



Climate-Related Development Finance, Energy Structure Transformation and Carbon Emissions Reduction: An Analysis From the Perspective of Developing Countries

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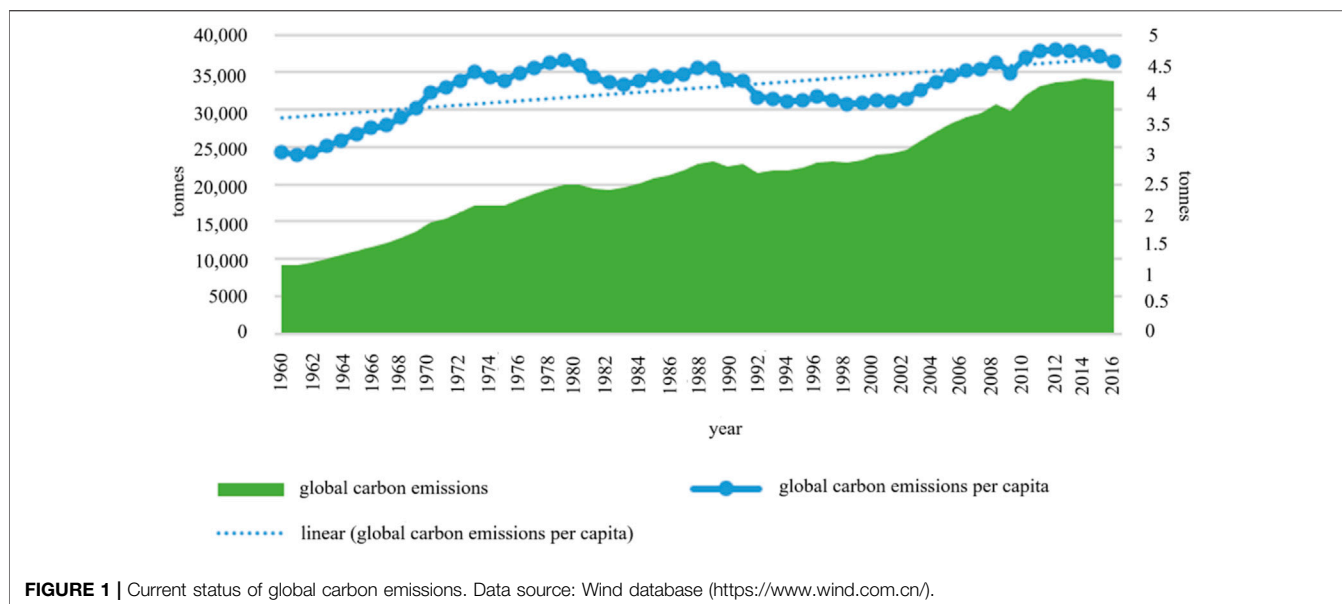
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With the frequent occurrence of extreme weather in cities, economic, ecological and social activities have been greatly impacted. The adverse effects of global extreme climate and effective governance have attracted more and more attention of scholars. Considering the differences between developed and developing countries in climate response capacity, a key issue is how to encourage developed countries to provide adequate assistance to developing countries and enhance their enthusiasm to participate in addressing climate change challenges. Given this background, we evaluated the carbon emission reduction effects of developing countries before and after a “quasi-natural experiment” which involved obtaining the assistance of climate-related funding from developed countries. Specifically, we analyzed the assistance behavior for recipient countries and found that climate assistance can effectively reduce the carbon emissions level of recipient countries, and this result has a better impact on non-island types and countries with higher levels of economic development. Furthermore, the achievement of this carbon emissions reduction target stems from the fact that climate assistance has promoted the optimization of the energy structure of recipient countries and promoted the substitution of renewable energy for coal consumption. In addition, climate-related development finance plays a significant role in promoting the scientific and technological level of recipient countries, especially the development impact of the adaptive climate-related development finance. Therefore, this paper suggests that the direction of climate assistance should focus more on island countries and countries with low economic development level, and pay more attention to the “coal withdrawal” of recipient countries and climate adaptation field.

Keywords: climate-related development finance, energy structure transformation, renewable energy development, developing countries, carbon emissions

INTRODUCTION

With the continuous increase of greenhouse gas emissions, greenhouse gas emissions represented by carbon emissions have gradually attracted the attention of scholars. Since 1960, global total carbon emissions and carbon emissions per capita have shown an upward trend, especially the former, showing continuity and rapidity. As shown in **Figure 1**. It can be seen that the climate problem is

