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Problems of Management

Original article

Managing the global energy transition in a carbon neutral environment: strategies, trends and measures

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Abstract. Energy is an important material basis for economic development. Under the background of increasing global climate change, vigorously developing low-carbon, clean and efficient renewable energy is the main direction of global energy transition. The article analyzes the current situation of global energy transition in three aspects: the change of global energy consumption structure, the change of global power structure and the change of energy consumption structure in different countries, and concludes that there are three major challenges in the process of global energy transition: the global fossil energy consumption accounts for a relatively large proportion, the power is highly dependent on fossil energy and the global energy structure is uneven. Finally, it puts forward some measures to promote global energy transition, such as the joint efforts of the government and enterprises to optimize the energy consumption structure. Promote clean energy technology innovation and reduce the dependence of electricity on fossil energy; strengthen international cooperation to solve the imbalance of global energy structure, thereby contributing to the global energy transition.

Keywords: energy consumption management, energy transition, innovations in clean energy technologies, optimization of energy consumption structure

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Проблемы управления

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Управление глобальным энергетическим переходом в условиях углеродной нейтральности: стратегии, тенденции и меры

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Аннотация. Энергия является важной материальной основой экономического развития. В условиях усиливающегося глобального изменения климата активное развитие низкоуглеродной, чистой и эффективной возобновляемой энергетики является основным направлением глобального энергетического перехода. В статье анализируется текущая ситуация глобального энергетического перехода в трех аспектах: изменение глобальной структуры энергопотребления, изменение глобальной структуры энергетики и изменение структуры энергопотребления в разных странах, и сделан вывод о наличии трех ключевых проблем в процессе глобального энергетического перехода: глобальное потребление

ископаемых видов энергии составляет относительно большую долю, энергетика значительно зависит от ископаемых видов энергии, а глобальная энергетическая структура неравномерна. В статье предлагаются некоторые меры по содействию глобальному энергетическому переходу: совместные усилия правительства и предприятий по оптимизации структуры энергопотребления; содействие инновациям в области технологий чистой энергии и снижение зависимости электроэнергии от ископаемых видов энергии; укрепление международного сотрудничества для решения проблемы дисбаланса глобальной энергетической структуры, внося тем самым вклад в глобальный энергетический переход.

Ключевые слова: управление энергопотреблением, энергетический переход, инновации в сфере технологий чистой энергии, оптимизация структуры энергопотребления

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1. Introduction

Energy is the foundation of human survival and development, and the cornerstone of the development of modern society. Economic development requires a large amount of energy support. Whether it is industrial production, transportation or agriculture, energy supply is needed. Throughout the history of economic development, the rapid development of economy is at the expense of energy consumption. In modern society, the degree of energy exploitation and utilization is getting higher and higher, but the excessive use of energy brings some problems. On the one hand, with the increasing global demand for energy, the problem of global energy shortage has become increasingly prominent.

On the other hand, the use of energy has a certain impact on the environment, including air pollution, water pollution and land destruction. In order to solve the increasingly prominent energy shortage problem and deal with the environmental problems caused by energy consumption, countries have put forward the concept of “energy transition”. Especially, since 2022, affected by the conflict between Russia and Ukraine and extreme weather, the global energy prices such as oil, coal and natural gas have risen sharply, and the world has fallen into an energy crisis. This has sounded an alarm for the development of energy transition, which also reflects the urgency of energy transition.

2. Literature review

Under the background of Climate change in the world and resource shortage, energy transition has become the focus of global attention, and more and more scholars have also focused on energy transition. At present, humans have completed two energy transitions. Hou M.F., Pan S.Q. and Liu H.L. (2021) think that Global energy transformation presents four major trends: cleanness, science and technology, electrification and intelligence [1].

Energy transition is helpful to solve climate change and protect the environment. Wang J.D. (2023) used the panel data of 71 economies from 2003 to 2019 to build an econometric model of the impact of renewable energy transition on carbon emissions. The research shows that renewable energy transition significantly reduces carbon emissions [2].

Energy transition is influenced by many factors. Adekoya O.B., et al. (2023) found that from a global perspective, economic complexity hinders energy efficiency and renewable energy transition [3].

