A feasible plan for changing the direction of China's energy structure

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Abstract. With the growing global environmental pollution problem and the continuous increase in human demand for energy, the utility of sustainable clean energy has drawn a widely public attention. China, a great energy consuming country, must convert the energy structure that currently adopts coal as the main energy source for easing domestic energy pressure and meeting international environmental protection targets. In this paper, two countries with completely different energy development structures in Japan and Germany are taken as examples to propose three structural reform proposals and analyze the pros and cons of each program in light of China's national conditions.

1. INTRODUCTION

With the continuous progress in the development of human society, the endless increase in energy consumption, the progressive advancement in the use of energy technologies, and the change in energy structure, people can now efficiently use coal to generate electricity compared to the past. With the deepening of energy use, a series of environmental problems are also increasing.

In recent years, China has maintained the fastest economic growth rate in the world. In the past 30 years, the growth rate of China's GDP has exceeded 10% [1], and the demand for energy is also pretty clear. Since 2007, China has become the world's largest emitter of carbon dioxide and the largest energy consumer since 2010 [2, 3]. According to the plan developed by the Energy Research Institute of the National Development and Reform Commission, by 2050, the electrification rate will increase from the current 23% to 62%, and the electricity consumption in 2050 will be three times that in 2015. Although Chinese government has made some changes to the previous energy structure, it is imperative to implement the new energy strategy, completely change the status quo of coal-fired energy, and achieve sustainable development of the country.

This paper analyzes the causes and processes of energy structure changes, combines the current national conditions and energy situation in China, and lists the advantages and disadvantages of current renewable energy and nuclear energy!

2. ENERGY REFORM SCHEMES AND RESULTS IN VARIOUS COUNTRIES

2.1. Japan

Fig.2.1 shows the power generation of various fuels in Japan from 1979 to 2015. It can be seen that Japan has been making efforts to develop nuclear power since the world oil crisis until the Fukushima nuclear accident [4].

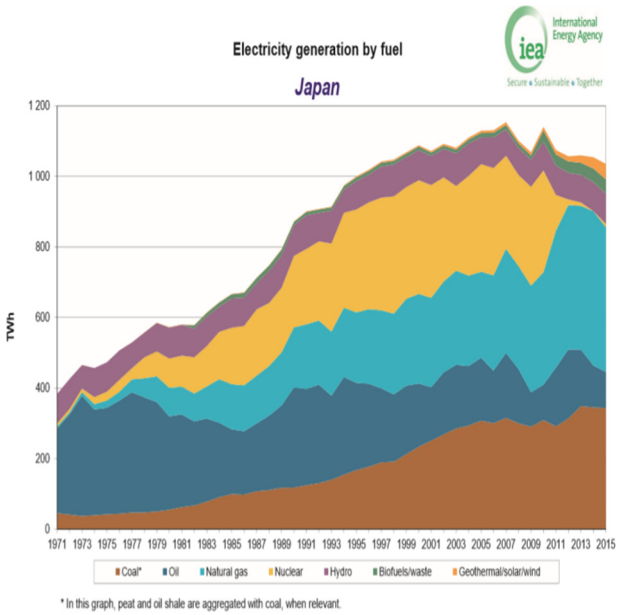

Fig. 2.1.The electricity generation by various fuel in Japan from 1979 to 2015 [4]

Due to the low domestic energy self-sufficiency rate, the rapid growth of power demand and the independence of power grids [5, 6], Japan needs a stable self-sufficient energy source, thus, nuclear power has become an ideal energy alternative. According to the statistics of the International Energy Agency, Japan's nuclear power production in 2010 has reached approximate 25% of the country's total electricity output. Nuclear energy and oil, coal, and natural gas have become Japan's four major supply and consumption energy sources.

After the Fukushima accident, the Japanese government shut down all commercial nuclear power plants in 2012. Fig.2.2 shows Japan's domestic energy use from 1971 to 2015 [7].

