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Opportunities and Challenges from Energy Transition: Based on Carbon Neutrality Strategy Case Study in China

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Abstract: Humans have released a significant amount of greenhouse gases into the atmosphere as civilization has grown, contributing to environmental issues such as global warming. Of them, China faces the brunt of the duty to protect the environment for human habitation, being the nation with the highest emissions. This review focuses on three main areas: the current state and future planning of China's energy technology field; the development of China's carbon trading market; and the Chinese government's 2030 "carbon peak" and 2060 "carbon neutrality" two major goals and related guiding policies. The sector of new energy is expanding quickly, public awareness of environmental protection is rising, and the carbon trading market is steadily getting better under the direction and control of the government. However, China still has enormous technical challenges in satisfying its massive energy needs. The Chinese government's continued economic and policy support will hasten the advancement of technology and enhance market performance.

1. Introduction

The fast development of society has resulted in an unprecedented need for energy. Burning chemical resources has been the main method used in recent decades to maintain the massive energy demand of development. As a result, billions of tons of carbon dioxide were released into the atmosphere, and this is now one of the main causes of the greenhouse effect. As indicated by figure 1, CO_2 emissions are rising steadily throughout the time [1]. In 2020, the world has emitted a total amount of 35.26 billions of tons of carbon dioxide, most of which are emitted during the consumption of coal, oil and gas, as figure 2 illustrated, in older to generate electricity and heat, support transportation, and other necessities [2]. Meanwhile, China’s carbon emissions have also increase overtime as figure 1 presented and now become the largest carbon emitter of all countries, accounting for 26.7% of global carbon emissions in 2019. However, in contrast to the whole consumption of the world, which consumes roughly the same amount of oil and coal, China's primarily source of carbon dioxide emissions is its coal use, accounting for nearly 70% of total emissions.

The greenhouse effect gives rise to global warming, as seen by the increase in world average temperature in 2020, which was 1.02 degrees higher than the long-term average, as measured from

1951 to 1980. The ramifications of increasing temperatures are multifaceted and challenging to quantify. This phenomenon has not only led to a surge in extreme weather events like droughts, heavy rainfall, and hurricanes, and a decline in biodiversity, but also contributed to melting ice and rising sea levels that endanger coastal areas, threatened marine organisms through ocean acidification, and introduced other potential risks that are yet to be fully understood by humans. Therefore, there is a pressing need to engage in the process of energy transition and mitigate carbon emissions.

Hence, the present paper will concentrate on the analysis of China's strategies and measures aimed at addressing the issue of greenhouse effect and mitigating carbon emissions. The article will be structured into three sections. The initial section will introduce reports and policy documents pertaining to carbon neutrality that have been proposed in different conferences held in China. The subsequent section will focus on conducting an analysis of the pathway for China's transition towards clean energy. Lastly, the final section will examine the development of the carbon trading market in China.

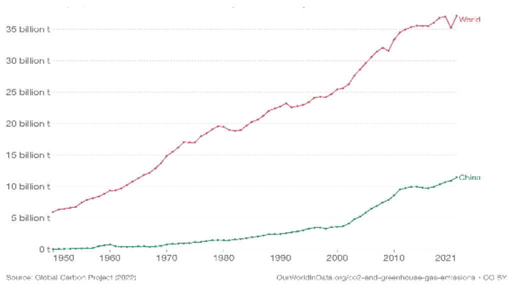

Figure 1: Annual carbon emissions.

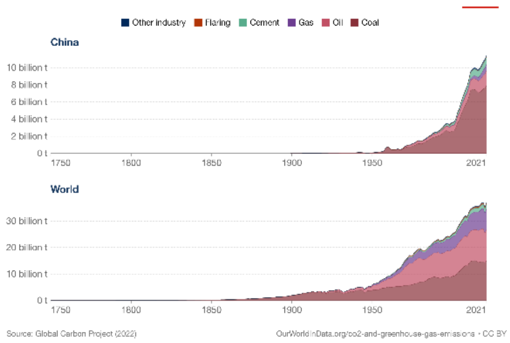

Figure 2: Carbon emissions by fuel.