Khalid K.,Wei C.S.(2022) assessed the relationship between technological innovation and renewable energy in G10 countries. The results show that technological innovation has a significant effect on the progression of renewable energy in various countries, including Germany, the Netherlands, Sweden, the United Kingdom and the United States [4].

Afonso L.T., Marques C.A. and Fuinhas A. (2021) studied the determinants of long-term energy transition in OECD countries from 1971 to 2016. It turns out that energy efficiency and foreign trade conducive to energy transformation, while the carbon strength of energy consumption is limiting energy transformation [5].

Sun X.S., Xu H.W. (2018) put forward that policy, technology and investment are the key elements of energy transformation. They stressed that these three elements must be closely combined to jointly promote the energy industry to move in the direction of low-carbon, high-efficiency and sustainable development [6].

In the process of energy transition, research and application of energy technology is the core. Lv Q.G., Chai Z. (2022) made an in-depth analysis of the present situation of fossil energy use in China, and put forward some suggestions for the efficient utilization and transformation of coal, efficient utilization of oil and natural gas and treatment of "three wastes" in coal chemical industry, in order to provide scientific and technological support for building new energy systems [7].

Different countries have different energy transition paths. Based on the comparative analysis of different energy transition paths, Jin Z.J., Zhang C. (2024) pointed out the diversified characteristics of China's carbon-neutral path, and proposed a path that comprehensively considered economic cost, environmental cost and system reliability [8].

Gao Z.N., Jiang N., Chen Q.X., et al. (2024) taking the German electricity market as a reference object, this paper compares and summarizes the process and effect of promoting the consumption of new energy, and provides a useful reference for the construction of the electricity market in Inner Mongolia [9].

Thus, the analysis of literary sources has shown that energy transition is beneficial for reducing carbon emissions and help solve climate problems. Energy transformation is influenced by many factors, among which technological innovation, energy efficiency and foreign trade promote energy transformation, while economic complexity hinders energy transformation.

3. The trends of the global energy transition in a carbon neutral environment

3.1. Differences in global energy consumption framework

Figure 1 indicates that in 2019 global energy consumption reached 587,43 EJ[1], and in 2020, affected by the COVID-19 epidemic, it decreased by about 4% to 564,01 EJ. From the perspective of energy consumption structure, from 2011 to 2021, the proportion of coal in global energy consumption showed a decreasing trend year by year: in 2011-2014 the proportion of oil in global energy consumption showed a downward trend, but after a small rebound in 2015 and 2016, it continued to decline in 2017-2021, as shown in Figure 2.

The proportion of natural gas shows an overall upward trend, but the increase rate is not large, from 22,3% in 2011 to 24,4% in 2021. The proportion of renewable energy has increased greatly, surpassing nuclear energy for the first time in 2017, rising from 2,3% in 2011 to 6,7% in 2021, and its proportion has increased by about three times.

The proportion of hydropower in energy consumption has remained relatively stable at around 7% overall.

