WEP Warwick Evans Publishing

International Journal of Social Sciences and Public Administration

ISSN: 3005-9836 (Print), ISSN: 3005-9585 (Online) | Volume 8, Number 3, Year 2025
DOI: https://doi.org/10.62051/ijsspa.v8n3.01
Journal homepage: https://ijsspa.org

From Carbon Sources to Carbon Sinks: Technological Innovation and Industrial Transformation under the Global Carbon Neutrality Strategy

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ABSTRACT

The frequent occurrence of extreme weather events caused by global warming has made carbon neutrality a core strategy for countries to address climate change. As of 2024, over 130 countries and regions have set carbon neutrality targets. China has explicitly pledged to achieve carbon neutrality by 2060, and the European Union plans to do so by 2050. Against this backdrop, the coordinated advancement of "carbon source control" and "carbon sink enhancement" has become crucial, and technological innovation is the core driving force for overcoming emission reduction bottlenecks and promoting industrial transformation. Through literature analysis and empirical case studies, this article systematically explores the logic of the balance between carbon sources and carbon sinks under the global carbon neutrality strategy. It focuses on the technological pathways for carbon source reduction (energy, industry, and transportation) and carbon sink enhancement (natural and artificial). It summarizes low-carbon transformation models for energy-intensive industries and experiences in cultivating emerging low-carbon industries. Furthermore, it proposes countermeasures to address issues such as high technology costs and insufficient regional coordination. Research has found that achieving carbon neutrality through a single technological or industrial transformation is difficult. Instead, a coordinated system of "technological innovation, industrial upgrading, and policy support" is needed. By leveraging both carbon sources and carbon sinks, this system can drive the global low-carbon transition. This article can provide a reference for countries formulating carbon neutrality policies and for businesses implementing low-carbon practices, thereby contributing to the realization of global climate governance goals.

KEYWORDS

Carbon Neutrality; Carbon Source Control; Carbon Sink Technology; Industrial Transformation; Technological Innovation.

1. INTRODUCTION.

The IPCC's Sixth Assessment Report indicates that if global greenhouse gas emissions continue to increase, global temperature rise may exceed the critical 1.5°C by 2030. Disasters such as extreme heat waves, floods, and hurricanes will have irreversible impacts on ecosystems and human society. Against this backdrop, "carbon neutrality" has evolved from a concept to a practical reality, becoming a global consensus. Its core objective is to achieve a "balance" between greenhouse gas emissions and absorption over a given period through human intervention. The key to this process lies in resolving the dual contradictions of "excessive carbon sources" and "inadequate carbon sinks." From a global perspective, developed countries are taking the lead in promoting low-carbon transitions, leveraging their technological advantages. For example, Germany is reducing its share of coal consumption through its "Energy Transition Plan," and the United States is increasing its investment in CCUS (Carbon Capture, Utilization, and Storage) technology research and development.

Developing countries, on the other hand, face the dual pressures of "development and emissions reduction." For example, China needs to promote the transformation of energy-intensive industries such as steel and cement while ensuring energy security. Currently, the global carbon neutrality process still faces numerous challenges. On the one hand, high dependence on fossil fuels and immature industrial process emission reduction technologies make carbon source control difficult. On the other hand, the capacity of natural carbon sinks is declining due to ecological damage, and the cost of artificial carbon sink technology remains high. Based on this, this article focuses on the dual perspective of "carbon source and carbon sink," analyzing the practical path of global carbon neutrality from the perspectives of technological innovation and industrial transformation. By reviewing typical technologies and industrial cases, summarizing replicable experiences, and identifying current challenges, it provides theoretical and practical references for promoting the realization of global carbon neutrality goals.