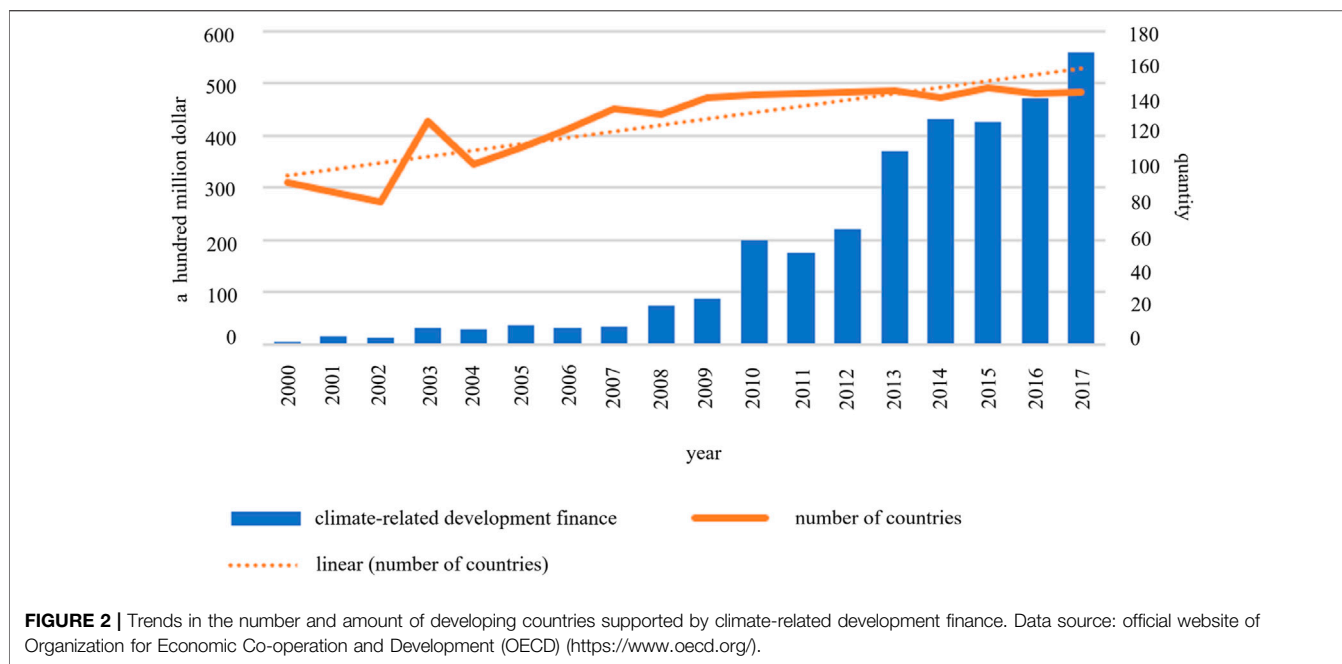


becoming more and more serious. Severe climate problems lead to frequent extreme weather and climate in the urban environment. Drought, flood and heat wave seriously threaten the economic development and ecological protection of the city. According to the report of the Food and Agriculture Organization of the United Nations (FAO) in 2021, food prices around the world have risen for 12 consecutive months, reaching the highest level in 10 years. And drought is one of the important reasons for this food crisis. In July 2021, Henan Province, China continued to experience extreme heavy rainfall. Zhengzhou, the provincial capital, suffered a severe rainstorm. The rainfall exceeded the historical extreme value. The rainstorm killed more than 300 people and the economic loss was difficult to measure. The fifth report issued by the Intergovernmental Panel on Climate Change (IPCC) concluded that since 1950, the number of land-based heavy rainfall events may have increased rather than decreased in more parts of the world (>66% probability). From a global perspective, with the increase of extreme rainfall, more noteworthy phenomena are the frequent occurrence of extreme weather such as drought and high temperature, which together pose a severe challenge to global climate governance.

Under the background of intensified climate change, Glasgow climate conference was held in November 2021, which is of great significance for promoting countries to increase the intensity and speed of emissions reduction and strengthening the cooperation between developed and developing countries so as to jointly advance the process of climate governance. The 2018 Nobel Prize in economics was awarded to William Nordhaus, a researcher in the field of climate change, which also reflects the urgency of raising global attention to climate governance. The disastrous impact of global climate change has introduced unprecedented challenges to human survival. Climate change increases the risk of extreme weather and natural disasters (Li et al., 2017; Pour et al., 2020; Sarkodie and Strezov, 2018), which is a great threat to the development of biodiversity and the

maintenance of ecosystem balance. There is no doubt that human development needs to be based on the existence of natural sustainability. However, the abnormal climate phenomena caused by human economic activities directly threaten the operation of natural systems. When the global climate change exceeds a certain critical threshold, the natural basis for human survival may be completely destroyed. Without a stable ecosystem, there is no way for human economic development. Besides the impact on nature, abnormal climate change caused by human activities also affects human activities in turn. Some studies show that it has different degrees of impact on agriculture, tourism, and other industries in various countries (Vernon, 2006; Andric et al., 2019; Arsum et al., 2020).

