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Carbon emission control technology and policy: Path analysis for promoting green and low-carbon development

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Abstract:
This paper explores the synergistic relationship between technological paths and policy mechanisms in the process of achieving carbon neutrality. The article systematically reviews key emission reduction technologies such as carbon capture and storage (CCUS), renewable energy, and energy efficiency, and evaluates the implementation effects of policy tools such as carbon pricing and green finance. Through case analysis of China's CCUS demonstration project and the EU carbon trading system, the article reveals the effectiveness and challenges of current carbon emission reduction practices, including high costs, insufficient policy coordination, and limited public acceptance. The study shows that although low-carbon technologies have great potential, their effective promotion still depends on coordinated policy support. This study provides empirical evidence for low-carbon transformation and puts forward strategic suggestions for policymakers in the coordinated promotion of technological innovation and institutional guarantees. It highlights the importance of aligning long-term policy planning with technological readiness. Moreover, stakeholder engagement and cross-sector collaboration are identified as key factors for success. Future research should further explore adaptive governance models that can respond to dynamic climate and market conditions.

Keywords: Carbon Capture and Storage (CCUS); Renewable Energy; Energy Efficiency; Green Finance; Carbon Trading Mechanism.

1. Introduction

Global climate change has become one of the most serious challenges of the 21st century. Scientific research shows that greenhouse gas emissions are the main factor causing global warming, among which carbon dioxide (CO_2) emissions account for the majority. Since the signing of the Paris Agreement, more and more countries have committed to achieve carbon neutrality around the middle of this century. To achieve this goal, countries have taken measures to reduce the use of fossil energy, improve energy efficiency and accelerates deployment of renewable energy, while strengthening carbon emission control policies [1][2]. On the one hand, the technical path includes the development of innovative technologies such as low-carbon energy and carbon capture to reduce emissions; on the other hand, the policy path guides the economy to transform to a low-carbon economy through means such as carbon pricing and green finance [3][4]. These technologies and policies combine to form an important strategic framework for reducing global carbon emissions and addressing climate change.

At present, the technical solutions for carbon emission reduction are becoming increasingly abundant. Typical technologies include carbon capture and storage (CCS), renewable energy replacing fossil fuels, improving energy efficiency, and electrification of transportation. For example, CCS technology can capture CO_2 directly from industrial sources and store it to prevent it from entering the atmosphere and plays a critical role in achieving the path of net zero emissions [3]. In terms of renewable energy, the cost of clean energy such as wind power and solar energy has dropped significantly in recent years, the installed capacity of various countries has grown rapidly, and the proportion of renewable energy in the energy structure has continued to increase [5]. At the same time, improving energy efficiency through technological improvements is regarded as one of the most direct and economical ways to reduce carbon emission intensity [6]. In terms of policy, the government has introduced a variety of incentives and constraints to promote emission reduction. Typical examples include carbon pricing mechanisms such as carbon taxes and carbon trading, which encourage companies to reduce emissions and develop low-carbon technologies by increasing emission costs; and the development of green finance, which guides capital flows to clean energy and energy-saving projects through financial means such as credit, bonds and subsidies, to achieve coordinated development of the economy and the environment [1][7]. It can be said that giving equal weight to technological innovation and policy guidance has become the basic consensus and practical direction for countries to reduce carbon emissions.

However, despite certain progress in both the technology and policy aspects of carbon emission control, there are still many challenges and shortcomings. First, in terms of technology, low-carbon technology is costly and difficult to apply on a large scale. For example, although CCS has been applied in several demonstration projects, it is still in the early stages of commercialization, and its cost remains high [3]. However, the variability of renewable output coupled with storage and transmission limitations prevents it from fully replacing fossil fuels at this stage [5]. Second, in terms of policy, coordination between different departments and regions is difficult, and there is uncertainty in policy implementation and supervision. Taking the carbon market as an example, there are obvious differences in carbon prices among countries and regions, and cross-regional cooperation needs to be deepened, which affects the overall efficiency of global emission reduction [2]. At the same time, the public and enterprises are not very receptive to low-carbon transformation, and the short-term economic impact that may be brought about by the green transformation process has caused certain resistance, and it is necessary to strengthen public awareness guidance [2]. Therefore, how to effectively combine technological innovation with policy mechanisms, coordinate economic development and carbon emission reduction, and achieve green and low-carbon transformation has become an urgent issue to be solved [7]. Based on the above background and challenges, this paper will focus on three aspects: 1) the actual impact of renewable energy on carbon emissions, especially the emission reduction effects in different countries and development stages; 2) the relationship between energy efficiency improvement and carbon intensity change, and analyze the role of energy efficiency in emission reduction; 3) the implementation mechanism and effectiveness of green financial policies, including the operation experience of green credit, green taxation and green bonds in different regions and systems. By comprehensively analyzing these three types of representative technical paths and policy tools, this paper aims to sort out their emission reduction mechanisms and actual effects and provide empirical support and policy inspiration for achieving carbon neutrality goals

