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Review

A review of global carbon emission management studies

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Abstract: Under the background of climate warming, the importance of global carbon emission management has become more and more significant. This article reviews and organizes the existing literature on carbon emission management, focusing on the research status from the perspectives of economic instruments for carbon reduction and international cooperation. It explores the economic effects of different policy tools and the emission reduction measures of various countries. This article intends to see the progress and shortcomings of global climate governance through the organization of past research results and provide directions for future research.

Keywords: carbon emission management; economic instruments; international cooperation

1. Introduction

The increase in global carbon emissions has become one of the most pressing environmental issues of our time. With the large-scale use of fossil fuels and rapid economic development since the Industrial Revolution, the emission of greenhouse gases, especially carbon dioxide (CO_2), has risen significantly, leading to the increasingly serious problem of global climate change. In recent years, at the sector level, the transport sector has seen the most significant increase in carbon emissions, rising by nearly 2.4 million tonnes globally. The electricity sector had the second largest increase and the highest regional disparity: emissions fell sharply in advanced economies while rising sharply in emerging markets and developing economies. Industrial emissions saw a slight increase, as reductions in advanced economies were insufficient to offset the increases from industrial development in emerging markets and developing economies. The construction sector was the only one to see a decrease in emissions globally, mainly due to the mild temperatures experienced in 2023. **Figure 1** is a chart illustrating the change in CO_2 emissions from combustion by sector and region from 2022 to 2023, from a report of the International Energy Agency [1] in 2024.

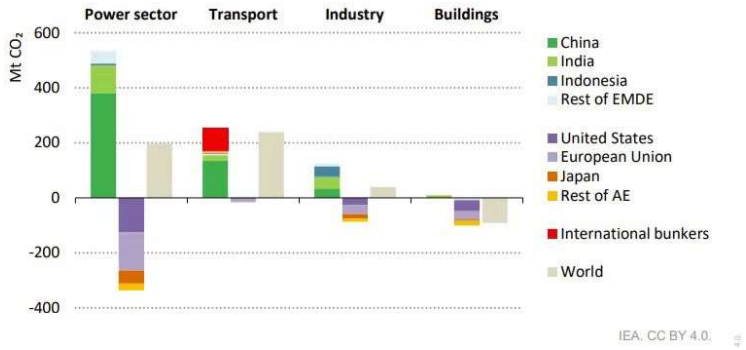

Figure 1. Change in CO_2 emissions from combustion by sector and region, 2022–2023.

It is widely recognized by the scientific community that sustained carbon emissions will not only lead to an increase in global temperatures but will also trigger a series of ecosystem imbalances, sea level rise, and the frequency of extreme weather events. These changes not only threaten the natural environment but also have far-reaching impacts for the global economy and social fabric. In view of the critical situation of global climate change, governments, international organizations, and academics are actively seeking effective strategies for the governance of carbon emissions. From the implementation of carbon tax and carbon trading systems to the formation of a cooperative framework for global synergistic governance, a variety of policy tools and technical instruments have been widely discussed and applied. This article aims to explore the current research status of global carbon emission management by systematically sorting out and reviewing the existing literature on carbon emission management. This article is structured into three sections for comprehensive analysis: The first section examines the primary economic instruments for carbon emission management; the second section explores the policy frameworks for global carbon emission management; and the third section provides a summary and outlook on future developments. It is hoped that the comprehensive analysis of related studies can provide valuable references for policymakers, academic researchers, and the public and promote the further development of global carbon emission governance.

2. Main economic instruments for carbon emissions management

Currently, countries around the world are widely adopting various economic tools to reduce greenhouse gas emissions in the process of carbon reduction management, primarily including two market mechanisms: carbon taxes and carbon trading. By taxing carbon emissions or setting emission quotas and allowing trading, these mechanisms incentivize companies to reduce emissions. As of 2020, there are 61 countries or regions worldwide that have implemented or planned to implement carbon pricing mechanisms, with 31 adopting carbon trading markets and 30 adopting carbon taxes [2]. Each continent has its own representative countries, including North America: Canada, Mexico; Europe: The European Union, Norway, Switzerland; Asia: China, Japan, South Korea; Latin America: Chile, Colombia; Africa: South Africa; Oceania: New Zealand. In addition to these two main mechanisms, many countries also use economic means such as green subsidies, energy efficiency labels, and carbon offset projects to guide all parties to actively participate in emission reductions and jointly address the challenge of climate change. Given the importance of carbon taxes and carbon trading markets, this paper mainly reviews the research on these two economic tools.