In view of this situation, attracting more countries to actively participate in the process of climate governance is the key to promoting the solution of global climate problems. As an important part of the world, the role of developing countries could not be ignored. From an economic perspective, developing countries have become major participants in the global economy (Kovačević, 2004). With the economic growth of developing countries, their export and import capacity are expanding (Rondinelli and Kasarda, 1992). Due to the needs of economic development, greenhouse gas emissions in developing countries will show an upward trend in the future (Halsnæs, 1996). From the perspective of energy use, with the development of population and economy, the global demand for energy will continue to increase in the future, and most of this growth will occur in developing countries. The share of energy consumption in these countries will increase from 46 to 58% between 2004 and 2040 (Keho, 2016). It can be seen that the impact of economic development and energy use on global climate change is also increasing in developing countries. However, as an economy with a low degree of economic development, it is greatly restricted by capital and technology in promoting its own climate governance process.



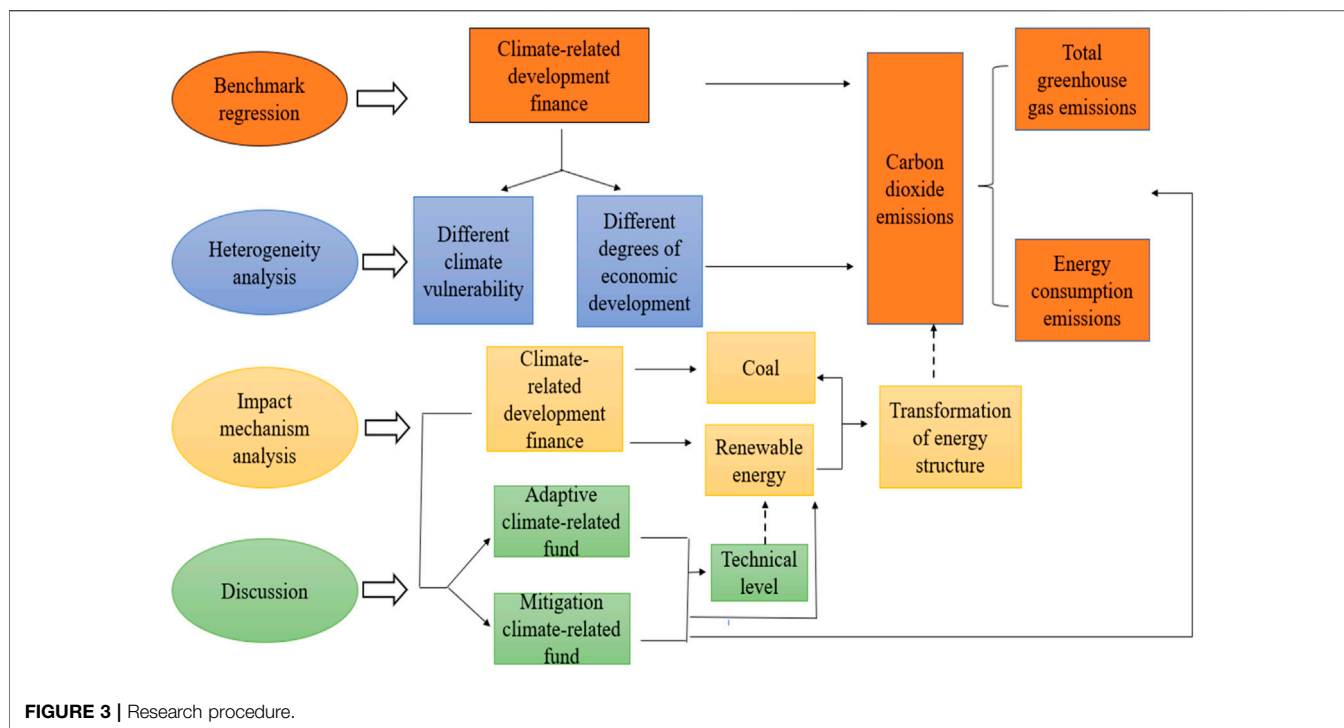
The excessive emission of greenhouse gases represented by carbon emissions is an important reason for the current serious climate problems, and the massive use of fossil energy is the key to excessive carbon emissions (Rehman et al., 2019; Shi et al., 2021; Li et al., 2021). For developing countries, energy subsidies are a common phenomenon (Kosmo, 1989), especially fossil fuel subsidies, which are huge and extensive (McCulloch et al., 2021). According to the International Energy Agency (IEA), fossil fuels receive more than four times as much cash support as renewable energy (Yau and Chen, 2021). Excessive subsidies to fossil energy may distort its price, resulting in inefficient energy use and wasteful consumption (Ouyang and Lin, 2014). Therefore, through the above analysis, it can be considered that the economic development of developing countries still relies heavily on fossil energy such as coal. Under this background, if developing countries want to smoothly promote their own climate governance process, they need to focus on the transformation of energy structure. In order to achieve this goal, it needs to reduce the dependence of economic development on coal, improve energy efficiency and actively develop renewable energy, and on this basis, improve the substitution degree of the latter to the former, which needs to be supported by a large amount of capital and a high level of technology. For developing countries, these two elements are precisely the most scarce.