2. THE LOGIC OF BALANCING CARBON SOURCES AND SINKS: THE CORE FRAMEWORK OF CARBON NEUTRALITY

The essence of carbon neutrality is achieving a dynamic balance between "carbon source emissions" and "carbon sink absorption." Clarifying the conceptual boundaries and interactive relationships between these two is crucial for building a scientific framework for low-carbon transition. Carbon sources refer to the sources of greenhouse gases such as carbon dioxide, and can be categorized as energy, industrial, and transportation. Energy sources account for the largest proportion-according to the International Energy Agency (IEA), global energy-related carbon emissions accounted for 73% of total emissions in 2023, with coal, oil, and natural gas consumption being the primary contributors. Industrial sources rank second, with industries like steel, cement, and chemicals facing challenges in reducing emissions due to the combined effects of "process emissions" and "energy consumption emissions" in their production processes. Transportation carbon sources continue to rise with the growth of global motor vehicle ownership, reaching 16% of global transportation emissions in 2023. Carbon sinks are the vehicles that absorb and store carbon dioxide, and are categorized as both natural and artificial. Natural carbon sinks rely on ecosystems, with forests, wetlands, and oceans as core carriers. Global forests absorb approximately 2.6 billion tons of carbon dioxide annually, accounting for 30% of anthropogenic emissions. China's wetlands hold 5 billion tons of carbon, equivalent to 5% of the country's annual carbon emissions. Artificial carbon sinks achieve carbon capture and storage through technological means, with CCUS technology and the cultivation of carbon sink forests being the primary methods. However, the current scale of artificial carbon sinks remains relatively small, with the global CCUS annual storage capacity less than 200 million tons, representing only 7.7% of natural carbon sinks. The core contradiction in the current global imbalance between carbon sources and carbon sinks lies in the fact that the rate of carbon source reduction lags behind emissions growth, and the expansion of carbon sink capacity is unable to keep pace with emission reduction needs. For example, in China, energy-related carbon emissions will still reach 11 billion tons in 2023, while forest carbon sinks will absorb approximately 1.2 billion tons annually, offsetting only 10.9% of emissions. Therefore, a carbon neutrality strategy must simultaneously focus on both "source control" and "sink enhancement," reducing carbon source emission intensity through technological innovation and increasing carbon sink capacity through ecological restoration and technological innovation, thereby establishing a "two-way synergy" balance[1].

3. TECHNOLOGICAL INNOVATION IN CARBON SOURCE CONTROL: BREAKTHROUGHS IN EMISSION REDUCTION FROM ENERGY TO INDUSTRY

Carbon source control is the primary task of achieving carbon neutrality. Technological innovation must be implemented in core sectors such as energy, industry, and transportation to achieve the dual goals of "reduction" and "substitution." Technological innovation in the energy sector focuses on "clean energy substitution" and "energy efficiency improvement." In the clean energy sector, photovoltaic and wind power technologies have achieved large-scale application. By 2023, global photovoltaic installed capacity will exceed 1.5 TW, and China's photovoltaic conversion efficiency will reach 26.8%, a 10 percentage point increase from 2010. Offshore wind power unit capacity will exceed 16 MW, generating enough electricity to meet the annual power needs of 12,000 households. Regarding energy efficiency, supercritical CO2 power generation technology can increase the efficiency of thermal power generation from 45% to 55%. China has already built the world's first supercritical CO2 power generation demonstration project in Gansu, reducing annual CO2 emissions by 150,000 tons. Furthermore, hydrogen, as a zero-carbon energy carrier, is seeing its storage and transportation technologies mature. Upon its commissioning, China's "West-to-East Hydrogen Transmission" pipeline project will be able to transport 1 million tons of hydrogen annually, replacing 20 million tons of coal consumption. Technological innovation in the industrial sector is centered around process reengineering and recycling. The steel industry is promoting "mini-steelmaking" technology, which uses scrap steel as a raw material instead of iron ore, reducing carbon emissions per ton of steel from 2 tons to 0.3 tons[2]. China aims to achieve a 20% share of mini-steelmaking by 2025, an 8 percentage point increase from 2020. The cement industry is developing "low-carbon cement" technology, replacing 30% of limestone with industrial solid waste such as steel slag and fly ash, reducing carbon emissions per ton of cement by 15%. Anhui Conch Cement has built the world's largest low-carbon cement production line. The chemical industry is reducing carbon emissions in ammonia and methanol production by replacing gray hydrogen with green hydrogen. BASF Group's green hydrogen chemical project, upon commissioning, is expected to reduce annual CO2 emissions by 500,000 tons. Technological innovation in the transportation sector is centered around electrification and intelligence. New energy vehicle technology is rapidly evolving. China's power battery energy density has reached 300Wh/kg, with a range exceeding 1,000 kilometers. By 2023, the penetration rate of new energy vehicles is expected to reach 30%, reducing annual CO2 emissions by 20 million tons. Hydrogen fuel cell technology is being promoted in the commercial vehicle sector. The Toyota Mirai hydrogen fuel cell heavy-duty truck boasts a range of 800 kilometers and a refueling time of just 15 minutes. Furthermore, intelligent transportation systems can reduce vehicle energy consumption by 10% through optimized route planning. Shenzhen has established the world's first full-area intelligent transportation pilot project, reducing transportation carbon emissions by 5% annually.