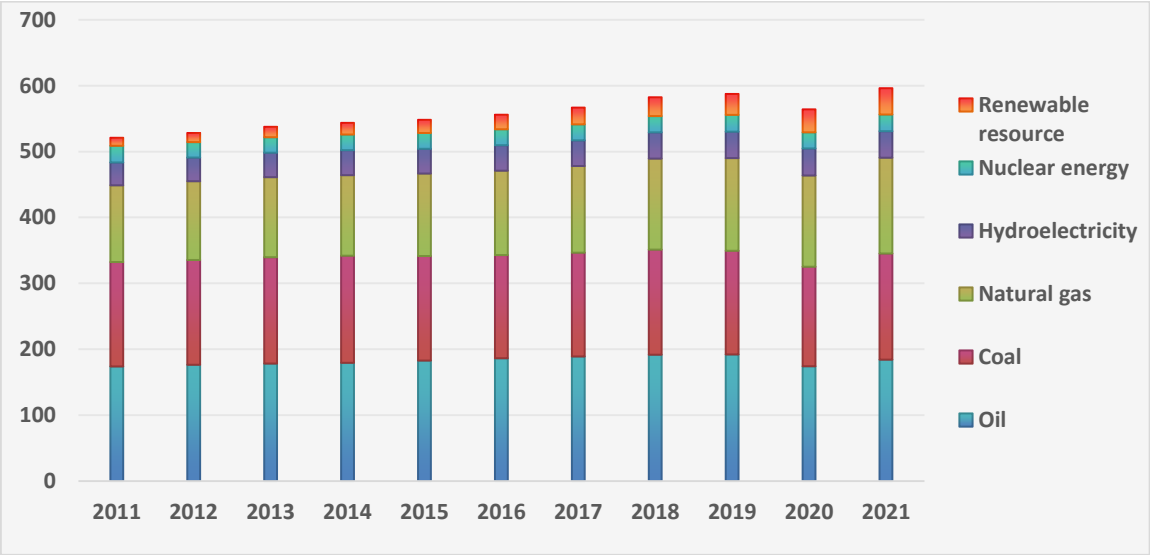

Fig. 1 Global energy consumption structure (absolute quantity), 2011-2021, EJ [10]

[1] ExaJoule (1 EJ=1018 Joules).

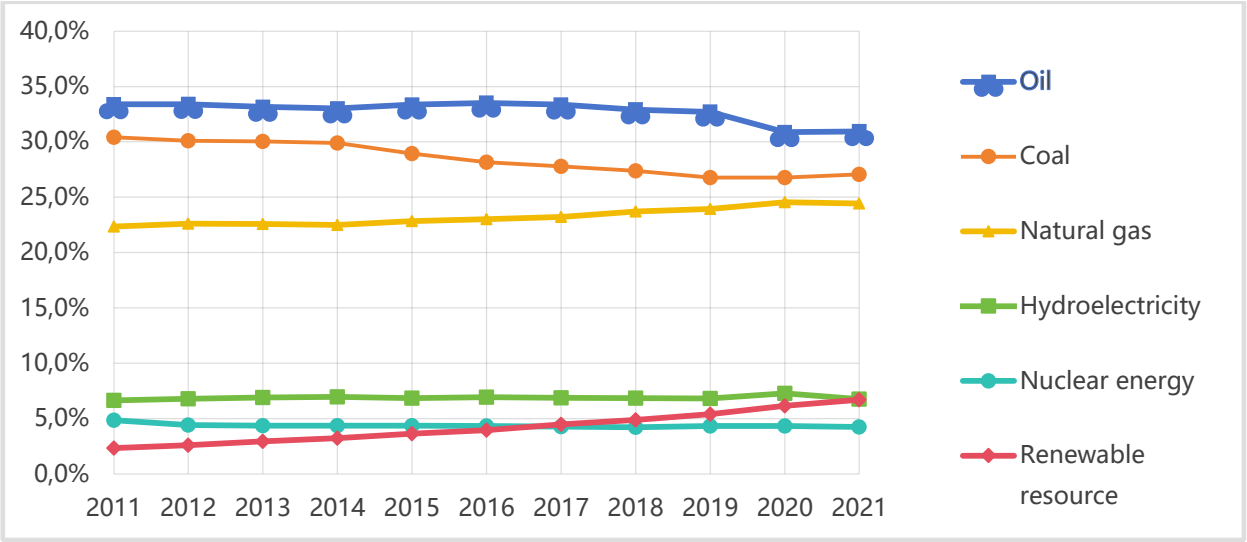

Fig. 2. Global energy consumption structure, 2011–2021, % [10]

Thus, the following phenomena are manifested in the structure of global energy consumption: the proportion of fossil energy has decreased, while the proportion of clean energy has increased year by year, which shows that the global energy consumption structure has been optimized to some extent.

3.2. Changes in global production power structure

As a clean energy, electricity is an important material basis for production and life in modern society. In 2017-2021 global electricity mainly comes from fossil fuel energy, in which coal occupies for the top ratio of the total global power production, and renewable energy power production came second, as shown in Figure 3.