Facing the severe challenge of climate change, all countries in the world have the responsibility and obligation to devote themselves to the process of climate governance. Due to historical reasons, developed countries should shoulder more responsibilities for world climate change. Facing the urgent situation of coping with climate change, the all-round support and guidance of developed countries is of positive significance to

promote the process of global climate governance, especially to improve the enthusiasm of developing countries to participate in climate governance. The support of developed countries for climate-related development finance of developing countries is an important way to solve the financing gap of climate governance of the latter, which makes it possible for developing countries to explore diversified carbon emissions reduction paths.

Since 2000, the amount of climate-related development finance from developed countries has shown a rapid upward trend. By 2017, it has exceeded 56 billion US dollars, and the number of developing countries assisted has also shown an increasing trend. By 2017, more than 140 countries have benefited from the climate-related development finance, indicating that more and more countries have been actively guided into the process of climate governance. It can be seen that the positive climate assistance behavior of developed countries helps to mobilize the enthusiasm of more developing countries for climate governance. The specific results are shown in **Figure 2**.

Under this background, has climate-related development finance effectively played its role in reducing the carbon emissions level of recipient countries? Will this result be heterogeneous due to the different urgency of coping with climate change and countries with economic fragility, that is to say, does climate assistance focus on the countries that are in urgent need and priority need help? Furthermore, will the promotion of climate assistance optimize the energy structure of recipient countries, and thus have a certain radiative impact on changes in their carbon emissions? In addition, the impact of different types of climate-related development finance and the development status of different recipient sectors are the focus of this article.



Through research in this article, it is found that climate assistance can effectively reduce the carbon emissions level of recipient countries, and this result has a better impact on non-island types and countries with higher levels of economic development. Furthermore, the achievement of this carbon emissions reduction target stems from the fact that climate assistance has promoted the optimization of the energy structure of recipient countries and promoted the substitution of renewable energy for coal consumption. In addition, climate-related development finance plays a significant role in promoting the scientific and technological level of recipient countries, especially the development impact of the adaptive climate-related development finance, which lays a foundation for the development of renewable energy. Furthermore, climate financing mainly focuses on environmental related fields such as transportation, energy and education, indicating that there is no deviation in the inflow of specific sectors.

At present, the research on climate assistance mainly focuses on acquisition, management, and distribution of climate-related funding, and there is little discussion on the impact of “South-North cooperation” climate governance model on carbon emissions reduction from the perspective of cooperation between developed and developing countries. Climate-related development finance in developed countries is an important force to promote global climate governance. Therefore, there is still a gap in the research focusing on climate assistance from developed countries to developing countries from the global level. Based on this, the marginal contributions of this study include the following: 1) from the global level, scientifically evaluate the carbon emissions reduction effect brought by climate assistance from developed countries to developing countries, and fill the research gap of “South-North cooperation” climate

governance model on a global scale from a macro perspective. 2) This paper takes the total carbon emissions equivalent value of greenhouse gas emissions as the research object, expands the scope of the research object, corrects the previous research only taking carbon dioxide emissions as the unique index, and improves the accuracy of policy effect evaluation. Meanwhile, differences-in-differences method (DID) is used to study the subject of this paper, which could better eliminate the impact of other factors on the research object, and then accurately identify the “net effect” of the target policy to ensure the scientificity of the research. 3) Starting from the energy structure, especially the development of renewable energy, this paper deeply analyzes the internal transmission path of the impact of climate assistance on carbon emissions reduction in recipient countries, and supplements the analysis from the perspective of energy structure transformation. In addition, the impact analysis of different types of climate-related development finance also enriches the research content related to climate assistance.

The remainder of this paper is arranged as follows: **Section 2** introduces the literature review. **Section 3** includes the research methodology and data. **Section 4** presents the empirical results and discussion. **Section 5** presents the impact mechanism test. **Section 6** presents further discussions, and finally, conclusions are drawn in **Section 7**.

LITERATURE REVIEW

Whether climate-related development finance could effectively reduce the carbon emissions level of developing countries

