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Exploration of Energy Structure Adjustment and International Cooperation Path under Long term Carbon Emission Trends

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Abstract: For a long time, the increase in carbon emissions caused by global climate change has posed great risks to the world's economic and social development. This article will discuss the general trend and possible paths of the world's energy transition under the long-term trend of carbon emissions, as well as the current international cooperation situation, methods, and further directions for promotion. This article first reviews the relationship between global carbon emissions trends and energy consumption, emphasizing the huge gap between the current use of fossil fuels and climate vision. Based on this, it explores how to achieve the goal of optimizing energy structure from the perspectives of technology, government management, and economy: developing clean energy; Clean and efficient utilization of fossil fuels; Building a flexible and reliable power grid system; Promote the substitution of electricity. At the same time, the existing Paris Agreement and global commitment actions, regional alliances, cross-border connectivity projects, carbon trading markets, and sustainable financing were introduced. Fourthly, suggestions have been put forward from the perspective of strengthening international exchanges, such as establishing a technology sharing platform, unifying carbon prices and trade policies, supporting developing countries, and establishing energy security cooperation mechanisms, in order to achieve global energy development fairness, stability, and low-carbon goals while addressing climate change.

Keywords: Carbon emission trends, Energy structure adjustment, Renewable energy, International cooperation, Climate governance, low-carbon transition.

1. Introduction

Since the Industrial Revolution, the large-scale burning of fossil fuels has brought about rapid economic development, but has also led to a rapid increase in greenhouse gas concentrations in the atmosphere. The assessment reports of the Intergovernmental Panel on Climate Change (IPCC) have repeatedly emphasized that human factors are the main cause of recent climate change. To keep global warming within the range set by the Paris Agreement - no more than 2 ℃ compared to pre industrial levels and strive to limit it to 1.5 ℃ - the world needs to peak greenhouse gas emissions in the near future and achieve net zero emissions around the mid-20th century. There is a huge gap between this ambitious goal and the current emission trends, which poses unprecedented pressure for the transformation of the existing global energy system. Energy is the main source of carbon emissions, therefore optimizing the energy structure has become the fundamental way to achieve low-carbon development. However, energy transformation is not simply about technological substitution, but involves various issues such as economy, industry, employment, society, and even international relations [1]. It is not something that a single country can undertake alone to solve. Therefore, it is necessary to strengthen international cooperation and seek a fair, reasonable, and effective way of transformation. Based on the analysis of long-term carbon emission scenarios, this article discusses the driving forces and key tasks of energy transformation, and explores the issues of innovation and deepening international cooperation to promote global low-carbon energy transformation.

2. Global Energy Demand and Emission Reduction Challenges Under the Long-Term Trend of Carbon Emissions

The current global primary energy consumption is still dominated by fossil fuels such as coal, oil, and natural gas. Despite the rapid development of renewable energy, its proportion in the global primary energy is still not high. According to IEA data, under current policy measures and commitments, global demand for energy will continue to grow in the coming decades, particularly driven by the industrialization and urbanization of emerging economies [2]. This means that if the growth rate dominated by fossil fuels continues, its carbon emissions will also increase, which will put enormous pressure on global temperature control targets.

The pressure to reduce emissions is mainly reflected in the following difficulties. The first is the structural contradiction between energy demand growth and emission reduction targets. Many developing countries are in the process of industrialization and urbanization, and there is a contradiction between the rigid growth of energy demand and its short-term emission reduction capacity. The second is the locking effect of existing energy infrastructure. A large number of existing coal-fired power plants, industrial facilities, etc. have a lifespan of several decades. Early withdrawal will result in huge sunk cost losses, while failure to withdraw will continue to generate carbon emissions; The third is the constraint of technological economy and resource endowment.

Although the costs of wind and solar power have significantly decreased, key technologies such as battery storage, transmission and distribution expansion and

transformation required for large-scale grid connection still need to be further developed and matured. The manufacturing raw materials for related equipment are not evenly abundant worldwide, and there are certain potential risk points; The fourth issue is the transition towards social equity and justice. The energy transition may have an impact on traditional energy production areas and practitioners. Ensuring employment and social stability, and achieving fair transition, is also an important policy challenge facing governments around the world. The above issues are interrelated, making the path of global emissions reduction full of complexity and uncertainty.

