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International Carbon Emissions: Evolutionary Patterns, Trends, and Influencing Factors

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Abstract: This paper investigates the status and trends of global carbon emissions, including total emissions, per capita emissions, and emission intensity. It reviews the evolution and influencing factors of international carbon emissions. The increase in emissions is mainly concentrated in emerging economies and developing countries. Developed nations, despite having high total emissions, exhibit low emission intensity and stable or declining trends, often aiming for "carbon neutrality." Emerging economies, including newly industrialized countries, are experiencing rapid increases in emissions, and are setting targets for carbon peaking and neutrality. Additionally, this paper examines global carbon emission policies, summarizing strategies and commitments for emission reduction. In the end, it anticipates future policy directions for global carbon emissions.

Keywords: Global Carbon Emissions; Developed Economies; Emerging Economies; Emission Reduction Policies.

1. Introduction

In the context of global climate governance, carbon emissions have emerged as a critical strategic issue related to national security. The global and long-term impacts of climate change might not only threaten human survival and development, but its irreversible trend also positions it as one of the major global challenges. The frequent occurrence of extreme weather events and the resulting social and economic disasters have significantly impacted social stability, underscoring the urgency and necessity of global climate governance. In this context, in-depth research on the evolution, trends, and influencing factors of international carbon emissions is crucial for formulating effective climate policies and emission reduction measures.

2. Main Concepts Related to Carbon Emissions

Global carbon emissions, per capita carbon emissions, and carbon emission intensity are crucial indicators for measuring climate change and evaluating countries' emission reduction efforts. Global carbon emissions provide an overall perspective of climate change, while per capita emissions and emission intensity help identify key areas and targets for reduction. Monitoring these indicators helps evaluate the effectiveness of reduction measures and guide future policy and international cooperation.

Total carbon emissions refer to the sum of carbon dioxide emissions of a country or region within a specific period. In 2023, global energy-related CO_2 emissions increased by 1.1%, reaching a record high of 37.4 billion tons [1].

Carbon emission intensity is a key indicator for assessing the relationship between a country or region's economic activities and carbon emissions. High carbon emission intensity may indicate inefficient production and consumption patterns, which have a greater negative impact on the environment. This indicator is measured by comparing the CO_2 emissions per unit of GDP, reflecting the emissions per unit of energy consumption. Reducing carbon emission intensity signifies a transition to cleaner and more efficient production and consumption, thereby reducing environmental pressure. According to statistics, 86% of countries have begun to decrease their carbon emission intensity and have achieved relative decoupling of emissions from economic growth. However, progress towards carbon neutrality varies significantly. Only eight countries have reduced their emission intensity by more than 75% from their peak, while 27 developing countries, mainly in Asia and Africa, have continued to increase their carbon emission intensity [2].

Carbon emissions per capita measure the level of emissions relative to population size, reflecting the intensity and density of emissions. Lower per capita emissions indicate that a country or region has lower emission intensity, and the population bears a lighter burden of emissions. As the population size increases, the overall CO_2 emissions of an economy naturally increase, and the population structure significantly impacts energy consumption and emissions. In short, per capita emissions reveal the average contribution of each population member to emissions, providing an important indicator for evaluating and comparing the emission efficiency of different countries or regions.

These indicators interact and influence each other and need to be considered comprehensively. For example, a country may have high total emissions but low per capita emissions, indicating a large population with relatively low per capita emissions. Alternatively, a country may have high emission intensity but low energy intensity, suggesting that while its production and consumption methods are inefficient, its energy utilization is high. Therefore, conclusions should not be drawn solely based on individual indicators. Instead, it is essential to consider the development stage, total population, and structure of a specific country. Additionally, environmental and energy policies significantly impact emissions. Some countries may adopt effective policies to reduce emissions and improve energy efficiency. Thus, when evaluating a country's emission level, government policies and various socio-economic factors must be considered. Assessing a country's carbon emissions is complex and requires a comprehensive consideration of multiple factors. Only by understanding all relevant environmental and social factors can accurate conclusions be drawn and effective recommendations be made.

