy, especially the energy crisis in the Yangtze River Delta economic circle. The “west to east gas pipeline” project has also played an important role in improving the large environmental resources.

5.3 Energy saving& scheduling mechanism

The targets of energy generation schedule [29] are to make an open, fair and just environment for energy saving and environmental protection. The primary goal is to make the power system be operated safely and stably to provide continuous power supply. According to the level of energy consumption and pollutant emissions, it invokes fossil generation resources from low to high, minimizes energy resource consumption and pollutant emissions, promotes the efficiency of power systems. Fig.1 is the generator scheduling order (priority order from bottom to top), the same type of coal-fired generating unit orders from low to high in accordance with the energy consumption level, giving priority to energy conservation; When energy consumption levels are the same, the rank is from low to high according to the level of pollutant emissions.

5.4 UHV Power Grid Construction

In order to solve the unbalance of energy resources and the load distribution, the UHV has become the focus of State Grid. In the UHV AC project, State Grid has formed the "Three vertical, three horizontal and one loop" UHV transmission network at the end of 2015. The development of UHV power grid can output power resource from the western region and alleviate environmental pressure of the east area. This development can optimize the allocation of resources in the national scope. This can promote the intensive development of large hydropower, coal, nuclear power and renewable energy power base to achieve a wider range of optimal allocation of energy resources. The reallocation plays an important role in reducing coal consumption, increasing the power grid penetration of renewable energy, achieving energy structure optimization and improving energy efficiency. Fig.2 displays the planning of UHV development in 2015.

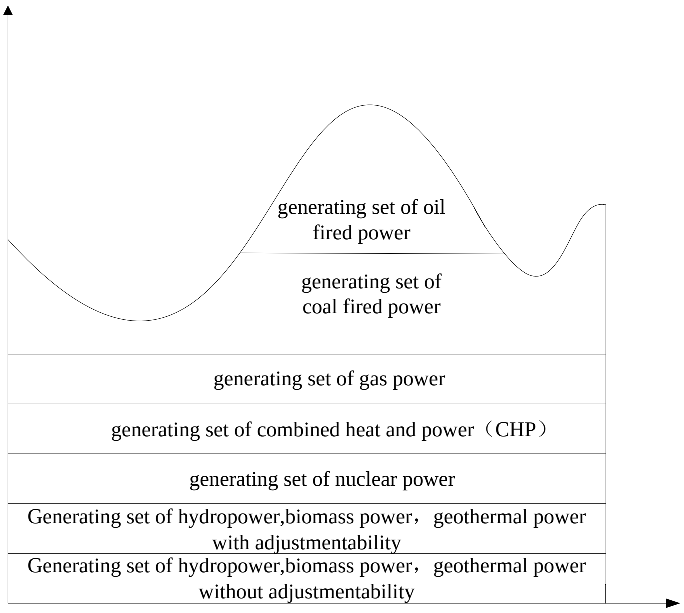

Fig.1 Merit order of generation dispatch

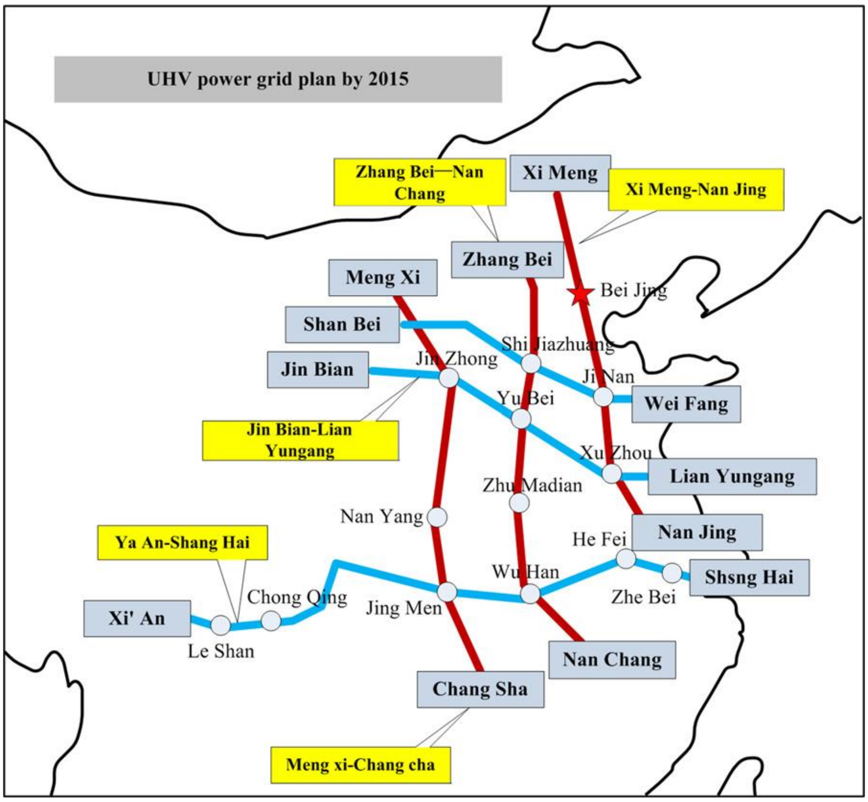

Fig.2 UHV power grid plan by2015

5.5 Other Mechanisms

(1) Coal to natural gas

Domestic demand for natural gas is large and the technology is relatively mature. But the construction of natural gas plants is relatively restricted by natural gas pipeline availability and lower prices of the domestic natural gas. The development orientation of coal to natural gas in China is treated not as the main source of supply of natural gas, but as the supplement of natural gas. The coal gas can achieve the transfer of high-carbon energy to low-carbon, which will be an important part of natural gas in China.