4. TECHNICAL PATHWAYS FOR CARBON SINK ENHANCEMENT: SYNERGISTIC INTEGRATION OF NATURAL RESTORATION AND ARTIFICIAL ENHANCEMENT

Carbon sink enhancement is a crucial supplement to carbon neutrality. It requires combining natural ecosystem restoration with technological innovation in artificial carbon sinks to build a dual "natural + artificial" carbon sink system. The technical approach to natural carbon sinks focuses on "ecological restoration" and "functional enhancement." Regarding forest carbon sequestration, China is promoting "precision afforestation" technology. By selecting tree species with strong carbon sequestration capabilities and combining density control with tending management, plantations have achieved an annual carbon sequestration capacity of 8 tons per hectare, a 30% increase compared to traditional afforestation. Simultaneously, China is implementing "forest tending carbon sequestration projects" to improve forest structure through thinning and pruning. The forest tending project in Sanming, Fujian Province, has added 100,000 tons of carbon sequestration annually and is now included in the national carbon trading market. Regarding wetland carbon sequestration, China is implementing "wetland restoration projects" to restore degraded wetlands through water level control and replanting. Following the wetland restoration project in Yancheng, Jiangsu Province, wetland carbon storage increased from 200 tons per hectare to 350 tons per hectare, adding 500,000 tons of carbon sequestration annually. Regarding marine carbon sequestration, "marine ranching" technology uses artificial reefs and seaweed cultivation to enhance the carbon sequestration capacity of marine ecosystems. A marine ranch in Weihai, Shandong Province, has achieved annual carbon sequestration of 50,000 tons while also increasing fishery income[3]. The technological path for artificial carbon sequestration centers on breakthroughs in "CCUS" and "carbon sequestration technology innovation." CCUS technology has moved from the laboratory to large-scale application. China has built the world's first onshore CCUS demonstration project in Shanxi. This project captures carbon dioxide from coal-fired power plant flue gases and injects it into underground saline aquifers for storage, with an annual storage capacity of 1 million tons. China is also exploring carbon utilization, using the captured CO2 for oil recovery and the production of carbonated beverages. The CCUS oil recovery project at PetroChina's Jilin Oilfield has achieved an annual storage of 500,000 tons of CO2 while increasing crude oil production by 15%. Furthermore, direct air carbon capture (DAC) technology is maturing. Climeworks' DAC facility in the United States captures 12,000 tons of CO2 annually, reducing costs from $1,000 to $600 per ton, with further reductions expected in the future. Currently, the synergy between natural and artificial carbon sinks requires addressing the issue of regional matching. For example, China is deploying CCUS projects in high-carbon emission areas in the northwest while simultaneously strengthening forest and wetland restoration in the southeast, forming a regional synergy model of "source control in the northwest and sink enhancement in the southeast." The EU, through its "carbon sink trading" mechanism, encourages member states to integrate natural carbon sink projects with artificial carbon sink technologies. Germany has incorporated forest carbon sinks into the EU carbon market, with an annual trading volume of €1 billion, which in turn supports the development of artificial carbon sink technologies.