receiving assistance is the focus of this paper. Based on this theme, this paper combs the research in related fields, mainly from the perspectives of research related to climate financing and ways of carbon emissions reduction. First, in terms of climate financing, funding to protect the environment and mitigate climate change had been relatively scarce for many years in developing countries (Ferraro and Pattanayak, 2006; Syed, 2019; Zhang, 2016), and certain industries greatly affected by climate change, such as fisheries, have lacked strong financial support (Guggisberg, 2019). Studies have indicated that the gap in climate adaptation financing is increasing, and whether climate adaptation financing has been appropriately managed and delivered is worth discussing (Khan et al., 2020). At the same time, the questions of how to make more effective use of existing adaptation funds and promote more adaptive investment have become key issues (Xu and Liu, 2018; Sam, 2014; Ornsaran et al., 2020). In recent years, the various financial programs supporting climate action and sustainable development have been expanding. Climate-related funds, such as the Global Environment Facility (GEF), the Green Climate Fund (GCF), and the World Bank BioCarbon Fund, differ in their size, funding type, and funding duration (Clark et al., 2018). To broaden the channels of climate financing, researchers proposed that more climate financing needs could be met by improving the climate financing within and among developing countries (south-south climate financing) (Ha et al., 2016; Ye, 2014; Dumisani, 2016). Private sector involvement can also expand the scale of climate financing (Stein et al., 2010) to supplement the lack of governmental environmental protection (Sudmant et al., 2017; Clark et al., 2018; Vandenberg, 2018). In view of this, although the current scale and demand of climate financing cannot fully address the problem, the overall scale of climate financing is on the rise (Chen et al., 2019b).

As far as the management of climate financing is concerned, at present, global climate-related funding is still in a relatively developmental state (Pickering et al., 2017). Through research, some scholars proposed that international development and cooperation agencies should jointly manage climate-related funds, and should try to resolve any differences in the assistance objectives of the funds (Brunner and Enting, 2014; Pickering et al., 2015). For aid projects, a sound and mandatory data system should be established to track the climate-related funds of developed countries, to help developing countries cope with evolving climate change commitments, and to facilitate the verification of international climate assistance commitments (Simon et al., 2016).

Regarding the allocation of climate financing, the directional flow of climate-related funding is not only related to the economic and geographical distribution (Román et al., 2016) but also to political factors (Purdon, 2017; Geddes et al., 2020) and the strategic economic considerations of donor countries (Román et al., 2019). Developed countries from different regions have different methods of allocating climate-related funding to developing countries. In general, countries that are more vulnerable to climate change are eligible for more assistance (Betzold and Weiler, 2017; Scandurra et al., 2020); however, European

countries are more concerned about the business partners they engage with and therefore prefer to allocate their climate-related funding to specific recipient countries, while the US and Japan allocate their climate aid funds through different projects (Scandurra et al., 2017).

In addition, scholars have explored the specific factors influencing climate financing. The driving forces of international financing in developed countries has also been discussed, and the majority of countries are mainly influenced by their material interests (Urpelainen, 2012; Weikmans and Zaccai, 2017). Others argued that, if the promotion of green climate-related funding continues to play an active role in the global climate finance system, China should play the role of a bridge between the developed and developing countries. Guiding green climate-related fund voting reforms to eliminate political factors will help to lessen the negative impact of long-term development (Chen et al., 2019a).

Second, the discussion on the ways of carbon emissions reduction focuses more on the improvement of the carbon emissions trading market. Some scholars first analyzed the factors affecting carbon emission reduction, and believed that the efficiency of the emission reductions is closely related to the economic scale, economic structure, energy utilization efficiency, and energy structure of an economy (Xu and Song, 2010; Sun and Zhang, 2014; Hargrove et al., 2019). In regard to governance measures, emission trading systems (ETS) are a powerful tool to achieve carbon emission reductions (Zhang et al., 2020). An ETS regulates carbon emission activities through market means, improving the enthusiasm of enterprises to reduce emissions, and thus achieving the carbon emission reduction targets (Dong et al., 2019; Song and Xia, 2019). Due to the earlier emergence of a carbon emission trading market in the EU (European Union), Australia, and other regions or countries, scholars have authored a great deal of theoretical analyses and experience summaries on the mode of operations in existing markets (Qi and Wang, 2013; Liang and Cao, 2015). In addition, the market operation efficiency generated by a carbon quota allocation method was further compared and analyzed to provide theoretical support and an experience summary for the practical operation of the carbon market (Hu et al., 2018).

Through the review of literature, we can see that the current analysis of climate-related development finance mainly focuses on acquisition, management and distribution, while the research on the realization path of carbon emissions reduction mainly focuses on the improvement of market model. However, there is still a research gap on the impact of climate financing on carbon emissions reduction, especially on the impact of the model represented by climate assistance from developed countries on developing countries at the global level. On the one hand, the lack of this research will bias the scientific and comprehensive assessment of climate assistance, which may hinder the further promotion and improvement of climate assistance. On the other hand, the lack of this research will limit the discussion of the diversification of carbon emissions reduction approaches. Based on this, starting from the climate-related development finance behavior of developed countries, this paper attempts to evaluate the impact of climate-related development finance on carbon

emissions changes in developing countries to provide experience reference for improving the current climate assistance policies and promoting the exploration of diversified carbon emissions reduction methods in developing countries.