At present, there are 50 coal-to-gas projects under construction or in the planning stage. It proposes that coal gas output should achieve 225 billion cubic meters per year in 2020 according to the "The 13th Five Year Plan". In order to achieve this goal, government needs to formulate industrial policies according to the proportion of coal gas in clean energy.

(2) Electric Vehicles

The development of electric vehicles is gradually adjusting the energy structure. Electric vehicles can increase the demand for the generation of wind, solar, tidal and other intermittent renewable energy as energy storage device. What’s more, they can optimize and upgrade the power structure based on coal-fired generation, promote energy structure optimization, and accordingly achieve the target of improving energy efficiency.

6. Conclusion

To sum up, energy structure adjustments can promote energy efficiency. In order to alleviate the increasingly severe economy-energy-environment contradiction, the Chinese government should attach importance to energy structure adjustments and achieve the improvement of energy efficiency. This paper gives recommendations from the following aspects:

diversified development, reduce dependence on coal

Energy structure adjustment should adhere to the coal-dominated and diversified development strategy. It should also increase the proportion of natural gas, hydropower, nuclear power and other new energy sources, then make effort to adjust and optimize energy consumption structure, promote coal resources integration, promote the use of clean coal technology and coal conversion technologies. This will reduce dependence on coal and furthermore reduce environment pollution.

strengthen international cooperation

The energy enterprises in China should actively carry out cross-border energy trade, particularly natural gas and electricity. In natural gas, China has signed natural gas import cooperation agreements with Russia, Kazakhstan, Turkmenistan and other countries. The completed transnational gas pipelines in China include Central Asia gas pipeline, Russia gas pipeline, and China-Burma oil and gas pipeline. On the electricity side, the China State Grid Corp has signed a cooperation agreement or intent letter for electricity imports with the electric power enterprise of Russia, Mongolia, Kyrgyzstan and other countries. To strengthen international cooperation, the measures have been taken as follows: 1) expanded the cooperation with international organizations; 2) strengthened pragmatic cooperation with power countries; 3) deepened real cooperation with developing countries; 4) actively carried out cooperation in clean development mechanism projects.

Increase investment in energy infrastructure.

From the point of improving the long-term energy supply capability, it is necessary to maintain an appropriate advanced construction scale [39]. At this stage, we should make efforts to eliminate the limitations and bottlenecks, improve energy supply security capabilities and build a solid foundation for the rapid economic growth in the next round through optimizing the energy structure and strengthening the energy infrastructure. The key energy infrastructure construction investment should focus on the following aspects: 1) optimizing the energy structure of great significance, the effect of nuclear power projects obviously, wind power and other renewable energy projects; 2) building coal, electricity, oil and gas delivery corridors across the region; 3) constructing smart grid, rural power, biogas, solar and other infrastructures 4) constructing oil, natural uranium and other strategic reserve facilities.

Promote energy technology innovation.

Diversified development and international strategy cooperation require technological support. At present, the energy technology in China was mainly dependent on import, compared with developed countries, there was still a considerable gap in new and advance energy fields [41]. The "The 13th Five-Year Plan" gave priority to energy technology to accelerate the progress of energy technologies and technical support for the energy sustainable development. The focus should be advanced energy-saving technologies, clean coal technology, advanced power technology and nuclear power, wind power and other alternative energy technologies in order to promote energy structure optimization.

Deepen the reform of the energy system and mechanism.

At current stage, the energy reform in China should follow the principle of economic rationality and benefit new energy development, new energy Internet standards and pricing mechanisms.

First, we should construct the Internet standards for new energy generation and utilization equipment, implement mandatory certification systems for wind power and solar energy product and promote the scale and normalize new energy industry development.

Secondly, we should clarify the development goals of all new energies and form comprehensive-guided- goals mechanism, especially for the new energy technology lack of market competitiveness or in need of government subsidies, and should put forward a clearer development plan and leave enough room in the development aggregate at different market stages[43].

Finally, we should form the pricing mechanism of new energy products according to the principle of benefit for new energy development and economic rationality [44]. The cost of new energy power generation is relatively high, the market competitiveness is relatively weak, so its development needs the encouragement of reasonable price mechanism, but the pricing mechanism of current domestic new energy products is still not sound, the country needs to form and implement new energy products pricing and social sharing mechanisms.

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