3. Evolution and Trends of Global Carbon Emissions

3.1. Evolutionary Stages

Global carbon emissions have been increasing since 1965, although the growth rate has decelerated over the past decade. According to BP data, global emissions surged from 11.19 billion tons in 1965 to 16.3 billion tons in 1973, with an average annual growth rate of 4.8%. However, during the 1973-1975 oil crisis, carbon emissions slightly decreased due to economic disruptions and reduced energy consumption. Despite energy supply constraints during the 1979 Iranian Revolution and the Iran-Iraq War, total carbon emissions remained around 18 billion tons. Before 2000, emissions rose from 18.1 billion tons to 23.6 billion tons, with a slowed average annual growth rate of 1.6%. From 2001 to 2008, the rise of the Chinese economy accelerated global carbon emissions to 30.3 billion tons, with an average annual growth rate of 3.4%. The 2008 financial crisis caused a brief decline in emissions due to the global economic downturn. From 2010 to 2019, global carbon emissions entered a low-growth phase, increasing from 31.028 billion tons to 34.095 billion tons, at an average annual growth rate of 1.1%. This slowdown is generally attributed to global climate change mitigation efforts, rapid renewable energy development, and increased forest carbon sinks. In 2020, the COVID-19 pandemic led to a significant global economic recession, causing carbon emissions to drop by 5.9% to 32.07 billion tons. However, emissions rebounded in 2021 as the global economy recovered post-pandemic.

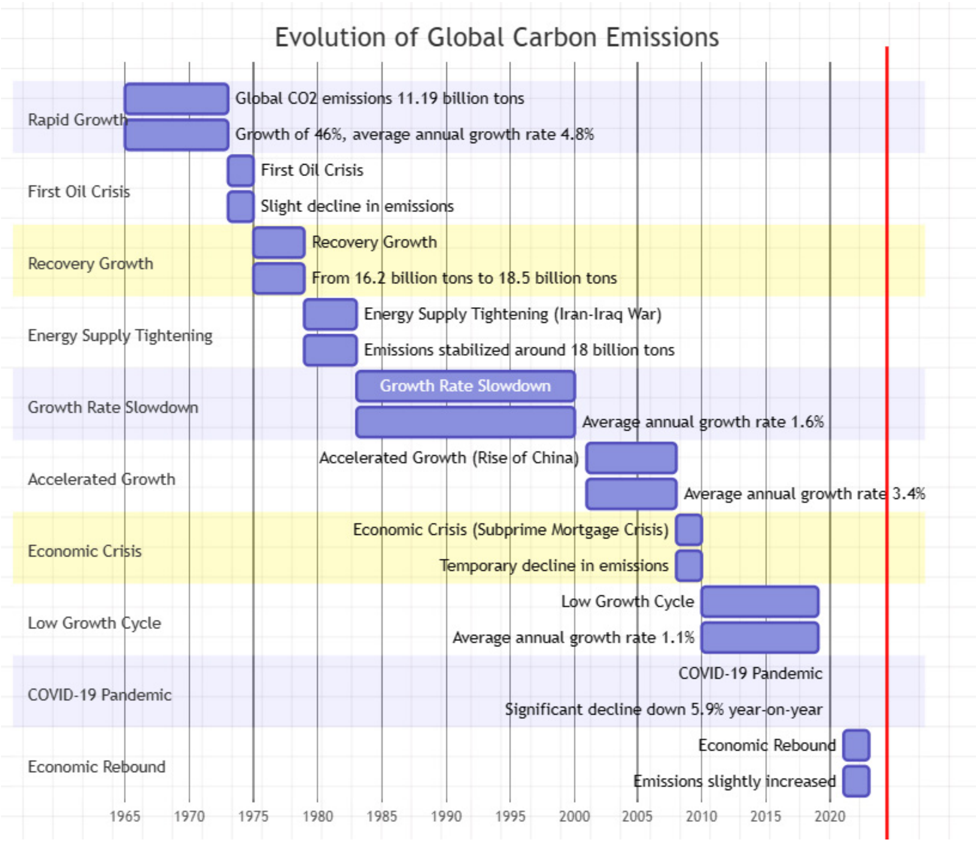

Figure 1. Evolution of Global Carbon Emissions

The patterns observed in global carbon emissions reveal that economic activity is a significant driver of emission trends, with rapid industrial growth leading to increased emissions. However, economic, and political crises can cause temporary declines in emissions. In recent decades, there has been a noticeable deceleration in emission growth due to global efforts to combat climate change, the development of renewable energy, and the increase in forest carbon sinks. Major global events, such as the COVID-19 pandemic, can lead to significant but temporary reductions in emissions, followed by rebounds as economies recover.