2.1. Carbon tax

A carbon tax is a kind of environmental tax that aims to reduce greenhouse gas emissions by taxing carbon emissions in order to cope with the problem of global climate change. Its basic principle is to internalize the external cost of carbon emissions through the price mechanism so as to incentivize enterprises and individuals to reduce carbon emissions. The concept of a carbon tax emerged in the late 1980s and early 1990s, coinciding with the growing awareness of global warming and climate

change issues. During this period, both academic circles and policymakers began to explore the potential of this economic instrument to effectively reduce greenhouse gas emissions.

Early studies highlighted the relevance and coordination of carbon taxes and other taxes. In the early 1990s, Poterba [3] examined the design of carbon taxes as a fiscal policy response to global warming, highlighting a critical issue in the coordination with other fiscal tools aimed at reducing greenhouse gas emissions. He finds that ensuring comparability of tax rates on CFCs and fossil fuels is particularly important to avoid unnecessary distortions in production or consumption decisions. Bovenberg and Goulder [4] provide an insight into the optimal way to set environmental taxes in the presence of other taxes, emphasizing the importance of considering the interactions between different tax systems. Goulder [5] analyzes the impacts of carbon taxes in economies with prior tax distortions, emphasizing that the cost of a carbon tax is closely related to the level of existing taxes and that the cost of a carbon tax increases accordingly when the level of existing taxes is high, and vice versa.

The implementation effects of carbon taxes have been studied extensively across multiple countries. Cornwell and Creedy [6] examined the potential impact of a carbon tax on reducing carbon dioxide emissions in Australia. Callan et al. [7] examined the distributional impact of carbon taxes in Ireland, revealing that carbon taxes exhibit a regressive nature. However, they found that by allocating the tax revenues to enhance social welfare programs and tax credits, it is possible to improve the financial situation of households without depleting the overall carbon tax revenues. Andersson [8] conducted a quasi-experimental study in Sweden, which found for the first time a significant causal effect of a carbon tax on emissions and empirically analyzed the imposition of a carbon tax and a value-added tax on transportation fuels in Sweden. The results showed that the carbon tax contributed the largest share of the nearly 11% drop in transportation CO_2 emissions.

2.2. Carbon trading market

The carbon trading market is a market-based environmental policy tool aimed at controlling and reducing greenhouse gas emissions by means of economic incentives through the setting of emission limits and allowing the trading of carbon emission allowances between enterprises. It includes two main mechanisms: the setting of aggregate controls and the trading of carbon credits.

The background of the proposed carbon trading market stems mainly from the concern over global climate change issues and the joint efforts of the international community to reduce greenhouse gas emissions. Since the adoption of the Kyoto Protocol in 1997, the international community has explored a variety of mechanisms and policy tools to address climate change on a global scale. The Kyoto Protocol introduced flexible mechanisms such as the Clean Development Mechanism (CDM), Joint Implementation (JI), and International Emissions Trading (IET), aiming to promote global emission reduction through market means. As the problem of climate change becomes increasingly serious and countries seek more effective policy tools, the carbon trading market has gradually gained widespread attention and support as a

flexible and cost-effective solution.

Existing studies have explored different aspects of such economic instruments, including the economic impacts of international carbon emissions trading programs, policy design challenges directly related to existing programs, and the construction of a carbon trading system in China in the post-CDM era. Meckling [9] comprehensively examined the rise of carbon trading, arguing for the role of corporations in using this policy instrument as a central pillar of global climate governance. The authors explained how a coalition of multinational corporations actively promoted international carbon trading as a compromise policy solution in the face of political deadlock. Wang and Zhao [10] used a structural equation modeling approach to study the impact of global equity and energy markets on the EU Emissions Trading System (ETS). The study proposed sustainable development recommendations to promote a virtuous cycle in the global carbon emissions market and high-quality development of the global economy. The effectiveness of carbon trading mechanisms varies across different industries, closely related to the policy design for each sector. Bakam et al. [11] studied the estimation of carbon prices in a closed emission trading system in Scotland's agricultural sector. Their model simulation indicated that carbon prices rise with higher emission reduction targets and lower farm compliance rates, and that farmers who implement emission reduction measures and sell surplus credits gain slightly higher profits. Jiang et al. [12] reported on the development of the ETS in Shenzhen's transportation sector in China, finding that quota trading and carbon offset mechanisms provided sufficient flexibility, making emission reductions, the use of new energy vehicles, and green travel economically attractive within Shenzhen's urban transportation system, effectively reducing the overall social cost of emission reductions. Pan et al. [13] focused on carbon leakage in the energy and forestry sectors, emphasizing that a mature global carbon trading market and relatively high carbon prices can attract more participants and reduce carbon leakage.