2. Research Status and Technological Progress

2.1 Carbon emission control technology

The technical path of carbon emission control is a core approach to reducing emissions. Current major technologies include carbon capture and storage, renewable energy, and energy efficiency improvement, each with its own characteristics and challenges:

Carbon capture and storage (CCS): CCS captures CO_2 from industrial sources and stores it underground to keep it out of the atmosphere. It is considered crucial for deep emission cuts, with some large-scale demonstration projects already underway [8]. However, the large-scale appli-

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cation of CCS still faces high costs and increased energy use, requiring policy incentives to support its deployment [3][8]. Some innovative approaches, such as integrating CCS into coal-fired power systems to improve flexibility and renewable energy integration, show promise [9]. Overall, CCS still needs further cost reduction and assurance of safety and effectiveness before it can be widely deployed [3].

Renewable energy: Renewable energy development is a key path to replace fossil fuels and cut carbon emissions. Numerous studies confirm that expanding renewable energy helps curb CO_2 emissions. For example, when renewable energy use exceeds a certain threshold, its impact on per capita CO_2 emission growth becomes significantly negative [5] and increased renewable consumption has been shown to effectively reduce emissions in developing countries [6]. This indicates that a higher share of renewables is vital for achieving carbon peak and carbon neutrality goals. However, due to output variability, improvements in energy storage, grid management, and inter-regional coordination are needed to fully realize renewables' emission reduction potential [5].

Energy efficiency improvement: Enhancing energy efficiency is one of the most cost-effective ways to reduce emissions. Empirical studies show efficiency gains have a significant impact on cutting emissions. For instance, in 30 developing economies, improved energy efficiency was the main contributor to reduction of emissions, whereas changes in industrial structure had a much smaller (sometimes negative) effect [6]. This suggests that compared to broad industrial restructuring, efficiency improvements more directly reduce carbon emissions. Additionally, higher energy efficiency often lowers energy costs and brings environmental benefits. Many countries have adopted efficient standards and technology retrofits to tap this potential. As a result, for example, China's energy intensity has steadily declined in recent years, leading to a parallel drop in carbon intensity [6]. Overall, energy efficiency improvements have proven effective in lowering carbon intensity and are considered a "hidden force" in achieving emission targets.

2.2 Carbon emission control policy

At the policy level, governments around the world have used a series of policy incentives and market mechanisms to control and guide the reduction of carbon emissions. The main carbon emission control policies currently include carbon pricing mechanisms, green finance policies, and international cooperation and policy coordination.

Carbon pricing and emissions trading: Carbon taxes and emissions trading systems are widely used market-based tools for emission reduction. Putting a price on carbon motivates companies to adopt low-carbon technologies and reduce unnecessary emissions. Experience in the EU and elsewhere shows that carbon markets can improve reduction efficiency while capping total emissions [2]. China piloted regional carbon trading in 2013 and launched a national carbon market in 2021, covering major emitters like the power sector [10]. These carbon market policies have significantly promoted green innovation in enterprises; for example, firms participating in trading saw markedly improved green innovation efficiency [11]. The effectiveness of carbon markets also depends on supporting systems such as verification, oversight, and allocation methods. To improve performance, China is adding more emissions reduction projects (e.g., CCUS) into its certified voluntary emission reduction (CCER) trading system to expand supply and stimulate low-carbon investment [3][10]. In general, carbon pricing uses the market's "invisible hand" to integrate emission reduction into economic logic and is regarded as an effective policy tool for driving green transformation.