3. Key Directions for Energy Structure Adjustment

To achieve deep emissions reduction, the global energy system must undergo a thorough structural adjustment, with the core being to promote the cleanliness of the energy supply side and the high efficiency and electrification of the consumption side.

One is to vigorously promote the large-scale application and technological innovation of renewable energy. On the basis of continuing to increase the installed capacity of wind and solar power generation, we will vigorously develop other types of renewable energy such as geothermal energy and ocean energy. Strengthen key technological innovation, improve photovoltaic power generation efficiency, reduce offshore wind power costs, promote the application of long-term energy storage in the power grid (including new batteries, compressed air energy storage, hydrogen energy storage), and carry out research and development of nuclear fusion technology [3]. Thirdly, establish a new form of power system with a high proportion of renewable energy access, and enhance the flexibility, resilience, and stability of the power grid through digital and intelligent technologies.

The second is that the low-carbon transformation of traditional energy is a necessary path during the transition period. This includes the implementation of carbon capture, utilization, and storage (CCUS) technology transformation for existing coal-fired power plants, promoting the co firing of low-carbon gases such as natural gas and hydrogen energy, and developing advanced biomass energy technologies. Although the proportion of fossil fuels will decrease in the long term, some industrial sectors may not be able to achieve electrification in the short term, and low-carbon utilization remains an important option in the medium term.

Thirdly, the system's flexible peak shaving capability and irreplaceable energy storage provide guarantees for the consumption of new energy. In addition to pumped storage, various forms of electrochemical energy storage, flywheel energy storage, and demand side response are developed to guide users to participate in grid regulation. By relying on technologies such as smart grids and virtual power plants, effective aggregation management and scheduling control of decentralized resources can be achieved. Improve the overall efficiency of the system.

The fourth is that the electrification and energy efficiency improvement of the end use energy sector are the most direct ways to reduce carbon emissions on the consumer side. Accelerate the development of electric and hydrogen vehicles in transportation, as well as the construction of charging and hydrogen refueling facilities. Promote green building standards and efficient use of electrical appliances and electric heating such as heat pumps in construction. Promote electric furnace steelmaking, electric heating and other processes in industry, and comprehensively improve the energy utilization efficiency of various industries [4]. Behavioral energy-saving and circular economy models will also play a role.

4. Current Situation and Mechanism of International Cooperation

Adapting to climate change has a strong global public good nature, therefore international cooperation is not only necessary, but also essential. At present, various forms and levels of international cooperation models have been formed at the international level to promote international energy transition and climate governance.

4.1. Energy Cooperation Framework under Multilateral Climate Agreements

The international regulatory system centered around the United Nations Framework Convention on Climate Change and the Paris Agreement is the core of global climate governance. The Paris Agreement establishes the institutional arrangement for Nationally Determined Contributions (NDCs) and requires parties to regularly report and update their respective action plans, thereby forcing countries to develop and improve their domestic capabilities and climate policies [5]. The technical and financial mechanisms under the convention framework promote low-carbon technology and transfer, as well as provide financial assistance to developing countries to enhance their adaptation capabilities.

4.2. Regional Green Energy Alliance and Technology Transfer

Regional and multi-level green energy alliances and cooperation plans are constantly emerging. If the EU proposes to become the world's first climate neutral continent through the "Green Deal" and implement CBAM in the region; East Asia, ASEAN, the African Union, and others are also planning regional power grid interconnection and cooperation in renewable energy. Technology transfer is carried out through South South cooperation, trilateral cooperation, and multinational corporations' business models, but issues such as intellectual property protection and sharing, as well as technology localization adaptability, remain difficult cooperation problems.