RESEARCH METHODOLOGY AND DATA

Methodology

In order to test the environmental impact of developed countries' climate assistance to developing countries, this paper selects total greenhouse gas emissions of carbon dioxide equivalent and energy consumption emissions of carbon dioxide equivalent of countries as a climate environmental indicator from 1990 to 2017. It also analyzes the climate-related development finance assistance behavior of developed countries to developing countries since 2000, which was published by the OECD as a quasi-natural experiment, and utilizes the DID (differences-in-differences) method to identify the causal effect. From the perspective of recipient countries, this paper regards developing countries (regions) receiving aid as intervention groups, and other developing countries (regions) not receiving aid as control groups. By comparing the samples in the intervention groups and control groups, we can evaluate the net effect of the "South-North cooperation" aid behavior. The specific model is set as follows:

$$Carbon_{it} = \alpha_0 + \alpha_1 CRF_{it} + \alpha_2 \sum Control_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (1)$$

In the formula above, $Carbon_{it}$ refers to total greenhouse gas emissions thousand tons of carbon dioxide equivalent (CO_2) and energy consumption emissions thousand tons of carbon dioxide equivalent ($energyCO_2$) in each country and region. CRF_{it} indicates whether country i is a recipient target in year t . This paper defines it by setting a dummy variable. If a country has received climate-related development finance, it is assigned a value of 1, which is regarded as a treatment group. Otherwise it is 0, and is regarded as a non-treatment group (control group). This definition could distinguish recipient countries from non-recipient countries, and lay a foundation for setting treatment group and non-treatment group, so as to meet the application conditions of DID method. The treatment group is the object affected by the policy, and the non-treatment group is the object not affected by the policy. Through the DID method, that is, after two differences between the treatment group and the non-treatment group, the "net effect" of policy implementation could be effectively identified, so that the policy could be evaluated more scientifically. Control refers to controlling other factors that may affect carbon emissions, while μ_i refers to the national fixed effect, δ_t refers to the time fixed effect, and ε_{it} refers to the random factors involved. α_1 is our major concern here.

In order to further analyze the internal reasons for the positive impact of climate assistance on carbon emissions reduction, this paper discusses the transmission mechanism by analyzing the relationship between climate assistance and energy structure change from the perspective of energy structure. The specific model is constructed as follows:

$$energy_{it} = \beta_0 + \beta_1 CRF_{it} + \beta_2 \sum Control_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (2)$$

$$coalpower_{it} = \gamma_0 + \gamma_1 renewables_{it} + \gamma_2 \sum Control_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (3)$$

$$coalpower_{it} = \theta_0 + \theta_1 renewables_{it} \times CRF_{it} + \theta_2 energy_{it} + \theta_3 \sum Control_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (4)$$

Among them, **formula (2)** represents the impact of climate assistance on energy changes in recipient countries. $energy_{it}$ represents proportion of coal power generation in total power generation ($coalpower_{it}$) and renewable energy power generation ($renewables_{it}$). **Formula (3)** shows the impact of renewable energy development on coal power consumption in developing countries, which can reflect the degree of substitution of the former for the latter. **Formula (4)** shows the impact of renewable energy development in developing countries on coal power consumption under the background of climate assistance.

In order to ensure the comprehensiveness of the regression results, the significance level of the results is also reported here. This paper uses t test for analysis. In addition, to make the research results more logical, this paper presents the subsequent research procedure in the form of a diagram. The specific results are shown in **Figure 3**.

Variable and Data Source Descriptions

Explained variable: the total greenhouse gas carbon emissions equivalent value (CO_2), energy consumption carbon emissions equivalent value ($energyCO_2$). The above two variables are measured by carbon emissions level, and the unit is thousand tons of carbon dioxide equivalent. The reason why the total greenhouse gas carbon emissions equivalent value is selected as the research object is that non carbon dioxide emissions may distort the results of climate change policies. Limiting carbon dioxide emissions in climate change policy analysis will greatly underestimate the actual impact of policies. Therefore, it is necessary to take non-carbon dioxide emissions as the research object (Nong et al., 2021). In addition, because the total carbon emissions can't fully reflect a country's contribution to carbon emissions reduction, this paper makes a supplementary analysis from carbon emissions per capita and carbon emissions per unit of GDP in benchmark regression.

Core explanatory variables: In this paper, we select the climate assistance behavior in 2000 as the core explanatory variable, and the value of the countries receiving assistance is 1¹, otherwise it is 0. In addition, the amount of climate-related development finance, the amount of a climate-related development finance with adaptation (*adapt*), and the amount of a climate-related development finance with mitigation (*mitigate*) are also regarded as the core explanatory variables in the subsequent test.

Control variable: Considering the great influence of economic factors on carbon emissions, this paper mainly identifies and controls carbon emissions from the perspectives of economic development, consumption, and investment and trade activities,

¹Considering the integrity of the data, this paper eliminates the countries with serious data gaps. There are 145 recipient countries finally included in the analysis of this paper. A list of specific countries is presented in the appendix.

TABLE 1 | Descriptive statistical analysis of major variables.