Although the proportion of coal power generation decreased from 38,3% to 36,3% in 2017-2021, it decreased by 2%. However, in 2021, the proportion of coal in the total global power generation was still as high as 36,3%, because the cost of coal power generation was lower than other energy sources and the energy utilization rate was higher. Therefore, coal is still dominant in global power generation. As a clean energy source, natural gas accounts for a relatively stable proportion of 23% in the global power structure. In 2021, the proportion of renewable energy power generation was 28,1%, an increase of 3,6 percentage points over 2017.

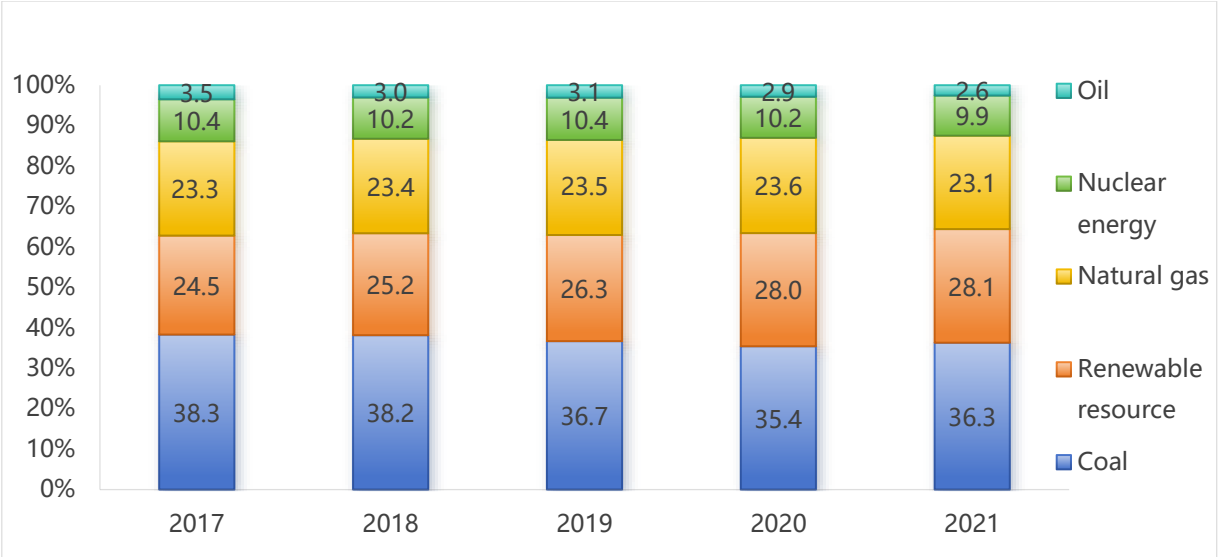

Fig. 3 Global Electricity Production Structure, 2017-2021, % [10], [11]

3.3. Changes in energy consumption structure of major countries in the world

Due to the differences between different countries in climate, financial circumstances, energy status and energy support, their energy framework shows conspicuous different. In this article, the energy framework of the United States, German, Russia, Japanese and China is deeply analyzed, as shown in Tables 4-9.

Tables show the energy consumption structure of major countries in the world in 2016-2021, respectively. Tables indicate that in 2016-2021, the energy consumption structure of all five countries has been optimized to some extent, indicating that each country has made certain achievements in energy transition.

Table 4. Energy consumption structure of major countries in the world, 2016, % [11]

	Oil	Natural gas	Coal	Nuclear energy	Hydroelectricity	Renewable resource
USA	40.7	29.0	15.3	8.6	2.7	3.7
Germany	35.7	22.2	23.1	5.9	1.4	11.7
Russia	22.1	52.4	12.9	6.5	6.1	0.04
Japan	42.4	22.2	26.3	0.9	4.0	4.2
China	19.3	5.9	62.0	1.6	8.6	2.7

Table 5. Energy consumption structure of major countries in the world, 2017, % [11]

	Oil	Natural gas	Coal	Nuclear energy	Hydroelectricity	Renewable resource
USA	40.9	28.4	14.9	8.6	3.0	4.2
Germany	35.8	23.1	21.3	5.1	1.3	13.4
Russia	21.9	52.3	13.2	6.6	5.9	0.04
Japan	41.3	22.1	26.4	1.4	3.9	4.9
China	19.4	6.6	60.4	1.8	8.3	3.4