Green finance policy: Green finance directs financial resources toward low-carbon industries and projects and is an important mechanism for aligning emission reduction with economic development [7]. Governments have introduced various green finance initiatives (e.g., green credit, green bonds, green funds) to channel capital into clean energy, energy conservation, and environmental protection projects. Evidence shows these policies help reduce emissions. For instance, China's green finance pilot zones significantly lowered carbon intensity by spurring green technology innovation and optimizing industrial structure [1]. Similarly, green credit has reduced financing costs for clean companies and green bonds have provided large funding for renewable energy and energy-saving projects, accelerating low-carbon investment [1]. Globally, the green bond market has expanded rapidly, and many regions have set standards and incentives to encourage financing for low-carbon projects. The growth of green finance not only restricts funding for high-emission projects but also signals firms to pay more attention to environmental performance [2]. Studies further show that green finance has become an effective strategy to reduce CO_2 emissions, exerting a negative impact on emissions across different levels of economic development [7]. Therefore, strengthening the green finance policy framework. For example, through fiscal incentives, mandatory environmental information disclosure, and lower financing thresholds for green projects in less-developed regions is crucial to guiding capital toward low-carbon transformation [2][7].

International cooperation and policy coordination: Climate change is a global issue, so no country's emission reduction efforts can be fully effective without international cooperation. Through multilateral agreements and bilateral partnerships, countries have established a common-but-differentiated responsibility framework that commits major emitters to reduction targets and provides for technical and financial support [2]. International cooperation extends beyond targets to sharing low-carbon technologies and policy experience. For example, countries face common challenges in bringing carbon capture, utilization and storage (CCUS) projects into carbon markets, which require shared standards and exchange of project experience [12]. Likewise, international initiatives in green finance encourage financial systems to incorporate climate risk considerations and improve information sharing and regulatory alignment [2]. Cross-border policy coordination can reduce problems like “carbon leakage” and prevent distortions in emission reduction efforts between countries. Meanwhile, developed nations provide financial and technical support to developing countries to help them enhance their capacity to tackle climate change, an important aspect of global mitigation. Looking ahead, only by strengthening international cooperation and building a multi-level climate governance system can all countries work together toward carbon neutrality and sustainable development, achieving the global temperature control goals set by the Paris Agreement [2].

In summary, while both technological and policy tools offer promising pathways for emission reduction, their actual effectiveness varies by context. Therefore, it is necessary to evaluate their real-world performance across different economies and policy environments.

3. Case study

3.1 Case of China‘s CCUS Demonstration Project

Project Background: In order to promote the realization of carbon peak and carbon neutrality goals, China has launched a number of carbon capture, utilization and storage (CCUS) demonstration projects in recent years. Among them, the most representative is the “Qilu Petrochemical-Shengli Oilfield” CCUS project built by Sinopec in Shandong. The project was officially completed and put into operation in August 2022, becoming my country’s first million-ton CCUS full-process demonstration project [3]. The commissioning of the project marks that my country’s CCUS industry has moved from research and development experiments to a mature commercial demonstration stage [3]. According to the design, about 1 million tons of carbon dioxide can be captured and stored each year, which is equivalent to the amount of carbon absorbed by planting about 9 million trees [3]. This project is regarded as an important practice for establishing the “artificial carbon cycle” model, providing valuable experience data for subsequent large-scale CCUS projects, and helping my country to achieve the “dual carbon” goals as scheduled [3].

Implementation path: The “Qilu Petrochemical-Shengli Oilfield CCUS Demonstration” realizes the full-process application of carbon dioxide from emission source to final storage through the mode of industrial source capture + oilfield oil recovery and storage [3]. First, Qilu Petrochemical uses the carbon capture device independently developed to purify and recover carbon dioxide from high-concentration CO_2 flue gas emitted during chemical production; CO_2 purification and liquefaction process adopted makes the capture process more efficient and low-consumption, and all equipment is domestically produced [9]. Subsequently, the captured liquid CO_2 is transported to Shengli Oilfield in Dongying, Shandong by a special transport fleet, and injected into the underground reservoir through oil recovery and geological storage. The project selected ultra-low permeability old oil reservoirs as the storage target area, deployed 73 CO_2 injection wells, and it is expected that more than 10 million tons of carbon dioxide will be injected in 15 years, which can increase crude oil production by about 3 million tons, and increase the oilfield recovery rate by more than 12 percentage points [3]. This path achieves cross-industry coordinated emission reduction between the chemical industry and oil fields, safely stores a large amount of carbon dioxide while increasing oil production and achieves a win-win situation of “carbon reduction” and “increased oil” [13].