2. Government Measure

In recent decades, the rapid development of China's economic and technological strength has attracted world attention. However, this technological progress has been accompanied by ecological sacrifices. Consequently, China has become the country with the highest carbon emissions in the world. In 2019, China's carbon footprint reached 37 billion metric tons, accounting for about 26.7% of global carbon emissions. The Chinese government clearly recognizes that sustainable development and ecological protection have become urgent tasks and has begun to deploy important strategies to reduce carbon emissions. In pursuit of carbon neutrality, the Chinese government initially announced its commitment to reducing emissions globally. Subsequently, it had formulated comprehensive guidelines and continued to refine several relevant complementary policies aimed at facilitating the realization of that goal.

2.1. Commitment

The 2014 China-U.S. joint Statement on Climate Change introduced a significant proposal by the Chinese government, outlining the vision to achieve the peak of carbon dioxide emissions by the year 2030 [3]. The commitment made by China at the 21st Conference of the Parties in November 2015 entails ensuring that its overall carbon emissions do not increase beyond the year 2030. In 2020, the president announced at the 75th United Nations General Assembly that China will achieve 'carbon neutrality' by 2060, meaning making no net release of carbon dioxide to the atmosphere. In China, the combined objectives of achieving “Carbon Emission Peak” and “Carbon Neutrality” are commonly denoted as the "dual Carbon" targets. The statement emphasizes the Chinese government's commitment to these environmental goals, suggesting that they will be pursued with the same vigor as earlier initiatives like poverty alleviation [4].

2.2. Macro Guidance

China has subsequently released a series of guiding documents. On 2021.2.22, the state council announce the documents of "State Council calls for green, low-carbon and circular development”, which aim to accelerate the development of the green energy industries. On 2021.3.11, the government want to promote green industry development and management through digitalization, and therefore announce the document, “The 14th Five-Year Plan for National Economic and Social Development and the Long-range Goals to 2035” [5]. On 2021.10.26, the government first announce specific requirements and goals of “Peak Carbon dioxide emissions” [6] , illustrated in table 1, in the document of “Notice of The State Council on Issuing an Action Plan for Carbon Peaking before 2030.”

Table 1: Goals of “Peak Carbon Dioxide Emissions”.

Item	2025	2030
Non-fossil energy consumption	The proportion of non-fossil energy consumption should reach about 20%	The share of non-fossil energy consumption should reach about 25%
CO_2 emissions per unit GDP	Carbon dioxide emissions per unit of GDP should be reduced by 18% from the 2020 level	Carbon dioxide emissions per unit of GDP should be reduced by more than 65% from the 2005 level
Energy storage	The installed capacity of new energy storage will reach more than 30 million kilowatts.	The installed capacity of pumped storage power stations will reach about 120 million kilowatts, and the provincial power grid will have a peak load response capacity of more than 5%.
Waste recycle	The amount of recycled nine major renewable resources, including steel, copper, aluminum, lead, zinc, paper, plastics, rubber and glass, will reach 450 million tons	Same type of recycled resources will reach 510 million tons.
Wind and Solar power		The total installed capacity of wind and solar power will reach more than 1.2 billion kilowatts.
Transportation		The proportion of new and clean energy powered vehicles will reach 40%.

Another crucial aspect is the implementation of a policy framework known as the "1+N" system, aimed at achieving carbon neutrality and reaching a peak in carbon emissions. The document denoted as "1" encompasses two distinct texts, namely the ‘Opinions of the Central Committee of the Communist Party of China and The State Council on the Full, Accurate, and Comprehensive Implementation of the New Development Concept’, as well as the “Effective Execution of Carbon Peaking and Carbon Neutrality” [7].The two aforementioned publications provide specific objectives for China to accomplish by the years 2025 and 2030, as depicted. Additionally, the individual possesses a comprehensive strategy outlining the specific domains that local government policies should encompass. These areas can be broadly categorized into four main components: general foundational aspects, initiatives aimed at reducing carbon emissions, measures for carbon removal, and the establishment of marketization mechanisms. The letter "N" refers to the implementation plan for key areas and major industries, as well as the associated support plan. Simultaneously, each province has developed their respective carbon peak implementation strategies. Overall, the organization has successfully implemented a comprehensive carbon peak and carbon neutral policy framework that encompasses well-defined objectives, rational allocation of responsibilities, efficient strategies, and seamless coordination.