Table 6. Energy consumption structure of major countries in the world, 2018, % [12]

	Oil	Natural gas	Coal	Nuclear energy	Hydroelectricity	Renewable resource
USA	38.8	30.9	13.9	7.9	2.7	5.8
Germany	34.4	23.0	21.6	5.1	1.2	14.7
Russia	21.6	54.5	12.1	6.1	5.7	0.03
Japan	40.5	22.1	26.5	2.3	3.8	4.7
China	19.6	7.5	58.8	1.9	7.9	4.3

Table 7. Energy consumption structure of major countries in the world, 2019, % [12]

	Oil	Natural gas	Coal	Nuclear energy	Hydroelectricity	Renewable resource
USA	39.1	32.2	12.0	8.0	2.6	6.2
Germany	35.6	24.3	17.5	5.1	1.4	16.1
Russia	22.0	53.7	12.2	6.2	5.8	0.1
Japan	40.3	20.8	26.3	3.2	3.5	5.9
China	19.7	7.8	57.6	2.2	8.0	4.7

Table 8. Energy consumption structure of major countries in the world, 2020, % [10]

2020	Oil	Natural gas	Coal	Nuclear energy	Hydroelectricity	Renewable resource
USA	36.7	33.8	10.4	8.5	3.0	7.5
Germany	34.1	25.4	14.6	4.7	1.4	19.7
Russia	22.0	52.8	11.4	6.8	7.0	0.1
Japan	37.9	21.9	26.7	2.3	4.3	7.0
China	19.5	8.2	55.8	2.2	8.5	5.8

Table 9. Energy consumption structure of major countries in the world, 2021, % [10]

2021	Oil	Natural gas	Coal	Nuclear energy	Hydroelectricity	Renewable resource
USA	38.0	32.0	11.4	8.0	2.6	8.0
Germany	33.1	25.8	16.8	4.9	1.4	18.0
Russia	21.4	54.6	10.9	6.4	6.5	0.2
Japan	37.3	21.0	27.1	3.1	4.1	7.4
China	19.4	8.6	54.7	2.3	7.8	7.2

When analyzing the energy consumption structure of various countries around the world, it found out that there is seriously unbalanced in the development of energy structure among countries. In 2021, coal and oil still dominate the energy consumption structure of China and Japan. These two kinds of energy are non-renewable resources, resulting in resource shortage. Meanwhile, the use of coal and oil is accompanied by the emission of a large amount of harmful gases, which have a bad influence on the climate.

The main reason for China's use of coal for power generation is: firstly, China's energy structure is relatively obvious, and China's reserves and production of oil and natural gas are relatively small. However, China's coal reserves are very large, not only the reserves are in the forefront of the world, the annual mining output is on the verge of half of the world, and the mining output ranks top in the world.

Secondly, compared to other fossil fuels, the price of coal is relatively low. Once again, China's coal power generation technology is mature and relatively stable. In Russia's energy framework, although coal and oil only occupy for 32,3%, the consumption of natural gas occupy for a large scale, upping to the level 54,6%, and natural gas is non-renewable energy. The energy consumption framework of the USA and Germany is relatively balanced, but the proportion of renewable energy is not high, and the pressure of global energy transition is still relatively large.

4. Challenges for global energy transition

4.1. Fossil fuels account for a large proportion worldwide

In the evolution of global energy consumption structure, the proportion of clean energy is growing annually. This phenomenon indicates that worldwide countries have made a special effort in supporting people to save energy and decrease discharge, given vigorously assist to the exploitation and implement of clearer energy skills, and achieved certain results, thus promoting the continuous optimization of energy consumption structure. Although the share of fossil energy in the worldwide energy consumption framework has shrunk, its core position has not been shaken. According to the statistics in 2021, the ratio of fossil energy in world-wide energy consumption is yet as high as 82,4%, which reflects that the energy consumption structure still needs to be further adjusted to achieve a more reasonable state.