3.2. Main Trends

According to international experience, the relationship between a country or region's economic development and carbon emissions could generally be divided into four stages (see Figure 2). In the first stage, carbon emission intensity gradually rises from the initial stage and continues to grow until it reaches its peak. In the second stage, carbon emission intensity begins to decline from its peak until reaching the highest point of per capita carbon emissions. The third stage occurs after per capita carbon emissions exceed their inflection point; although it has passed this point, per capita carbon emissions are still rising, gradually approaching the peak of total carbon emissions. Finally, the fourth stage marks the beginning of a stable period of gradual decline after total carbon emissions reach their peak.

Historical observations indicate that it is easiest to transition through the first stage of increasing carbon emission intensity, followed by the second and third stages. When analyzing the trends of total carbon emissions, per capita carbon emissions, and carbon emission intensity, population growth, economic development, and technological progress are widely considered the three core driving factors. Population growth directly increases total carbon emissions; however, its positive impact on economic expansion and technological innovation should not be underestimated. Sustained economic growth and continuous technological progress help reduce carbon emission intensity and per capita carbon emissions. Therefore, when studying the complex relationship between carbon emissions and economic development, it is crucial to fully consider the positive impact of economic and technological advancements on carbon emission intensity and per capita emissions.

Additionally, policy and institutional changes have also profoundly impacted carbon emissions. By promoting policy innovation and adjusting the economic structure, technological innovation can be stimulated, thereby reducing carbon emissions while promoting sustainable development.

With the increasing maturity of carbon emission reduction technologies and their core role in carbon emission management, the global carbon emission trend is anticipated to enter its fourth stage: a gradual decline following a peak in total emissions.

Generally, as the economy progresses, carbon emission intensity and per capita carbon emissions tend to rise initially before gradually declining. Total carbon emissions, however, typically continue to increase during periods of rapid economic growth. As the rate of economic growth slows, the growth rate of total carbon emissions will also decelerate, eventually stabilizing and entering a phase of gradual decline.

4. International Carbon Emission Characteristics and Influencing Factors

First, from the perspective of carbon emissions, the increase in global carbon emissions is primarily concentrated in emerging economies and developing countries. According to data from the International Energy Agency, the top ten countries in terms of carbon dioxide emissions in 2020 were China, the United States, India, Russia, and Japan, with emissions of 9893.5, 4432.2, 2298.2, 1431.6, and 1026.8 million tons respectively. The total emissions of these countries account for 58.2% of global emissions, with China alone contributing 29.5%. The emissions of these five countries significantly exceed those of other countries and regions, indicating that the increase in global carbon emissions is primarily driven by emerging economies and developing countries, where emissions are rapidly increasing.

From an economic perspective, considering a country's level of economic development (real GDP growth rate), what is the carbon emission pattern of major countries worldwide? Table 1 shows the distribution pattern of economic growth and carbon dioxide emission growth for the top 30 countries and regions by carbon dioxide emissions. These countries and regions can be categorized into four groups based on the difference between their real GDP growth rate and carbon dioxide emission growth rate. The first group includes seven major developed countries with low real GDP growth and negative carbon emission growth, such as the United States, Japan, Germany, and the United Kingdom. The second group comprises 18 countries and regions with medium-to-low economic growth and low carbon emission growth, including Russia, Iran, South Korea, Saudi Arabia, Canada, and South Africa. The third group consists of four Asian countries with medium-to-high economic growth and rapid carbon emission growth, such as India, Indonesia, Vietnam, and Kazakhstan. The fourth group is China, which, despite achieving sustained high economic growth, has a carbon dioxide emission growth rate roughly equivalent to the medium-to-high growth level of the third group of countries.

Table 1. Categorization of Countries and Regions by GDP Growth Rate and Carbon Emissions Growth Rate

Group	Country / Region	GDP Growth Rate	Carbon Emissions Growth Rate	Description
First Group	United States, Japan, Germany, United Kingdom, Italy, France, Spain	Low	Decline	Countries with low real GDP growth and reduced carbon dioxide emissions growth
Second Group	Russia, Iran, South Korea, Saudi Arabia, Canada, South Africa, Mexico, Brazil, Australia, Turkey, Poland, Thailand, UAE, Taiwan, Malaysia, Singapore, Egypt, Pakistan	Medium to Low	Low	Countries and regions with medium to low economic growth and low carbon dioxide emissions growth
Third Group	India, Indonesia, Vietnam, Kazakhstan	Medium to High	Rapid	Countries and regions with medium to high economic growth and rapidly increasing carbon dioxide emissions
Fourth Group	China	High	Medium to Low	A country with sustained high economic growth, where the carbon dioxide emissions growth rate is roughly equivalent to the average level of the high-growth group in GDP