2.3. Short Summary

Carbon tax and carbon trading market, as the two mainstream economic instruments for carbon emission management at present, have their own characteristics, advantages, and disadvantages. Comparing their similarities and differences, it can be found that: Firstly, the basic principles of the two are the same [14]. Both of them are internalizing negative externalities into enterprise costs, but the theoretical basis is slightly different. The former originated from Peguy's tax, while the latter originated from Coase's property rights theory, which advocates the use of competitive markets to solve the pollution problem by clarifying the property rights belonging to the carbon emissions. Secondly, the carbon trading market is easily accepted by companies at its initial implementation and shows significant short-term carbon reduction effects. However, its downside is the high volatility of carbon prices, which leads to uncertain price signals, affecting investment forecasts and causing economic fluctuations, thus being unfavorable for long-term economic stability and growth. On the other hand, carbon taxes have the advantage of stabilizing carbon prices, providing relatively stable price signals for companies [15,16], and are therefore more conducive to guiding green investments. The disadvantage of carbon taxes lies in the difficulty of

policy formulation, significant resistance at the initial implementation, and uncertain short-term carbon reduction effects. Thirdly, carbon taxes are more flexible and applicable compared to carbon trading markets. They can achieve emissions reductions at lower administrative costs and allow for government control over carbon pricing, mitigating the influence of monopolistic enterprises and other interest groups over the carbon market. Therefore, carbon taxes exhibit greater operational feasibility.

3. Policy framework for global carbon emission management

3.1. International agreements and cooperation

A review of the development of international cooperation on carbon reduction reveals a significant evolution under the basic framework of the United Nations Framework Convention on Climate Change (UNFCCC). The transition from the Kyoto Protocol to the Paris Agreement marks a crucial shift, showcasing the ongoing efforts and adaptations of countries worldwide in addressing climate change. Scholars have extensively discussed the impacts of both the Kyoto Protocol and the Paris Agreement.

The Kyoto Protocol, established in 1997 under the UNFCCC, aimed to reduce greenhouse gas emissions by creating an international carbon emissions trading market. Despite its uneven treatment of carbon emissions, which led to unequal incentives for changes in carbon stocks, the protocol's emissions trading framework provided economic incentives for countries to reduce greenhouse gas emissions in a cost-effective manner [17].

Kim et al. [18] employed impact assessment methods to analyze the environmental and economic effectiveness of the Kyoto Protocol among Annex I parties, examining CO_2 emissions and GDP data. Jalil and Wan Mohamed [19] investigated the influence of the Kyoto Protocol and institutional factors on per capita CO_2 emissions in developing countries, utilizing the Generalized Method of Moments (GMM) for their analysis. Additionally, Ali and Tiwari [20] provided an overview of the legal and policy measures related to carbon trading and renewable energy certificates in India, highlighting the country's obligations under the Kyoto Protocol and the implementation of various frameworks to facilitate emission reduction efforts. Overall, while the Kyoto Protocol's success was limited, its positive role in organizing global responses to climate change is undeniable [21], particularly as most Annex I parties have achieved their targets under the protocol [22].

The Paris Agreement, signed in 2015, represents a milestone in global carbon emission governance. Unlike the Kyoto Protocol, the Paris Agreement adopts a more inclusive and flexible approach, requiring all countries, not just developed ones, to submit and implement Nationally Determined Contributions (NDCs), detailing their respective emission reduction targets and strategies. The agreement sets an ambitious goal of keeping global warming well below 2 degrees Celsius above pre-industrial levels, with efforts to limit the temperature increase to 1.5 degrees Celsius.

The Paris Agreement emphasizes the uniformity of carbon trading and international accounting standards to ensure transparency and accountability, which is crucial for countries to fulfill their commitments [23]. Furthermore, the agreement addresses potential rebound effects, calling for global coordination to avoid

counterproductive local and national strategies in emission reduction. Through innovative strategies, policy commitments, and technological advancements, the Paris Agreement has driven deep decarbonization pathways in energy-intensive industries, particularly through technologies such as Bioenergy with Carbon Capture and Storage (BECCS) [24]. However, the agreement also faces challenges, including the difficulty of countries meeting their commitments and the complexity of global coordination mechanisms [25]. Nonetheless, the agreement provides essential policy tools and a cooperative platform for global climate change mitigation, warranting further exploration of its long-term impacts.

From the Kyoto Protocol to the Paris Agreement, global carbon emission governance has transitioned from mandatory emission reduction targets predominantly for developed countries to more inclusive and flexible voluntary commitments. This evolution reflects the international community's continuous efforts and progress in addressing climate change, underscoring the importance and necessity of global cooperation in achieving carbon reduction goals.

3.2. Diverse carbon emission reduction policies and measures adopted by various nations

Under the international cooperative framework established by the Kyoto Protocol and the Paris Agreement, countries around the world have adopted respective emission reduction policies and measures tailored to their national circumstances. Existing research indicates that while there are similarities in the strategies, technological applications, and policy management of carbon reduction measures between developed and developing countries, there are also significant differences.