4.2. Electricity production is highly dependent on fossil fuels

Due to the extensive use of electrical appliances, electricity plays a very important role in modern society. However, according to the above data analysis, the global electricity mainly comes from coal, because the cost of clean energy power generation is higher than that of fossil energy, and the power generation

technology is also limited by the natural environment. For example, wind power generation technology uses wind flow to convert wind energy into electricity, which is highly dependent on the environment. Similar to wind energy, solar power generation also depends on the environment, and the climate in each country directly impacts the use efficiency of solar energy. Apart from this, although nuclear energy is not confined by the environment, nuclear power production is easy to atomic accident and has dangers. Therefore, the present ratio of clean energy production is less than that of fossil energy, which delays the progress of global energy transition.

4.3. Uneven development of global energy consumption structure

From a global perspective, different countries' geographical location, resource endowments and economic development levels determine that there are great differences in their energy consumption structures. Therefore, the uneven development of global energy consumption structure is becoming more and more obvious. For example, due to the influence of resource endowment, Russia's natural gas consumption is relatively tall, occupying 54,6% of natural gas in 2021; Germany has a relatively big scale of renewable energy, about 18%; The scale of renewable energy in China grows from 2,7% in 2016 to 7,2% in 2021. Although the evolution of renewable energy in China is extremely quick, coal is still the primary energy in China, occupy a scale of 54,7%.

Scientific and technological progress is the main force to promote energy development, but the uneven development of energy technology among countries around the world is also one of the main reasons for the uneven energy consumption structure. In response to global climate change, clean energy has gradually become the focus of global energy technology innovation. Developed countries have taken the lead in completing industrialization and gradually focused on the research and development of clean energy technologies [6]. Some countries have invested heavily in energy technology R&D and have obvious technological advantages. For example, by 2024, global energy investment is exceeded $3 trillion for the first time, of which $2 trillion is used for clean energy technologies and infrastructure [13].

5. Strategies for Global Energy transition

In order to achieve global energy transformation, the following three points need to be achieved: firstly, the government and enterprises work together to optimize the energy consumption structure; Secondly, promote innovation in clean energy technology and reduce the dependence of electricity on fossil fuels; Thirdly, strengthen international cooperation to address the global energy structure imbalance. The detailed measures are as follows:

5.1. Cooperation between government and enterprises to optimize energy consumption

The targets of energy services are mainly energy enterprises and the public. However, government departments, as energy managers, play a very important role in energy transition. Therefore, in order to promote the optimization of energy consumption structure and realize energy transition, the government, enterprises and the public need to play their respective roles. For example, being a government sector, the government supports energy conservation and consumption reduction projects through financial investment, closes and eliminates high energy consuming and high polluting enterprises, provides tax incentives for low-carbon technologies and clean energy industries, such as reducing corporate income tax, value-added tax, and tariffs, lowers costs for enterprises and individuals, encourages research and application of low-carbon technologies, and promotes energy structure optimization.

As a firm, government departments utilize updated skill and device to advance energy usage efficiency; expanding the usage of clearer energy and advance energy species; by combining energy consumption with the Internet, implement monitoring and regulation of energy consumption, so that energy enterprises realize intelligent energy management, improve energy use efficiency and promote energy structure optimization.

5.2. Promote clean energy technology innovation

Under the goal of coping with peak carbon dioxide emissions and achieving carbon neutrality, energy transformation mainly focuses on two key areas: first, drop carbonation of energy through the implementation of carbon dioxide capture, utilization and storage technology (CCUs), it separates CO2 from industrial processes, energy utilization, or the atmosphere, and directly utilizes or injects it into geological formations

to achieve permanent CO2 reduction. Carbon capture includes pre combustion capture, post combustion capture, and oxygen enriched combustion, etc.

Carbon transportation refers to the transportation of captured CO2 to designated locations through pipelines, ships, and other means; carbon utilization refers to the process of resource utilization of captured CO2 through engineering techniques, including mineral carbonization, physical utilization, chemical utilization, and biological utilization; carbon sequestration is the process of injecting captured CO2 into deep geological reservoirs through certain technological means, isolating them from the atmosphere for a long time.