2.3. Micro Policy

Local governments have introduced subsidies and regulations aimed at fostering the growth of the new energy industry. To promote the adoption of new energy vehicles, numerous regional governments have implemented tax reductions and provided cash incentives to incentivize potential customers. In the city of Shanghai, the acquisition of specific new energy vehicles is accompanied by the provision of a Shanghai license plate. (Discontinued in the year 2023.) The implementation of these policies has effectively fostered the advancement of new energy vehicles within the Chinese context. Furthermore, the government is allocating substantial subsidies to the clean energy sector. In several areas, the government is assuming the responsibility of bridging the financial gap between green energy and thermal power, with the aim of fostering the use of sustainable energy sources and facilitating the growth of renewable energy enterprises.

3. Energy Transition

In order to attain carbon peak and carbon neutrality, it is imperative to consider not just governmental guidance and support, but also the indispensable factors of technological support and market forces. Coal power plays a pivotal role in China's energy provision and serves as a significant driver of economic progress. As of 2021, thermal power generation constituted a substantial portion, specifically 71.13%, of China's overall energy composition. Nevertheless, the pursuit of carbon peak necessitates the adoption of energy transformation, which has emerged as an irreversible trajectory. Currently, there exist several prominent green energy sources that have the potential to serve as viable alternatives to coal. These include wind energy, hydro energy, photovoltaic energy, and biological energy. Each of these sources possesses distinct advantages and disadvantages that warrant careful consideration.

3.1. Hydro Power

As of 2021, hydroelectric power constitutes 14% of China's overall electricity production, making it the most significant contributor among various renewable energy sources. Moreover, it is anticipated that the hydroelectric sector would further expand its market share in the foreseeable future, as China is the largest reserves of hydroelectric power resources globally. One of the notable benefits of hydropower is its inherent controllability and steadiness. Hydroelectric power facilities provide the ability to promptly adapt to fluctuations in energy demand, rendering them a favorable complement to variable renewable sources such as wind and solar energy. Certain hydroelectric power facilities have the capability to store electrical energy, functioning equivalent to a substantial-scale energy storage system. This technology can stabilize electrical networks through supplying electricity during periods of high demand. Moreover, reservoirs fulfill various functions, including the provision of water, mitigation of floods, and facilitation of irrigation. However, when compared to alternative forms of green energy, hydropower is subject to the highest level of criticism. This is mostly due to the potential negative impacts associated with the construction and operation of dams, which can disturb local ecosystems and have adverse effects on fish migration, water quality, and the overall integrity of local habitats. Consequently, the evaluation of the advantages associated with hydroelectric power plants has gotten increasingly intricate, thereby impeding the pace of their advancement.

3.2. Wind Power & Solar Power

According to projections, wind power and solar power generation are anticipated to contribute 6.99% and 2.26% respectively to China's overall power generation in the year 2021. While the current share of these two forms of green energy is very low, they possess substantial untapped potential. The wind and photovoltaic technologies have reached a state of stability, with a concurrent decrease in costs. Over the past decade, there has been a significant decline in the cost of photovoltaic power generation. Specifically, the price of crystalline silicon photovoltaic modules has experienced a substantial reduction from $1.2 per watt (W) to approximately $0.17 per W, representing a decrease of over 85%. The electricity cost for photovoltaic power in 2020 has down to the range of 0.31 to 0.41 yuan. Similarly, the cost of wind power has also decreased by approximately 35%. In 2020, the electricity cost for onshore wind power was 0.28 yuan, while offshore wind power cost 0.61 yuan. It is worth noting that both photovoltaic and onshore wind power have reached a point where they can achieve profitability without subsidies. Nevertheless, wind and solar energy are intermittent energy sources and cannot ensure a continual provision of power. However, when the two elements are integrated, they have the potential to compensate for this deficiency.

Solar energy and wind energy exhibit a high degree of temporal complementarity. Due to China's location within the monsoon climate region, it experiences a decrease in solar radiation intensity during the winter months due to strong winds. Conversely, during the summer season, when wind speeds are lower, China experiences an increase in solar radiation intensity. Hence, the effective utilization of the seasons in a mutually complementary manner can be achieved. Furthermore, it is observed that wind intensity is relatively low during daytime when solar radiation is at its peak. While light intensity diminishes at nighttime, wind energy is augmented by significant variations in surface temperature disparities. The integration of both wind and solar power technologies facilitates the generation of electricity in any weather conditions, offering enhanced economic, technical, and practical advantages compared to relying solely on wind or solar power individually [8].