Emission reduction effect: At present, the demonstration project is running well and has preliminarily verified the emission reduction benefits of CCUS at the million-ton level. Since it was put into operation, the project has injected about 640,000 tons of CO_2 in 20 blocks of Shengli Oilfield, stored more than 500,000 tons, and increased oil production by more than 100,000 tons. After the cross-domain transmission pipeline to be built according to the plan is completed, 1.7 million tons of carbon dioxide can be transported and stored annually [3]. In addition, the complete set of technologies such as carbon dioxide capture and purification, dense phase transportation, oil displacement and storage formed during the implementation of the project have laid a technical foundation for the subsequent larger-scale application of CCUS [8].

Real challenges: Although the CCUS demonstration project of Qilu Petrochemical has achieved phased success, overall, the development of CCUS in my country is still in the early stage of demonstration and faces many prac-

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tical difficulties. On the one hand, the costs of each link in the CCUS chain are high, and there is currently a lack of economic incentive mechanisms such as carbon prices to support it, and the commercial feasibility of large-scale promotion needs to be improved. On the other hand, some key technologies still lag the international advanced level, and geological storage conditions in different regions vary significantly [14]. In addition, regulations, standards, regulatory systems and public awareness also need to be improved. Therefore, although large-scale CCUS projects have shown emission reduction potential; to achieve large-scale application, it is still necessary to continue to work hard in terms of policy support, cost reduction and technical breakthroughs [15].

3.2 Cases of foreign carbon trading mechanisms (EU Emission Trading System)

Policy design: The EU Emission Trading System (EU ETS) is the world's first large-scale carbon trading market mechanism, which was officially launched in 2005. The system adopts a "cap and trade" model: setting a regional greenhouse gas emission cap and allocating tradable emission quotas to controlled enterprises [7]. In the early days, most quotas were allocated free of charge, and in recent years, they have gradually transitioned to an auction-based allocation method, supplemented by some free quotas to protect carbon leakage risks. EU ETS covers industries such as power generation, industry, and aviation, covering about 40% of EU carbon dioxide emissions; the system has now entered its fourth phase (2021–2030), and its coverage has been further expanded to areas such as shipping, with annual total reductions accelerating in response to climate targets [7]. As the cornerstone of the EU's climate policy, EU ETS prices corporate carbon emissions through market mechanisms to encourage low-carbon technology investment and industrial structure transformation [4].

Implementation effect: The EU ETS has experienced quota surpluses and carbon price fluctuations in the past two decades but has generally achieved significant emission reduction effects [7]. Studies have shown that despite the low carbon prices in the early days, the EU ETS still led to a cumulative reduction of about 1.2 billion tons of CO_2 in the EU between 2008 and 2016, which is about 3.8% of the emissions in the no-trading scenario. Controlled industries such as power and heavy industry are the main force in emission reduction. As of early 2023, emissions from controlled facilities have fallen by about 47.6% compared with 2005 [7].

Actual impact: The EU ETS has not only promoted local carbon emission reduction in the EU, but its market mechanism has also served as a model for other countries. The Canadian National Carbon Market, the Korean Carbon Trading System, and the Chinese National Carbon Market have all referred to the EU ETS approach in their design, including quota allocation, trading platform setting, and regulatory measures [4]. The successful operation of the EU ETS shows that the carbon pricing system is one of the efficient ways to achieve emission reduction targets and is particularly suitable for promoting industrial structure upgrading and the development of green financial policies.