Variable	Variable meaning	Computing method	Mean	Sd
CO ₂	the total greenhouse gas carbon emissions equivalent value	logarithm of total greenhouse gas emissions thousand tons of carbon dioxide equivalent	2.2531	4.3945
energyCO ₂	energy consumption carbon emissions equivalent value	logarithm of energy consumption emissions thousand tons of carbon dioxide equivalent	2.0998	4.1522
perCO ₂	greenhouse gas emissions thousand tons of carbon dioxide equivalent per capita	logarithm of greenhouse gas emissions thousand tons of carbon dioxide equivalent per capita	0.7808	1.5896
perenergyCO ₂	energy consumption emissions thousand tons of carbon dioxide equivalent per capita	logarithm of energy consumption emissions thousand tons of carbon dioxide equivalent per capita	0.6510	1.4072
gdpCO ₂	greenhouse gas emissions thousand tons of carbon dioxide equivalent per unit of GDP	logarithm of greenhouse gas emissions thousand tons of carbon dioxide equivalent per unit of GDP	1.9152	3.7373
gdperenergyCO ₂	energy consumption emissions thousand tons of carbon dioxide equivalent per unit of GDP	logarithm of energy consumption emissions thousand tons of carbon dioxide equivalent per unit of GDP	1.7626	3.4932
CRF	climate-related development finance	recipient country or not, dummy variable (0,1)	0.5386	0.4985
GDP	gross domestic product	logarithm of GDP amount	4.3805	2.228
GDP ²	GDP square	logarithm of the square of GDP	24.1526	20.7653
priconsum	private consumption	logarithm of household consumption	3.9283	2.1984
pubconsum	public consumption	logarithm of government consumption	2.5093	2.1146
grosscapital	total capital formation	logarithm of total capital formation	2.8833	2.2681
fixedcapit	fixed capital formation	logarithm of fixed capital formation	2.8296	2.2536
export	total exports	logarithm of total exports	3.1594	2.3769
import	total imports	logarithm of total imports	3.4605	2.0555
urban	urbanization level	(urban population/total population)*100	3.8404	0.5023
island	island country and region	island or not, dummy variable (0,1)	0.3121	0.4634
poordegree	poorest countries	poorest country or not, dummy variable (0,1)	0.2832	0.4506
coalpower	proportion of coal power generation in total	proportion of coal power generation in total	29.1878	31.8574
renewables	renewable energy power production capacity	renewable energy power production capacity	0.6825	7.2038
researcher	researcher	logarithm of researcher	5.8437	1.4452
adapt	climate adaptation related funds	sum of annual climate adaptation assistance	0.2156	0.9334
mitigate	climate mitigation related funds	sum of annual climate mitigation assistance	0.5043	2.4836

Source: by the author.

respectively, using GDP (*GDP*) (Wang, 2011) and its square (*GDP*²) (Acaravci and Ozturk, 2010), household consumption expenditure (*priconsum*) (Nonhebel and Moll, 2008), government consumption expenditure (*pubconsum*), total capital (*grosscapital*), fixed capital (*grossfixedcapit*), as well as export (*export*) and import (*import*) (Ferdousi and Qamruzzaman, 2017) to express the correlation. In addition, this paper believes that the degree of urbanization has a direct impact on regional energy consumption (Liu, 2009). Therefore, this paper uses the proportion of urban population in the total population to measure the degree of urbanization (*urban*) and adds it into the control variables.

This paper addresses developing countries, and the original data of climate-related development finance comes from the open database of the OECD². The data related to carbon emissions are mainly from Wind database. The data of proportion of coal power generation in total and renewable energy power production capacity are mainly from the World Bank (WB). The rest of the data comes from the public data collected by the United Nations Statistics Division (UNSD). In this study, all the variables involved were analyzed using descriptive statistics. The

mean of a variable represents the average level of all countries under this variable, and standard deviation represents dispersion degree of data of all countries under this variable. Since many variables need to be placed in the same model for analysis, a large numerical gap between variables may impact the stability of regression results. The mean value in a reasonable range shows that the relationship between variables is stable, which is conducive to improving the scientificity of regression results. Standard deviation in a reasonable range indicates that there is no abnormal value and the data is reliable. It can be seen that the values of all the variables were in a reasonable range, which shows that the variables selected in this study were effective. The specific results are shown in **Table 1**.

EMPIRICAL RESULTS AND DISCUSSION

Impact of Climate-Related Development Finance Behavior on Carbon Emissions: DID Estimates

This paper estimated model (1) to evaluate the effect of the assistance behavior of climate-related funding on the carbon emissions of recipients. The results are shown in **Table 2**. As can be seen from columns (1)–(2), the assistance behavior of climate-related development finance had an inhibitory effect on the total greenhouse gas carbon emissions equivalent value and

²This paper only collates the information of the countries with clear assistance objectives and excludes the other countries without clear assistance objectives.