After shutting down the nuclear power plant, Japan's electricity supply was severely deficient, and the energy self-sufficiency rate dropped sharply from 19.6% to 6.2%. In response to high energy dependence, unstable renewable energy generation and high cost of power generation, Japan restarted some nuclear power plants in July 2012. At present, Japan's energy resources mainly face with the following problems:

1) High dependence on foreign energy sources;
2) Intermittent nature of renewable energy sources;
3) Fear of nuclear power caused by the nuclear accident at Fukushima.

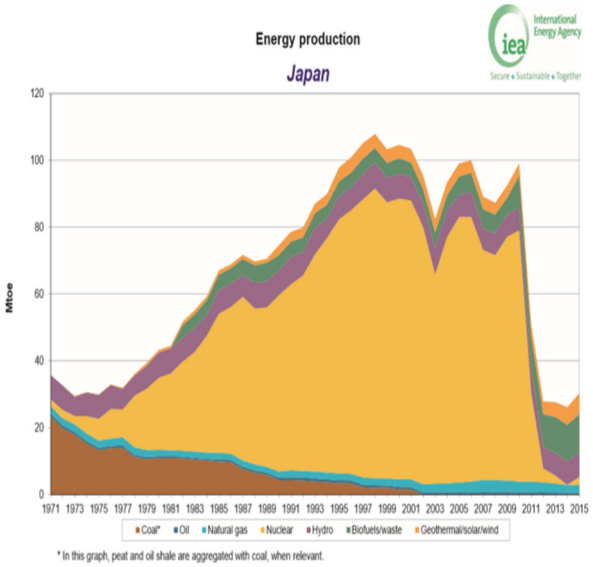

Fig.2.2. Japan's domestic energy use from 1971 to 2015 [7]

In the face of a series of problems after the Fukushima accident, Japan proposed the energy goals of 2030: 1. Do not give up nuclear power, which will account for 22% of the total power generation; 2. Develop renewable energy, renewable energy will account for 22%~24% of total power generation; 3. Increase energy self-sufficiency rate to 25%; 4. Reduce greenhouse gas emissions by 26% [8].

2.2. Germany

Since the 1990s, Germany has gradually eliminated nuclear power and has become a leader in renewable energy [6]. In 1980, Germany proposed the "Energiewende" [9] that renewable energy is a complete replacement for nuclear energy. It is estimated that renewable energy will account for 35% of total electricity by 2020 and reach 80% by 2050. Since the promulgation of the "Renewable Energy Law" in 2000, the consumption of renewable energy in Germany has grown rapidly. In 2017, Germany's renewable energy production has reached 216.6 trillion watt-hours, accounting for approximately 33.1% of Germany's total electricity generation. Figure.2.3 shows the distribution of energy structures in Germany in 2017.

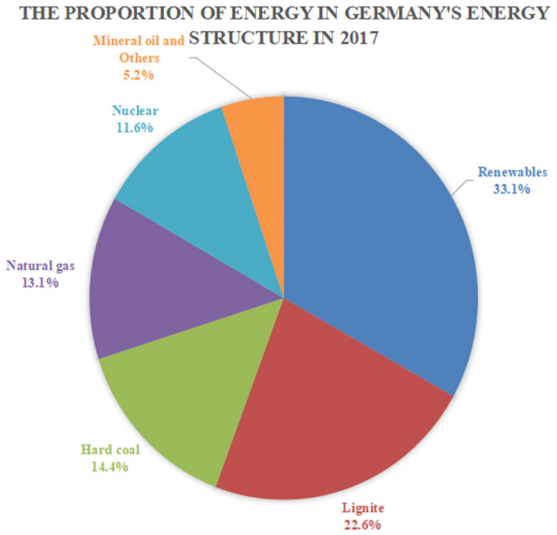

Fig.2.3. The distribution of energy structures in Germany in 2017

According to domestic conditions, Germany has vigorously promoted the development of renewable energy, changed the energy structure that was not dominated by fossil fuels and nuclear energy in the

last century, which greatly eased the dependence on foreign energy, traditional fossil energy on environmental pollution, nuclear pollution and other issues. The increase in the share of renewable energy is certainly incredible, but due to the high cost of power station construction and transmission, the cost of power generation is higher than the environmental pollution cost of over-emission of greenhouse gases, so the enthusiasm for clean energy power generation is affected; on the other hand, due to the limitations of the natural environment and resources, the intermittent nature of renewable energy sources will be significant, which will affect the stability of the power grid and the operation of the electricity market [10].