4.3. Cross border Energy Infrastructure Interconnection

Interconnection projects such as cross-border power grids and natural gas pipelines can help strengthen the mutual benefit and sharing of energy resources, improve regional energy security, and promote the consumption and utilization of clean energy. After the formation of power grid interconnection between Nordic countries and the European continent, cross regional power exchange of Nordic hydropower and wind power has been achieved; Southeast Asian countries are also studying the establishment of regional power grids. Intended to achieve complementary utilization of hydropower and solar energy. China's "the Belt and Road" plan also has many new energy power interconnection plans. But such plans involve issues such as political mutual trust, investment risks, coordination of technical standards, and distribution of benefits [6].

4.4. Carbon Market and International Green Finance Collaboration

The carbon market, as a market mechanism, has been launched in multiple countries and regions such as the European Union and China, and in the future, connecting multiple carbon markets to form a global or regional carbon price is also an important way to improve the effectiveness of the carbon market. In addition, the role of green finance is also highly valued internationally, such as multilateral development banks, climate investment funds, and private capital investing heavily in green projects including renewable energy and energy conservation [7]. Thirdly, various innovative financial products such as green bonds and transformational finance continue to be launched, leveraging global capital to tilt towards low-carbon areas.

5. Exploring the Path to Deepening International Cooperation

The current cooperation mechanism has been preliminarily established, and in the face of the arduous demand for emission reduction and increasingly complex international relations, it is still necessary to continue to expand and optimize on the existing basis in the future. Climate change and energy transition are at a critical stage, and it is difficult for countries to achieve the goals set forth in the Paris Agreement solely through their own efforts. There are also many problems in current international cooperation, such as the slow pace of developed countries transferring clean technologies to developing countries, lack of sufficient investment and technical assistance; Lack of unified standards and regulatory systems among different countries; Lack of effective preventive measures against potential environmental and climate risks, etc. This requires us to promote cooperation towards a more pragmatic, fair, and systematic development stage on the existing basis.

5.1. Jointly Build a Green Energy Technology Innovation and Sharing Platform

Strengthening the leading role of technological innovation, the progress of new energy technology is advancing rapidly, but the cost, difficulty, long cycle, and high risk of tackling core technologies are high. It is suggested to abandon the zero sum game mentality and jointly create an open and inclusive international clean and low-carbon energy technology research and innovation platform. An international clean energy technology innovation cooperation center should be established under the United Nations Framework Convention on Climate Change to carry out international joint research and development around common technological challenges such as long-term energy storage, low-cost green hydrogen production, advanced nuclear energy, and carbon capture and storage. The platform should establish an open source shared technology database and knowledge base, develop a technology maturity assessment and risk warning mechanism, and regularly release a global green technology development roadmap[8]. Establish a tiered technology transfer list and technology catalog suitable for different stages of development, and reduce costs through methods such as technology licensing, patent pool sharing, and local production cooperation. Initiated by the International Energy Agency, the International Renewable Energy Agency, and others, a global framework for mutual recognition of green technology standards has been developed to reduce trade barriers caused by inconsistent standards. In addition, multinational corporations, research institutes, and universities should be encouraged to form industry university research alliances to achieve research and development cooperation internationally, accelerate the development and commercialization of new technologies.

5.2. Coordinate Carbon Pricing Mechanisms and Trade Rules

Carbon pricing is the most important economic tool to encourage low-carbon investment behavior. There are currently dozens of active carbon markets or carbon tax systems internationally, but carbon prices are uneven and coverage varies in size, with each system being fragmented. The next step should be to promote the gradual unification of monitoring report verification, quota distribution methods, market stability reserve funds, and other elements among major carbon markets, in order to prepare for future interconnectivity. We can consider adopting the international carbon price floor mechanism recommended by the International Monetary Fund, setting different carbon price floors for countries with different levels of development, while ensuring emissions reduction and fairness. Adopt a cautious attitude towards new trade measures such as carbon border adjustment mechanisms, and if necessary, consider discussing them within the framework of the World Trade Organization to ensure that relevant measures do not violate the principle of fair competition, and provide a certain transitional period in developing countries; It is suggested to explicitly include carbon dioxide in the total trade volume on an international scale and attempt to increase carbon content labeling for goods and services. The International Accounting Standards Board and other organizations should quickly introduce standards for companies to disclose climate related financial information, so that the carbon cost of companies can be reflected in investment evaluations or internal decision-making processes [9].