There are notable differences between developed countries and emerging industrialized countries in addressing global carbon emissions. Developed countries, despite having high total carbon emissions, exhibit low carbon emission intensity. In contrast, developing countries and emerging economies have lower total carbon emissions but higher carbon emission intensity. These differences stem from variations in economic structure and energy usage. In emerging industrialized countries, rapid industrialization, urbanization, and changes in lifestyle have led to a significant increase in carbon dioxide emissions. Consequently, their demands and policy measures for global carbon emission reduction differ significantly from those of developed countries.

Table 2. Global Carbon Emissions Status and Policies

Country Type	Carbon Emissions Responsibility	Carbon Emissions Status	Carbon emission forecast	Carbon emission policies or propositions
developed country	Relatively high	Stable or declining	relatively stable	EU: Advocates the “carbon neutrality” goal and plans to reduce carbon emissions to almost zero by 2050.
				United States: Rejoined the Paris Agreement and plans to reduce carbon emissions to almost zero by 2050.
				Japan: Plans to halve carbon emissions by 2050.
Newly Industrialized Countries	gradually increase	increase rapidly	Continue growing	China: Advocates the goals of “carbon peak and carbon neutrality”, plans to reach carbon peak around 2030 and achieve carbon neutrality by 2060.
				India: Plans to increase the share of renewable energy to 40% by 2030.
				Brazil: Plans to increase the proportion of renewable energy to 45% by 2030.
developing country	relatively low	relatively stable	Continue growing	African countries: Advocate developed countries to provide financial and technical support to help developing countries promote sustainable development.
				Small island states: Call on developed countries to assume more historical responsibilities, reduce carbon emissions, and provide financial and technical support.

From a policy advocacy perspective, the developed countries have completed before the upcoming economy industrialization, and hence its consumption structure and level of production method are relatively advanced, and therefore, its total carbon emissions are relatively high. However, developed countries have technological advantages of reducing emissions, which helps to realize their targets through technical innovation and application. In addition, they might have the financial and technical capacities for supporting emission reduction in developing countries. By contrast, emerging countries have already completed industrialization and are still in the middle and late stages, therefore, and their economic structure is relatively underdeveloped and relatively low in production method, culminating in a high carbon emission intensity. Since their total carbon emissions are still in rapid growth, these countries emphasize economic growth and focus mainly on ways of emission reduction as a potential short-term hindrance to development. Therefore, under the principle of CBDR (Common But Differentiated Responsibilities), which is relevant to comparisons between the two groups, developing the emerging industrialized countries generally support the principle of “common but differentiated responsibilities” for fighting against climate change, arguing that developed countries must take a relatively higher responsibility for emission reduction and provide necessary technical and financial assistance to developing country to advance global carbon emission reduction efforts.

Industry-wise, the contribution of global carbon emission is astronomic and varies tremendously across industries all over the globe. In 2020, electricity and heat production were the largest contributors, accounting for approximately 42% of the total emissions. This sector generated a substantial amount of carbon due to the burning of fossil fuels for electricity generation and heating. The transport sector followed, responsible for about 24% of global carbon emissions, including emissions from road transport, aviation, shipping, and railways.

Industrial processes, including the production of cement, steel, and chemicals, contributed around 22% of global emissions. These processes are highly energy-intensive and emit significant amounts of CO_2. Buildings, encompassing both residential and commercial structures, accounted for approximately 6% of global carbon emissions. This includes emissions from heating, cooling, and cooking activities, highlighting the importance of improving building efficiency and energy use. The agriculture, forestry, and land use (AFOLU) sector contributed about 18% of global emissions, covering emissions from deforestation, agricultural practices, and other land use changes.

Other fuel combustion activities and fugitive emissions collectively made up 5% and 3% of global emissions, respectively. Fugitive emissions are unintentional releases of gases, such as methane leaks during oil and gas extraction and transportation. This detailed breakdown underscores the importance of sector-specific strategies for carbon emission reduction.