2.3. China's current national conditions and energy status

Table.2.1 reveals the change of some energy consumption in China from 1990 to 2016 and the energy consumption forecast from 2016 to 2040 [11]. It can be seen that the proportion of nuclear energy and renewable energy in China's energy structure has racked up, and coal energy has sustained reduction.

However, compared with Germany and Japan, the difference is that China's coal power generation has always occupied a large proportion. Figure.2.4 conveys the proportion of China's various types of electricity generation in total electricity generation in 2016.

Table.2.1. Changes and Forecasts of Energy Consumption in China (Coal,Nuclear,Renewable) [11]

Changes and Forecasts of Energy Consumption in China(Coal,Nuclear,Renewables)								
BP Energy Outlook	**Level**	**Change（abs.)**		**Change(%)**		**Change(annual)**		
	2016	2040	1990-2016	2016-2040	1990-2016	2016-2040	1990-2016	2016-2040
Total	3052	4319	2370	1266	347%	41%	5.90%	1.60%
Coal	1888	1552	1360	-336	258%	-18%	5.00%	-0.80%
Nuclear	48	325	48	277	>1000%	574%	>10%	8.30%
Renewables	88	784	88	696	>1000%	789%	>10%	9.50%
Primary energy consumption (units in Mtoe)								

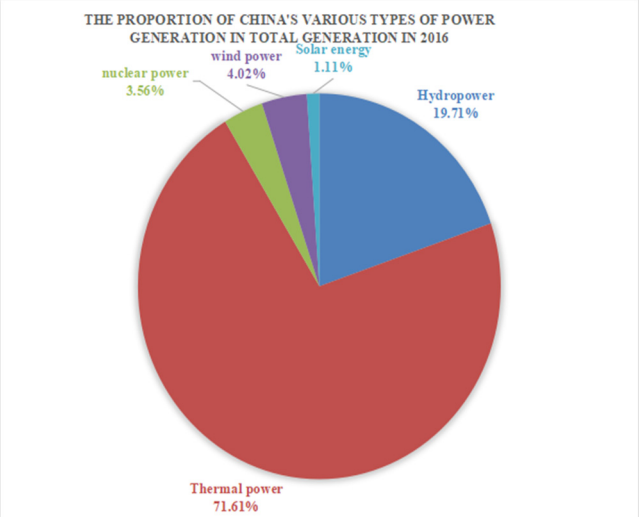

Fig.2.4. The proportion of China's various types of electricity generation in total electricity generation in 2016 [12]

With the deterioration of the global environment and the growing scarcity of energy, China urgently needs to change its current energy structure.

Renewable energy has become a preferred energy source in many countries due to its clean, recycled nature, such as the aforementioned Germany. As a country with high energy consumption, China should also actively develop and use renewable energy. The installed capacity of wind power in China increased from 743 MW in 2004 to 145,104 MW by the end of 2015, a year-on-year increase of 195 times. The installed capacity of photovoltaics increased from 64 MW in 2004 to 43180 MW by the end of 2015, an increase of 675 times [13].

In addition, in recent years, China has also accelerated the development of nuclear power. As of March 2017, 36 nuclear power generating units in China have been installed, with an installed capacity of 34.72 million kilowatts; and 20 nuclear power generating units under construction have an installed capacity of 231.1 million kilowatts. However, as of the end of 2016, China's nuclear power generation accounted for only 3.56% of the country's total electricity generation [14].

China's current energy resources are mainly faced with two problems: 1.The total energy supply is insufficient; 2.The energy consumption structure is irrational. In China's energy consumption structure, the proportion of new energy (renewable energy, nuclear power, etc.) is very low [15].