5. PRACTICAL MODELS OF INDUSTRIAL TRANSFORMATION: FROM HIGH-ENERGY EMISSION REDUCTION TO LOW-CARBON INDUSTRY CULTIVATION

Industrial transformation is the vehicle for achieving carbon neutrality. It requires low-carbon transformation of high-energy-consuming industries and the cultivation of emerging low-carbon industries, building an industrial system that "optimizes existing capacity and expands incremental capacity." The transformation model for high-energy-consuming industries focuses on "technological substitution" and "capacity integration." The steel industry is reducing outdated production capacity through "capacity replacement." China plans to reduce steel production capacity by 150 million tons between 2021 and 2023, while also promoting technological upgrades to existing capacity. Baowu Group's Baoshan Steel Base has reduced carbon emissions per ton of steel from 1.8 tons to 1.2 tons through full-process low-carbon transformation, becoming a global benchmark for low-carbon steel. The cement industry is promoting "peak-shaving production combined with green manufacturing," reducing winter carbon emissions by 20%. Conch Cement is also promoting the use of "co-processing solid waste in cement kilns" to dispose of municipal solid waste. This has reduced solid waste landfill by 1 million tons annually and lowered fuel consumption by 15%. The non-ferrous metals industry is replacing virgin metal with recycled metal, resulting in recycled aluminum production consuming only 5% of the energy of virgin aluminum. By 2023, recycled aluminum production in China is projected to account for 35% of total production, reducing annual CO2 emissions by 8 million tons. The development model for emerging low-carbon industries revolves around "technological industrialization" and "industrial chain development." The new energy industry has formed a complete industrial chain. China's photovoltaic industry accounts for 70% of global production capacity, boasting independent control over the entire supply chain, from silicon materials and solar cells to modules. By 2023, the photovoltaic industry's output value will exceed 1 trillion yuan, creating 5 million jobs[4]. The hydrogen energy industry is accelerating the development of its entire supply chain: production, storage, transmission, and utilization. China has built 350 hydrogen refueling stations, reducing the cost of green hydrogen production from 50 yuan per kilogram to 30 yuan per kilogram, with commercial application expected by 2030. Low-carbon services are developing rapidly, with the rise of carbon consulting, carbon verification, and carbon trading. China's carbon trading market is expected to reach a turnover of 12 billion yuan in 2023, with the emergence of specialized platforms such as the Beijing Green Exchange and the Shanghai Environment and Energy Exchange. In the low-carbon logistics sector, the "green packaging + new energy logistics vehicles" approach is being promoted. JD Logistics, through the use of biodegradable packaging and electric trucks, has reduced carbon emissions by 1 million tons annually. The key to industrial transformation lies in the combination of policy guidance and market-driven approaches. China is guiding industrial transformation through its "dual carbon" policy system, offering a 20% tax break for low-carbon technology research and development. The EU is forcing high-energy-consuming industries to reduce emissions through the Carbon Border Adjustment Mechanism (CBAM), imposing carbon tariffs on imported steel and cement starting in 2026, thereby promoting low-carbon transformation in global industries.

6. CHALLENGES AND COUNTERMEASURES OF COORDINATED DEVELOPMENT: THE FUTURE PATH TO GLOBAL CARBON NEUTRALITY

The coordinated advancement of carbon source control, carbon sink enhancement, and industrial transformation is key to achieving global carbon neutrality. However, multiple challenges remain, including technical, cost, and regional coordination, requiring multifaceted countermeasures to overcome bottlenecks. The core challenges of coordinated development currently lie in three key areas: First, uneven technological maturity. The high cost of artificial carbon sink technologies like CCUS and DAC (CCUS currently costs approximately 400 yuan per ton) hinders large-scale deployment. Second, significant regional disparities exist. Developing countries' energy structures are dominated by coal, and funding for industrial transformation is insufficient. For example, India consumes 55% of coal, but its investment in low-carbon technology R&D is only one-fifth of China's. Third, insufficient international cooperation exists. The world has yet to establish a unified carbon accounting standard, and some countries are pursuing "carbon protectionism," hindering the sharing of low-carbon technologies. Addressing these challenges requires addressing them from three perspectives: technology, policy, and international cooperation. At the technical level, China should strengthen collaborative innovation between industry, academia, and research institutions, establish a national low-carbon technology laboratory, and focus on breakthroughs in key technologies such as low-cost CCUS and green hydrogen storage and transportation[5]. China can leverage its "dual carbon" national laboratory to collaborate with universities and businesses on technological breakthroughs, aiming to reduce the cost of CCUS to 200 yuan per ton by 2030. Furthermore, China should promote technology accessibility by providing mature technologies such as photovoltaic and wind power to developing countries through low-carbon technology transfer centers. For example, China has donated photovoltaic production lines to Pakistan to help it achieve energy transition. At the policy level, China should improve the carbon pricing mechanism, expand the coverage of the carbon trading market, and use price signals to guide businesses to reduce emissions. By establishing a regional coordination mechanism, China can promote industrial transfer and carbon sink cooperation between its eastern, central, and western regions. For example, low-carbon industries could be transferred from the east to the west, and the west could provide carbon allowances to the east through forest carbon sink projects, achieving "East-West mutual assistance." At the international level, China should promote the establishment of a globally unified carbon accounting standard (such as ISO 14064) to avoid fragmentation. North-South cooperation should be strengthened, and a global low-carbon development fund should be established to help developing countries cope with the costs of industrial transformation. For example, the EU could increase low-carbon aid to Africa to help it build photovoltaic power plants and reduce its reliance on coal. Furthermore, it is important to prioritize social participation, raising public awareness of low-carbon development through scientific education and encouraging green consumption, thus forming a coordinated framework of government leadership, business as the main player, and public participation.