Developed countries, leveraging their technological advantages, generally achieve higher energy efficiency than developing countries. The study by Hekkert et al. [26] found that the high-efficiency end-use technologies in European countries reduced the demand for paper, leading to significant carbon emission reductions. Carbon reduction measures in developed nations encompass multiple sectors, including forestry, agriculture, energy, and transportation. Studies have shown that through forest management, energy renovation, and transportation system optimization, Europe and the United States can significantly reduce carbon emissions [27–30]. Additionally, developed countries widely adopt cap-and-trade systems to manage carbon emissions, complemented by supporting measures to achieve emission reduction targets [31]. For instance, the European Union successfully met the Kyoto Protocol targets through its carbon trading system. In Japan, robust public-private partnership models have facilitated the realization of a circular economy and zero carbon emissions, while South Korea incentivizes businesses to invest in green technologies to achieve broader societal impacts [32]. Innovation plays a pivotal role in the carbon reduction strategies of developed countries. In this context, a study focusing on G20 countries found that increased innovation in the industrial sector leads to reduced carbon emissions, whereas innovation in the building sector might increase carbon emissions [33]. Hu et al. [34] conducted a SWOT analysis of the carbon reduction financial measures in the UK, Japan, and the US, highlighting the positive role of financial innovation.

Despite lagging behind developed countries in economic development and technological advancements, developing countries' importance in global climate change dialogues has been increasingly recognized in the context of globalization. By participating in international climate agreements, these countries play a critical role in global emission reduction. Zhang et al. [35] focused on the impact of carbon tariffs on China's economy and carbon emissions, underscoring the importance of developing countries in reducing global emission responsibilities. Research by Bosetti et al. [36] suggests that if developing countries do not engage in international climate agreements, the emission reduction costs for developed countries might increase. Innovation is equally crucial for carbon reduction in developing countries. China's pilot carbon emission trading schemes have shown significant effects in energy saving and emission reduction, demonstrating that developing countries can also effectively reduce carbon emissions through environmental innovation and green supply chain management [37]. Developing countries implement measures across various sectors to reduce carbon emissions. For example, Garg and Avashia [38] discussed the greenhouse gas emissions of domestic airlines in India, highlighting the rising carbon awareness in the aviation industry. They suggested that policy interventions are needed to reduce greenhouse gas emissions from the aviation sector. Dash et al. [39] studied the impact of urbanization, industrialization, corruption, and other factors on carbon dioxide emissions in developing economies of Asia, Africa, and Latin America. Their findings underscored the complex relationship between governance and carbon emissions, emphasizing the need for effective policy interventions to reduce carbon emissions in these regions.

A comparative analysis of carbon emission reduction measures between developed and developing countries reveals that although there are strategic similarities, significant differences persist in technological applications, policy management, and cooperative models. Technological innovation plays a crucial role in both types of countries. Multi-sectoral and cross-sectoral emission reduction measures are prominently reflected in both. However, developed countries, due to their technological advantages, generally achieve higher energy efficiency, whereas developing countries need to enhance energy efficiency through technological advancements to reduce carbon emissions while achieving economic growth. Developed countries tend to use mature policy tools like cap-and-trade systems, while developing countries rely more on assistance from international climate agreements.

4. Conclusion and prospects

This paper has reviewed the primary economic instruments for global carbon emission governance and the carbon reduction policies and measures implemented by various countries. The findings indicate the following: (1) Carbon taxes and carbon trading markets, as the two main economic instruments, have both played a positive role in global carbon emission governance; (2) Although carbon taxes and carbon trading markets share the same fundamental principles, they exhibit significant differences in terms of price stability, flexibility, and applicability; (3) From the Kyoto Protocol to the Paris Agreement, global carbon emission governance has transitioned from mandatory emission reduction targets to more inclusive and flexible voluntary

commitments, signifying continuous progress by the international community in addressing climate change; (4) Developed countries, leveraging their technological advantages, have higher energy efficiency and more mature emission reduction policies compared to developing countries, though technological innovation and cross-sector collaboration remain crucial for both.

Looking ahead, the global carbon reduction endeavor continues to face various risks and challenges. Firstly, national carbon markets are not fully connected, and there is no globally consistent carbon pricing mechanism. This limits the effectiveness of carbon markets and makes it difficult to achieve global carbon reduction targets. Secondly, carbon reduction policies in many countries lack consistency and long-term planning and are often influenced by short-term economic interests. This leads to repetition and instability in the process of policy implementation, making it difficult to continuously promote carbon emission reduction. Furthermore, the substantial differences in economic development levels and interests between developed and developing countries complicate international cooperation, making the equitable distribution of emission reduction responsibilities and costs the primary challenge in international climate negotiations. Future research could expand on these issues with theoretical developments and policy recommendations, offering a more comprehensive and systematic perspective to advance carbon emission management.

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