The data provide clarification on the different contributions of each sector in global carbon emissions; hence, they are of utmost importance to come up with targeted emission policies. This way, policymakers will focus on sectors that have high emissions, thus being able to come up with strategies that are precise and effective in reducing emissions.

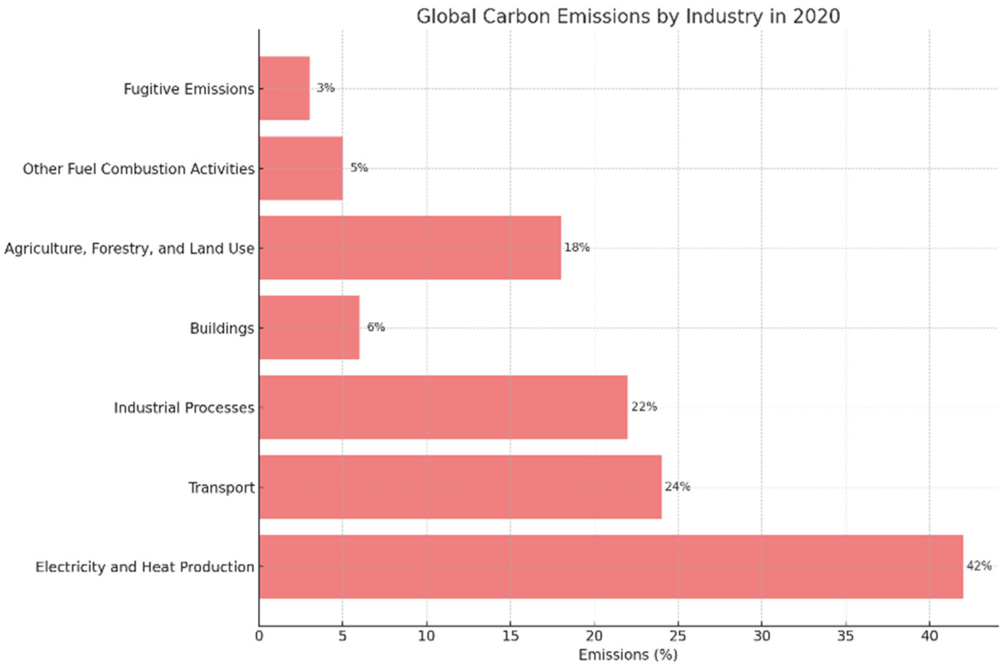

Figure 2. Global Carbon Emissions by Industry in 2020

5. Influencing Factors

Greenhouse gas emissions have been a significant focus of research globally. Both domestic and international scholars have conducted extensive studies, primarily from a macro perspective, on carbon dioxide emissions. Their analyses identify several key factors driving carbon dioxide emissions: population growth, economic development and income levels, urbanization, international trade expansion, total energy consumption, energy structure, energy intensity, energy prices, industrial structure, and technological advancements. These factors collectively influence the patterns and levels of carbon emissions worldwide.

The model greatly reduces production technology, consumption tendency, and direct carbon emission intensity related to consumption-based carbon emissions, but it renders residents' consumption-based carbon emissions caused by population growth, income level, and consumption structure [3]. The industrial structure, urbanization level, and energy structure majorly provide driving forces of residents' carbon emissions [4]; the carbon emission impact mechanism is a very complex system where energy-economy-environment is the three sub-systems, which not only affects each other, but also interacts with each other. Population and economic development are two critical variables; among the economic factors, the contribution to the carbon emissions resulting from the energy consumption is the most significant, and the energy intensity has the most considerable negative impact. Economic growth is the major factor driving fossil energy carbon emissions, and the suppression of fossil energy carbon emissions has a fundamental way to reduce the energy intensity, while the energy structure. The industrial structure has a very slight effect on reducing fossil energy carbon emissions; the population has a positive effect or plays against the reduction of the carbon emissions about the fossil energy [5]. Per capita GDP changes have a great effect on carbon emissions, in many cases, the environmental Kuznets curve is not easy to use, even an N type [6].