7. CONCLUSION

The core of the global carbon neutrality strategy is to achieve a dynamic balance between carbon sources and carbon sinks. Technological innovation is the core driving force behind the coordinated development of carbon source control, carbon sink enhancement, and industrial transformation. Through analysis, this article finds that emission reduction technologies in the fields of energy, industry, and transportation have been applied on a large scale. The ecological restoration of natural carbon sinks and CCUS technology of artificial carbon sinks have gradually matured. The low-carbon transformation of high-energy-consuming industries and the cultivation of emerging low-carbon industries have formed a "two-wheel drive" industrial transformation model, providing a practical path for global carbon neutrality.However, it should be noted that global carbon neutrality still faces challenges such as high technical costs, large regional disparities, and insufficient international cooperation. Actions by a single country or sector alone are unlikely to achieve the goal. In the future, a coordinated system of "technological innovation-policy support-international cooperation-social participation" is needed: At the technical level, cost bottlenecks in key low-carbon technologies should be overcome to promote the universal sharing of mature technologies; at the policy level, carbon pricing and regional coordination mechanisms should be improved to guide industrial transformation; at the international level, unified carbon accounting standards should be established to strengthen North-South cooperation and technology sharing; and at the social level, public awareness of low-carbon development should be enhanced to foster a low-carbon atmosphere with universal participation. Global carbon neutrality is a long-term project that requires all countries to abandon "carbon protectionism" and promote coordinated action based on the concept of "a community with a shared future for mankind." Only by leveraging both carbon sources and carbon sinks and deeply integrating technology and industry can global climate governance goals be achieved and the foundation for sustainable human development be laid. Future research can further focus on the economic evaluation of low-carbon technologies and regional differences in carbon neutrality paths to provide more precise theoretical support for global carbon neutrality.

REFERENCES

[1] Wang Ding, Zhao Zhongnan, Wang Guan, et al. From carbon source to carbon sink: Analysis of the path to achieve carbon neutrality in my country [J]. Water Resources Development Research, 2022, 22(05): 28-33. DOI: 10.13928/j.cnki.wrdr.2022.05.006.

[2] Zhou Xulei. Research on carbon governance performance in the Yellow River Basin under the goal of “carbon neutrality” [D]. Zhengzhou University, 2022. DOI: 10.27466/d.cnki.gzzdu.2022.000046.

[3] Wang Shanshan. Research on the production of artificial board based on the goal of carbon neutrality Dynamic life cycle model and carbon balance assessment of rural tourism[D]. Nanjing Forestry University, 2021.DOI:10.27242/d.cnki.gnjlu.2021.000282.

[4] Ding Yulian. Research on net carbon emission estimation and carbon compensation of rural tourism from the perspective of carbon neutrality[D]. Nanjing Normal University, 2015.

[5] Zhou Shuhan. Research on spatiotemporal distribution of carbon sources/carbon sinks and carbon profit and loss prediction in the three northeastern provinces[D]. Liaoning Normal University, 2023.DOI:10.27212/d.cnki.glnsu.2023.000251.