3. ENERGY STRUCTURE TRANSFORMATION PLAN

This paper presents and analyzes three energy options: use singly wind power and solar photovoltaic power, completely abandon nuclear power scheme; Merely use nuclear power, completely abandon wind power and solar photovoltaic power scheme; Wind power, solar photovoltaic power and nuclear energy Development of energy structure scheme. Based on the above three options, this paper discusses the advantages and disadvantages from different perspectives.

3.1. Use singly wind power and solar photovoltaic power, completely abandon nuclear power scheme.

Wind energy and solar energy can reduce the emission of carbon dioxide and other polluting gases, mitigate the greenhouse effect, and improve energy security, price stability, and affordability [16]. If only wind energy and solar energy are used as energy for power generation and nuclear energy is completely abandoned, it needs to be considered from the following three aspects:

3.1.1. Power Supply Reliability

Since solar energy and wind energy rely on natural resources to generate electricity, their power supply stability largely depends on the natural environment. Although renewable energy seems to be able to completely replace other energy sources, there are significant technical and economic costs due to the presence of intermittency [17, 18]. Therefore, the intermittent nature of renewable energy has become the colossal constraint for the development of solar and wind energy. The intermittent nature of energy has a great impact on the power grid. Most unscheduled renewable energy sources will require a large amount of standby power generation capacity and additional transmission capacity if reliable power and grid frequencies are to be maintained [10].

3.1.2. Environmental Impact

The use of renewable energy does not eliminate all environmental problems, but it can greatly reduce the consequences. However, by increasing the use of renewable energy to reduce greenhouse gas emissions will also have an adverse impact on the environment, merely focusing on greenhouse gas emissions will lead to ignoring other negative environmental impacts [19]. Renewable energy sources produce low levels of greenhouse gas emissions and conventional air pollution compared to other sources in the energy production process, but manufacturing and transporting them can also produce some emissions and cause some environmental problems [20]. In addition, the complete replacement of nuclear power with wind energy and solar energy leads to a significant increase in the release of greenhouse gases [10].

3.1.3. Economic costs

There is a positive impact on the use of wind energy and solar energy, as well as a negative impact.

Renewable energy sources assist to decrease the country's dependence on imported energy. With long-term accumulation, there are positive economic effects [21].

The use of wind and solar energy will inevitably increase economic cost due to transmission and grid capacity [10]. Take Sweden as an example, if wind power and solar energy are used instead of nuclear power, greenhouse gas emissions will increase substantially and costs will increase significantly. If we want to maintain low greenhouse gas emissions at the same time, we will greatly increase the cost.

3.2. Merely use nuclear power, completely abandon wind power and solar photovoltaic power scheme

As an important clean energy source, nuclear power plays a crucial role in ensuring energy supply and achieving low-carbon clean energy development. It has been widely used by countries in the world. Compared with wind power, solar energy and other renewable energy sources, nuclear power has the advantages of good economy, high unit investment and emission reduction benefits [22]. If it is possible to completely abandon solar energy and wind energy, it needs to be considered from the following three aspects:

3.2.1. Environmental Impact

In terms of emissions of pollutants, nuclear energy has almost no air pollution gas that threatens the global climate. Secondly, the amount of fuel (energy density) used to generate a certain amount of energy determines, to a large extent, the size of the environmental impact. Nuclear energy has high energy density relative to fossil and renewable energy sources. It is worth noting that the 1000 MW(e) nuclear power plant does not release toxic gases or other pollutants, but it produces about 30 tons of high-level radioactive waste fuel and 800 tons of low- and medium-level radioactive waste per year [23]. At present, nuclear waste is treated by placing it in a metal tank and then burying it deep underground or in the deep sea. There is no other technology that can completely handle nuclear waste.

3.2.2. Economic Costs

From the perspective of the economic efficiency of nuclear power development, although its investment cost is high, accounting for about 60% of the cost of power generation, its fuel cost proportion is below 25%, which means that once it is put into production, the cost of power generation for nuclear power plants will not be affected by excessive fuel price fluctuations [24]. On the other hand, due to the scarcity of uranium resources in China, it is challenging to meet the demand for domestic production, and foreign dependence will remain at a relatively high level, increasing the cost of nuclear energy. This is not conducive to the sustainable development of China's nuclear power industry [25]. It is worth mentioning that, unlike renewable energy, nuclear power supply is relatively stable, and it is generally used to provide the entire network operating base load, which makes it relatively stable economy.