4. Conclusion

Carbon emission control technology and policy mechanisms play a vital role in my country's process of achieving the "dual carbon" goal. This paper systematically reviews and analyzes the development status of core technology paths such as renewable energy, carbon capture and storage (CCUS), and energy efficiency improvement, sorts out the implementation results of policy tools such as green finance and carbon emission trading, and further combines the typical cases of China's CCUS demonstration project and the EU carbon market to analyze the actual impact of technology and policy interaction on carbon emission reduction. The study found that although advanced low-carbon technologies have significant emission reduction potential, they are currently in the stage of promotion and breakthrough due to cost, scale and infrastructure conditions; policy tools such as green finance and carbon markets have achieved remarkable results in stimulating corporate green transformation, but they also face challenges such as regional imbalance and institutional integration during implementation.

In the future, the coordinated promotion of technological innovation and institutional guarantees should be strengthened: at the technical level, the breakthrough of carbon capture cost bottlenecks should be accelerated to improve the low-carbon efficiency of the energy system; at the policy level, the connection between carbon pricing mechanisms, fiscal incentives and international rules should be strengthened to promote the widespread application of low-carbon technologies. This study provides insights the role of technology-policy linkage in low-carbon transformation and can also provide decision-making references for governments and enterprises, helping China and the global community achieve the strategic goal of sustainable development.

References

[1] Li H., Yu Z., Chen G., et al. Exploring the impact and mechanisms of green finance on regional carbon emission

reduction. *Scientific Reports*, 2025, 15: 17293.
[2] Fu C., Lu L., Pirabi M. Advancing green finance: A review of sustainable development. *Digital Economy and Sustainable Development*, 2023, 1(20): 1–15.
[3] Guo Y.T., Wang H., Li L., et al. Study on the carbon emission reduction accounting method of carbon capture and storage (CCS) technology. *Environmental Engineering*, 2025, 43(4): 1–10.
[4] Bhatnagar A., Sahoo P.K., Rath B.N. Green finance and decarbonization: Role in achieving carbon neutrality. *International Journal of Sustainable Finance & Investment*, 2022, 12(2): 887–903.
[5] Chen C., Pinar M., Stengos T. Renewable energy and CO_2 emissions: New evidence with a panel threshold model. *Renewable Energy*, 2022, 194: 117–128.
[6] Mirza F.M., Sinha A., Khan J.R., et al. Impact of energy efficiency on CO_2 emissions: Empirical evidence from developing countries. *Gondwana Research*, 2022, 106: 64–77.
[7] Meo M.S., Karim M.Z.A. The role of green finance in reducing CO_2 emissions: An empirical analysis. *Borsa Istanbul Review*, 2022, 22(1): 169–178.
[8] Liu K.F., Zhang Y., Gao X. Policies and measures for promoting the development of carbon capture, transportation, utilization, and storage (CCUS). *Chemical Industry and Engineering Progress*, 2023, 42(3): 1–10.
[9] Cui M.G., Wang Y., Yang D., Xiang J. Low-carbon dispatch of power-thermal systems considering carbon capture in ultra-supercritical power plants. *Journal of Huazhong University of Science and Technology (Natural Science Edition)*, 2023, 51(6): 1–8.
[10] Lu Z., Su X.F., Qian L.N., Guo L. Research on the development of China's CCER market under the vision of carbon neutrality. *Southwest Finance*, 2022(12): 3–16.
[11] Hu Y.Q., Zhao L., Hao B. The impact of carbon emissions trading on the green innovation efficiency of industrial enterprises: Evidence from Chinese listed companies. *Journal of Management Sciences in China*, 2023, 36(5): 1–12.
[12] Zhai M.J., Zhou C., Zhang Y., et al. Status, challenges and countermeasures of integrating carbon capture, utilization and storage (CCUS) projects into the carbon market. *China Environmental Management*, 2023, 15(6): 87–93.
[13] Long Y. Research progress and system construction of CCUS standards. *China Standardization*, 2023(3): 45–50.
[14] Zhou X.L., Liu Y.W., Han J.P. Comparative study on investment evaluation methods of carbon capture, utilization and storage (CCUS). *Theory and Practice of Price*, 2022(2): 1–8.
[15] Wu C.C., Wang X., Wang J.H. Research progress on carbon capture, utilization and storage (CCUS) technologies in the petroleum and petrochemical industry. *Petrochemical Industry*, 2022, 51(9): 972–979.