3.3. Biomass Energy

Currently, the utilization of biomass energy in China is a mere 1% of the overall energy consumption. The limitations associated with the development of biomass energy stem from its intrinsic drawbacks, primarily its low energy and mass density. These circumstances give rise to challenges in the acquisition and conveyance of raw materials, along with the associated financial burdens. Moreover, the energy conversion routes exhibit a restricted range of options, with only a few types being offered, and the efficiency of these conversions is rather poor. However, due to China's status as an agricultural nation, it possesses abundant biomass resources such as crop straw, agricultural product processing wastes, forestry residues, energy crops, and home garbage. China possesses approximately 6.3 billion tons of diverse organic waste resources, which can be equated to roughly 1-1.2 billion tons of standard coal. As the resolution of technical issues progresses, the future potential of biomass energy will increasingly manifest.

3.4. Nuclear Power

There are currently 53 commercial nuclear power units in China, which is 3.5 times more than the 15 units there were at the end of 2012; these units have an installed capacity of 55.6 million kilowatts, which is 4.4 times more than the 12.6 million kilowatts at the end of 2012; additionally, there are 23 nuclear power units under construction, with an installed capacity of 24.19 million kilowatts, and the scale of these projects continues to lead the world. China's current electricity system includes roughly 5% of nuclear power output, a major increase from roughly 2% a decade earlier.

China will need to continue approving roughly eight nuclear power units annually to meet its development goals and reach its carbon neutrality goal. By 2030, China's electrical system must incorporate roughly 10% nuclear power generation, which is in line with the present global average. China must generate 20% of its electricity from nuclear power by 2060, which is comparable to the average level of OECD nations at the moment.

3.5. Carbon Dioxide Capture, Utilization and Storage (CCUS)

The "China Carbon Dioxide Capture, Utilization and Storage (CCUS) Report (2019)" states that as of August 2019, China had completed 12 geological utilization and storage projects, including 10 full-process demonstration projects, and 9 pure capture demonstration projects. These projects demonstrate the significant advancements made in China's CCUS technology under the promotion of pertinent policies. Most China's CO_2 capture demonstration projects are in the thermal power, coal chemical, natural gas treatment, methanol, cement, fertilizer, and other industries. Pre-, post-, and oxygen-rich combustion capture are among the other industries included in this list. Currently, several sets of demonstration devices for CO_2 capture exceeding 100,000 tons have been constructed, with the largest set having a capture capacity of 800,000 tons annually.

The technological ties within CCUS are interconnected and mutually beneficial. Ideally, a downstream CO_2 demand market will be created, and a win-win situation of CO_2 fixation and economic benefits is realized through the front-end carbon capture link, which provides CO_2 for utilization and storage, the intermediate transport link, which guarantees CO_2 transportation, and the back-end CO_2 utilization, which turns CO_2 waste into treasure. In the reality, the investment and operating costs of the CCUS project are very high, and electricity price increases by nearly half after the installation of the post-combustion capture unit. However, 90% of CO_2 resources are turned into low-value products, such as urea and inorganic carbonate, and relatively little is converted into other high-value product. The corporate yield can only be sustained at 2% or less under this extreme cost pressure. Businesses' willingness to undertake CCUS demonstration projects will be adversely impacted if the benefits of emission reduction are not realized [9].

3.6. Energy Storage

Although the share of clean energy is steadily rising, large-scale unstable power supply presents difficulties for the power grid's ability to operate steadily. To increase the energy system's security and flexibility, energy storage technologies must be used in conjunction with renewable energy sources.

Pumped storage continues to be the most significant energy storage technique among them, making up 86.3%, or the same as the global average of 86.2%. However, the development space of pumped storage in the power system may be limited in the future due to the decline in the cost of new energy storage, such as electrochemical energy storage, because of the significant limitations imposed by topography during the construction cycle, which typically lasts seven years. By the end of 2022, China's installed capacity of new energy storage projects reached 8.7 million kilowatts, with an average energy storage period of around 2.1 hours, an increase of more than 110% over the end of 2021 [10].

New energy storage methods (Electrochemical energy storage) accounted for 12.5% of the total energy storage in China. Among them, from the perspective of the proportion of newly installed technologies in 2022, lithium-ion battery energy storage technology accounted for 94.2%, still in an absolute dominant position, and the proportion of new compressed air energy storage and liquid flow battery energy storage technology accounted for 3.4% and 2.3% respectively, accounting for significantly faster growth. In addition, a variety of energy storage technologies such as flywheels, gravity, and sodium ions have also entered the engineering demonstration stage.