3.2.3. Nuclear Safety

Since the beginning of human use of nuclear energy, there have been three major nuclear accidents worldwide, causing serious social harm. Considering the dangers of atomic energy security, with the nuclear accident in Fukushima in 2011, the world began to re-examine the issue of nuclear energy utilization. Many countries have initially eliminated nuclear power. As for China, at present, the probability of a large-scale radioactive leakage accident at the second-generation pressurized water reactor nuclear power plant in operation has fallen to one in a million, plus triple protection of pressurized water reactors and China’s three-tier defense system [26]. These factors have greatly magnified nuclear safety. However，On the other hand, a series of problems and challenges that exist in China, such as incomplete and weak nuclear control systems, lagging public participation, and insufficient nuclear workforce, have hindered the development of nuclear safety and nuclear energy [25].

3.3. Wind power and solar photovoltaic power and nuclear energy common development of energy structure scheme

Solar energy, wind energy and nuclear energy are all improving the environment and have made great

contributions to the decarbonization of the power industry. From the perspective of resource availability, these energy sources are all independently meeting all the electricity needs [27-29]. However, lots of technologies face various technical, economic and social challenges. Combining solar energy, wind energy and nuclear energy may become a more effective solution to the energy problem. This section discusses the feasibility of this program from the following three aspects:

3.3.1. Power Supply Reliability

For solar and wind energy, the main challenge is the variability of resources. With the large amount of solar energy and wind energy added to the grid, the net load has greater variability, which requires a high degree of flexibility for the grid. For this purpose, other energy sources can be introduced into the grid to improve the flexibility of the grid and compensate for the variables of the net load. In addition, nuclear energy is currently the single clean energy that can replace thermal power generation on a large scale, and it has superior economical efficiency under constant power operation [30].

3.3.2. Economic costs

In order to meet the needs of changes in net load, power plants have two economic impacts. 1, Change the output of power plants, increase the demand for power plant maintenance, and reduce the operating life and operating efficiency of the plant [31]; 2, Change the generator's output, lower its capacity factor, and increase the power station's cost of electricity sales. Although it is feasible to change the output of nuclear power plants, this will reduce the economic competitiveness of nuclear power.

3.3.3. Technical feasibility

From a technical point of view, although nuclear energy can increase the flexibility of the grid and compensate for the net load variable in the load-following mode, it will highly decrease the economic efficiency of nuclear power generation [30]. Therefore, in order to increase the compatibility of solar energy, wind energy and nuclear energy, China may improve the program with lower-cost thermal power generation, use coal energy to increase the flexibility of the power grid, and nuclear power to operate at constant power to ensure its economic benefits.

4. CONCLUSION

Due to the fast-growing economy and huge energy consumption, China is confronted with unique energy challenges. In order to achieve the climate goals under the Paris Agreement and realize China's sustainable development, China's overall energy structure must be transformed from a coal-based energy system to a sustainable energy system. However, in the decades to come, China still needs to rely on coal energy, and this change will be a long process .For wind energy and solar energy, due to their intermittency, they have a great impact on the power supply stability of the power grid. In addition, the current economic costs of wind energy and solar energy are uncompetitive with traditional energy sources, and they need to rely on government preferential policies and subsidies in order to survive and develop; With regard to nuclear energy, the issue of nuclear waste disposal and nuclear safety has always been a problem criticized by the public and social organizations. Public opinion plays a key role in policy decisions.

Starting from China’s national conditions, it is not feasible to develop a type of energy alone and completely abandon other energy sources. In order to achieve China's low-carbon goals and ensure economic efficiency, China should develop renewable energy (wind, solar energy) and nuclear energy at the same time, using the large amount of coal resources in China to increase grid flexibility and gradually decrease carbon emissions. In addition, China must increase investment in advanced energy technologies and improve energy policies to promote the development of low-carbon energy. All these provide a good opportunity for China to achieve sustainable energy development.

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