5.3. Strengthen Support for Energy Transition in Developing Countries

Developing economies are facing challenges in financing, technology, and capacity enhancement as they advance their energy transition. Developed countries should accelerate the realization of their historical arrears in climate funding and propose a roadmap for doubling funding after 2025. Funds should improve their allocation mechanism and increase the use of preferential credit, insurance, mixed financing and other means to attract private investment. Multilateral development banks should transform their investment and financing methods, focus on achieving climate goals as their main business, and accelerate the processing of green project related procedures. In addition, it is necessary to strengthen capacity building, provide support for developing countries to establish and improve energy and climate change policy frameworks, cultivate relevant technical and management personnel, and create conditions for local technology testing and application promotion; Developed countries and other stakeholders need to assist in formulating fair and reasonable transition plans for coal dominated and developing countries, and provide skill training and promote local economic transformation in affected areas. The climate vulnerable countries of the Alliance of Small Island Developing States and the Least Developed Countries group should first meet their demands for climate change adaptation.

5.4. Establishing an Energy Security Cooperation Mechanism in Crisis Situations

At the same time, energy transformation will also affect the world's energy geopolitical landscape. The relative concentration of key mineral resources for clean and low-carbon energy may also bring new supply risks. It is suggested to establish a key mineral supply chain communication mechanism covering producing countries, consuming countries, and transit countries through the existing International Energy Forum, and propose action plans on global reserves, resource recycling and reuse, and alternative technology research and development. In the event of supply interruption or abnormal price fluctuations, multilateral cooperation mechanisms can be activated to alleviate market impact. In addition, the frequent occurrence of extreme weather also puts higher demands on the resilience of the energy system. Power departments of various countries can strengthen cooperation, experience sharing, and joint exercises in disaster prediction, emergency dispatch, and rapid power restoration. When facing a serious energy supply crisis, temporary clean and low-carbon energy storage and mutual assistance mechanisms can be considered among important energy consuming countries. The G20 and other platforms can conduct more systematic and coordinated research on climate security and energy security, and build a comprehensive cooperation mechanism covering prevention, emergency response, and recovery. In short, it is necessary to strengthen international exchanges, enhance collaborative efforts in scientific and technological research and development, standard specifications, policy funding, risk prevention and control, and promote win-win cooperation with a more open and inclusive attitude while taking into account each other's legitimate rights and development needs [10]. Concrete and feasible forms of cooperation should be used to address the severe challenges brought by climate change, and ultimately achieve the dual goals of climate security and energy security.

6. Conclusion

The future carbon emission scenario reflects the huge imbalance between energy development and sustainable development in the world. Energy transition is a complex scientific, technological, social, and policy integrated project that will determine whether humanity can solve the major problem of climate change. This article believes that the technological roadmap for energy transformation has gradually become clear, that is, accelerating the construction of a new type of power system dominated by renewable energy and achieving electrification and energy efficiency improvement of terminal energy consumption are key. However, the speed and depth of energy transformation are not only constrained by technological development and economic costs, but also highly dependent on the coordination and cooperation efforts of the international community. The current global multilateral framework has made some progress in standard setting, financing, and technology transfer, but still cannot achieve the speed and scale required to support the Paris Agreement. In the future, the international community should continue to strengthen cooperation in building inclusive technology innovation alliances, promoting low-carbon investment guided by market and trade policies, based on the principles of trust, equality, and mutual benefit. Actively support the transformation efforts of developing countries and work together to build an energy security network that can withstand various risks. In short, climate action and energy transition are not only risk management measures to avoid disasters, but also the inevitable path to jointly build a clean and beautiful world, achieve prosperity, development, fairness and justice, and move towards a sustainable future. This requires all parties to show political courage and foresight, fulfill common but differentiated responsibilities, and take practical and leading measures to embark on a new journey of global carbon neutrality.

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