4. China's Carbon Dioxide Trading System

The carbon trading market, also referred to as the Emissions Trading System (ETS), is an important instrument for promoting the reduction of greenhouse gas emissions. By establishing a total carbon emission quota, it regulates the overall amount of greenhouse gas emissions and allows businesses to employ carbon emission quota trading to fulfill their commitment to reduce greenhouse gas emissions. Its objectives are to lower greenhouse gas emissions and promote low-carbon technology development and investment.

4.1. Market Structure

The national carbon market will be a unified market comprised of four primary systems: legal, quota management, monitoring report verification (MRV), and market supervision. The legal framework will legally define various national carbon trading systems and serve as the legal foundation for the national carbon market. The carbon emission quota and carbon emission data are managed throughout the process by the quota management system and the monitoring report verification system, respectively. The market oversight mechanism will effectively ensure that the carbon market runs smoothly and effectively. From the perspective of total volume, the trading scale of China's carbon quota market has expanded rapidly in recent years, quadrupling since 2016. In 2021, with the addition of the national carbon trading market, the trading volume exceeded 400 million tons of carbon dioxide equivalent in one fell, and the trading volume reached 1.29 billion euros, with a very rapid growth rate [11].

4.2. Trading System Development History

The National Development and Reform Commission released the "Carbon Emission Trading Pilot Work Notice" in 2011, announcing the beginning of China's carbon trading pilot program in seven provinces and cities (Beijing, Shanghai, Guangdong, Shenzhen, Tianjin, Hubei, and Chongqing) (Fujian was later added, making the total number of pilot units eight). These seven pilot units have finished a great deal of preliminary work since the trading pilot started in 2013, confirming the viability of carbon emissions trading. The top-level design of the carbon market is determined by its own industry structure, emission characteristics, emission reduction targets, and other factors [12].

An important milestone in the development of China's carbon trading market was the June 18, 2013, inauguration of the country's first carbon emission trading platform in Shenzhen. Since then, provinces and cities including Beijing, Tianjin, Shanghai, Guangdong, Hubei, Chongqing, and others have started carbon emission trading programs. Like other carbon trading markets, China's current market is split into two sections: China certified Voluntary emission reduction trading (CCER), which is primarily based on quota trading, and mandatory quota trading. Seven provinces and cities permit emission control enterprises to use a specific percentage of CCER(usually not more than 5% of the total) during the agreement's implementation. Most provinces and cities in the seven pilot areas issue free quotas to emission control enterprises, so the primary market of quota trading primarily uses administrative allocation to grant carbon quotas, though Guangdong, Shenzhen, and Hubei also use auction to issue some quotas to emission control enterprises.

The much-anticipated nationwide carbon emissions trading system went live on December 19, 2017. The nationwide Development and Reform Commission held a teleconference on the same day to launch the implementation of the "National Carbon Emission Trading Market Construction Plan (power generation industry)," and the building of a nationwide unified carbon market began.

5. Conclusions

China, as the world's greatest carbon dioxide emitter, has a critical role to play in protecting the global environment and countering the greenhouse effect. China will face numerous new opportunities and difficulties as a result of this process. To that end, the Chinese government has repeatedly demonstrated its determination and commitment to solving the problem, presenting a detailed plan and guidance program for the 1+N system centered on the goal of "dual carbon," and implementing several encouraging policies to assist China in accelerating its energy transition. The government's assistance will provide numerous benefits to the development of the new energy industry, including financial and policy support. As a result, China's new energy enterprises will grow fast in the future, not only creating many employments but also supplying China with more advanced technology and a stronger supply chain, as well as contributing to the government's goal of making China cleaner. However, technical improvements are urgently required due to China's massive energy consumption. China's energy revolution will be unachievable without efficient and abundant energy output. As a result, to achieve the aim of "dual carbon," China must combine the benefits of various new energy sources and rectify their flaws. China should limit hydropower expansion due to the environmental damage it causes. Furthermore, the complementing qualities of wind and solar energy should be utilized, making it the primary source of renewable energy. At the same time, bioenergy technology will be employed to turn waste into valuables energy supply, and nuclear energy will be developed to prepare for future energy supplies. In addition, China should continue to encourage the development of carbon trading markets, introduce more preferential policies to encourage individuals and enterprises to trade, and strengthen supervision to ensure that companies meet their own carbon emission targets. The leadership of the government, the backing of society, and the development of the firm are all critical and vital in this process.

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