The main methods of sequestration include geological sequestration and oceanic sequestration; secondly, actively promote clean energy sources such as wind and solar power. However, wind and solar energy are constrained and unstable by weather factors, which requires the creation of cleaner energy technologies. For the purpose of deal with the unsteadiness of wind and solar power production, push forward the R&D and spread of accumulation energy skill, and conserve overload wind and solar power, which raises steady-going ability and compliant ability of wind and solar power production. In addition, the R&D of nuclear pollution treatment technology help to improve the safety of nuclear power. In this way, the transition of clean energy instead of fossil energy gradually is achieved and accelerate the global energy transition.

5.3. Strengthening international cooperation

Strengthening international cooperation mainly refers to exchanges and cooperation between countries with advanced energy technology and countries with backward technology. At present, coping with the climate crisis is a global activity. Facing the challenge of unbalanced development of global energy structure, international cooperation is an effective countermeasure to this problem, and then realize global energy transition. By communicating with countries with strong clean energy technologies and attracting investment from developed countries, introducing advanced energy technologies and narrow the gap of energy technologies in different countries.

In addition, international cooperation is also reflected in energy complementarity. Different countries in the world have different energy advantages and high energy complementarity. For example, Russia is rich in coal, oil and natural gas, especially natural gas resources; China is rich in coal resources, but relatively scarce in oil and natural gas resources; Japan is a country lacking in energy, but its capital and energy technology are relatively high. Therefore, the benefits of energy cooperation are greater than those of competition, and energy complementarity is conducive to global energy transition. For example, China and Russia jointly built the “West East Gas Pipeline” natural gas pipeline. The pipeline project aims to transport natural gas from Russia to China to meet China’s growing demand for natural gas. This move also help Russia reduce its dependence on the European market and achieve diversified market layout.

German companies and Chinese enterprises have jointly developed wind power projects, achieving technology introduction and industrialization. The success of this cooperation case lies in the complementarity of technology and the alignment with market demand. Germany’s technology and experience provide valuable reference and support for China, while China’s huge market provides development space for German enterprises.

6. Conclusion

Human society has completed two important energy transitions. Currently, under the context of global endeavors to cope with climate matter, each and every nation are undergoing an energy transformation from fossil energy to renewable energy. In the process of global energy transition, there are many difficulties and challenges.

The key factor for the success of global energy transition is clean energy technology innovation. This is mainly based on the following reasons: 1) innovation in clean energy technology is conducive to reduce the production cost of clean energy. For example, breakthroughs in solar cell technology have significantly reduced the cost of solar power generation, making it an important choice for more and more countries and regions to replace traditional energy sources; 2) clean energy technology innovation has improved energy utilization efficiency. By optimizing the design and manufacturing processes of clean energy equipment, as well as developing advanced energy management systems, achieving the efficient utilization and refined management of clean energy. 3) Innovation in clean energy technologies helps address energy sustainability issues.

Through continuous innovation, the widespread application of clean energy and promote the substitution of traditional energy sources, thereby reducing dependence on fossil fuels and mitigating the risks of environmental pollution and climate change.

Strengthening exchanges and cooperation in energy technology between different countries is conducive to solve the problem of unbalanced global energy structure. This is mainly based on the following reasons: firstly, strengthening energy technology exchanges and cooperation among countries. Through technology transfer, joint research and development, and joint demonstration, countries share advanced technologies and experiences, accelerate the commercialization process of renewable energy technologies, and increase their proportion in the global energy structure. Secondly, strengthen energy technology exchanges and cooperation, promote the optimization of energy resource allocation among countries, and achieve complementary and shared energy resources.

Finally, the research and application of clean energy technology is inseparable from the financial support of the government. This is mainly due to two reasons: due to the uncertainty of technology research and development and the volatility of market demand, the research and development of clean energy technologies also face high risks. Private enterprises often find it difficult to bear such large investments and risks alone, and therefore require government funding support to share risks and encourage innovation. In addition, the research and application of clean energy technologies have the characteristics of public goods, that is, their achievements often are widely shared by society. Therefore, private enterprises lack sufficient motivation to invest research and development funds because their profits may not fully cover the investment costs. At this point, as the representative of public interest, the government needs to compensate for market failures and promote the research and application of clean energy technologies through financial support.

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