Energy structure and industrial structure demonstrate a dual causality relationship. A change in industrial structure has implications for the proportion of the various forms of energy consumption and energy structure, hence affecting the total energy consumption and carbon emissions. Studies have shown that industrial structure, efficiency, and labor inhibit the agricultural carbon emissions and that the tertiary industry in industrial structure leads to the decline of the total carbon emissions [7]. Of more importance that shows the increased relationship with the carbon emissions is the economic growth and population growth. The income gap, openness of trade, and the energy consumption structure exhibit a different influence on carbon emissions. Another factor that is very important to be considered in the carbon emissions is the trade openness. Researchers have studied the relationship of the openness of trade for different dimensions. While some literature postulates that it leads to carbon emissions to transmit and in the process destruction of the environment [8]. The contemporary "Trade Benefit Theory" posits that engagement in trade can facilitate the adoption of environmentally sound technologies and sophisticated, eco-friendly production processes, thereby contributing to a reduction in carbon emissions. This perspective underscores the potential of trade as a catalyst for sustainable development and environmental stewardship through the exchange of cleaner technologies and best practices [9]. However, some literature shows the fact that generally trade openness has increased the carbon emissions [10].

From the perspective of specific emission entities, it will at last lead to huge disparities in carbon emissions due to the profound differences in the levels of economic development and historical responsibilities of the specific emission subjects of the different countries. This has been a question focused on in the current international discussion. The large-scale emissions of greenhouse gases made by developed countries have inflicted great harm to the global climate in the early development of industrialization. Meanwhile, the high-speed development of the emerging industrialized country has led to a surge in their carbon emissions in the recent years. The high-speed development in the emerging industrialized countries constitutes an international issue, that is, how to equally allocate the developmental space for carbon emissions between the developed countries and the emerging industrialized countries. In addition, the carbon emissions issue between the two groups of countries must also consider the contribution of international trade to carbon emissions. Through a product's life cycle, all the direct and indirect greenhouse gas emissions can be embodied in the concept of "embodied carbon". Cross-border trade can also play a role in developing the global carbon footprint. Some of the developed countries have cut down on their own carbon emissions through the method of transferring high-emission industries to the emerging industrialized countries that have a relatively low level of economic development and a loose industrial structure, which has deepened the issue of international carbon emission inequality.

In addition, the issue of global carbon equity necessitates considering per capita consumption-based CO_2 emissions, which reflect the actual contribution of residents of a country or region to global climate change through their production and consumption activities. Unlike traditional production-end emissions, this indicator attributes emission responsibility more directly to final consumers by accounting for the impact of international trade. To calculate this indicator, first, the consumption-based emissions are considered, including the CO_2 emissions generated by residents through the purchase of goods and services. Then, trade adjustments are made by subtracting the emissions transmitted to other countries through exports and adding the emissions introduced through imports. Finally, the result is divided by the population to obtain the average CO_2 emissions caused by consumption per resident. This approach more fairly distributes global carbon emission responsibilities by adjusting for international trade impacts and avoids the unfair distribution seen with traditional production-end emissions. This is crucial for formulating effective global climate policies and cooperation.

Some countries transfer emissions by exporting carbon-intensive products, and per capita emission calculations based on consumption can more accurately reveal the environmental burden of these countries. This method also supports policy development that helps developing countries pursue sustainable development paths.

6. Conclusion

Global carbon emissions are influenced by many factors, including economic growth, population growth, energy structure, industrial structure, and technological level. Due to the complexity of these factors, global carbon emissions are uncertain and unpredictable. Energy generation and heating, transportation, manufacturing, and construction are the main sources of global carbon emissions. The peaks of carbon emissions and per capita carbon dioxide emissions do not always coincide, and substantial population increases can result in aggregate emissions lagging behind emissions on a per capita basis. Therefore, "per capita carbon emissions" may be a more reliable indicator of turning points. Additionally, climate change, policies and regulations, and the international environment also impact global carbon emissions, necessitating multi-faceted efforts and cooperation to reduce them.

The international community needs to strengthen cooperation and formulate fair and sustainable international trade rules to reduce carbon emission transfers. Additionally, countries should enhance technology transfer and financial support to help developing nations achieve sustainable development and reduce carbon emission transfers. Achieving global carbon equity is essential for ensuring the future of humanity and the sustainable development of the Earth. The significant achievements made by developed countries in energy conservation and emission reduction result from policy adjustments and technological progress. The experiences and practices of developed countries can serve as valuable references for other nations. By learning from the experiences and technologies of developed countries, the global emission reduction process can be accelerated. Therefore, countries need to promote economic development and social progress while reducing carbon emissions, achieving a balance between sustainable economic development and environmental protection.

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