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TABLE 2 | The impact of the assistance behavior of climate-related development finance on carbon emissions of recipient countries.

	CO₂	energyCO₂	perCO₂	perenergyCO₂	gdpCO₂	gdpenenergyCO₂
	(1)	(2)	(3)	(4)	(5)	(6)
CRF	-0.6800*** (0.2154)	-0.6034*** (0.1957)	-0.2110*** (0.0771)	-0.1505** (0.0636)	-0.5364*** (0.1845)	-0.4618*** (0.1645)
GDP	0.4738 (0.4460)	0.2505 (0.4051)	0.2334 (0.1596)	0.1139 (0.1316)	0.4967 (0.3820)	0.2303 (0.3406)
GDP ²	-0.0123 (0.0140)	-0.0130 (0.0128)	-0.0023 (0.0050)	-0.0039 (0.0041)	-0.0122 (0.0120)	-0.0132 (0.0107)
priconsum	-0.5427* (0.3120)	-0.5118* (0.2834)	-0.2880*** (0.1117)	-0.2353** (0.0921)	-0.5197* (0.2672)	-0.4753** (0.2383)
pubconsum	-0.0885 (0.1749)	0.0410 (0.1588)	0.0585 (0.0626)	0.0895* (0.0516)	-0.0884 (0.1498)	0.0440 (0.1336)
grosscapital	-0.1342 (0.2590)	0.0184 (0.2352)	-0.0047 (0.0927)	0.0786 (0.0764)	-0.1216 (0.2218)	0.0248 (0.1978)
fixedcapit	-0.0888 (0.2662)	-0.1895 (0.2418)	-0.1044 (0.0953)	-0.1383* (0.0785)	-0.0930 (0.2280)	-0.1710 (0.2033)
export	-0.2317 (0.1805)	-0.0649 (0.1640)	-0.0820 (0.0646)	0.0188 (0.0533)	-0.2617* (0.1546)	-0.0645 (0.1379)
import	0.4209* (0.2531)	0.2874 (0.2299)	0.1931** (0.0906)	0.1077 (0.0747)	0.4321** (0.2168)	0.2737 (0.1933)
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Region fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
_cons	3.4511*** (0.7412)	3.5917*** (0.6731)	1.0540*** (0.2652)	0.9785*** (0.2187)	2.8670*** (0.6348)	3.0838*** (0.5661)
N	4,746	4,746	4,746	4,746	4,746	4,746
F	21.7255	21.0733	17.3932	14.3128	22.0247	21.4325
r2_a	0.1081	0.1041	0.0812	0.0610	0.1099	0.1063

Note: *, **, *** are significant at the level of 10, 5 and 1%, respectively; In parentheses is the value of standard error.

energy consumption carbon emissions equivalent value of recipient countries, and above results passed the 1% significance level test (the *p*-values here are all 0.002), respectively. Specifically, there was a unit of assistance behavior of climate-related development finance, the total greenhouse gas carbon emissions equivalent value in recipient countries will be reduced by 68%, while energy consumption carbon emissions equivalent value will be reduced by 60%. This shows that assistance behavior of climate-related development finance can effectively reduce the carbon emissions level of recipient countries and improve their climate governance status. Because the total carbon emissions can't fully reflect a country's contribution to carbon emission reduction, this paper makes a supplementary analysis from carbon emissions per capita and carbon emissions per unit of GDP. The specific results are listed in column (3)—(6). It can be seen that climate assistance behavior also helps to reduce carbon emissions per capita and carbon emissions per unit of GDP in recipient countries, which demonstrates that the climate assistance behavior of developed countries to developing countries is effective in reducing local carbon emissions.

The reason for this result may be that the economic development level of developing countries is generally low and their financial strength is weak, particularly given the limited financial support for addressing the challenges of climate change. The financial support provided by developed countries eliminates, to some extent, the financing gap of climate finance in developing countries. This provides more opportunities for exploring feasible ways to reduce carbon

dioxide and, thus, directly promotes the realization of carbon emission reduction in these countries. Additional data analysis revealed that the number of developing countries receiving assistance expanded from 93 in 2000 to 145 in 2017, and the support for climate-related development finance for developing countries increased from 398 million dollars in 2000 to 56 billion dollars in 2017. This demonstrates that it is the support of external capital inflow that promotes the realization of carbon emission reduction effects in developing countries.

It is necessary for developed countries to provide climate assistance to developing countries. Most developing countries mainly rely on the development of fossil energy such as coal to promote economic development (Akram et al., 2020). This model of sacrificing the environment for economic growth is an important reason that restricts them to achieving good results in climate governance. Therefore, promoting the process of climate assistance to developing countries can provide them with sufficient funds from the outside, so that the funds can flow into the fields of environmental governance, renewable energy development, education and scientific research, fundamentally change their economic development model, and then achieve sustainable development. In addition, climate governance is a problem that all countries in the world need to face. Therefore, climate assistance from developed countries to developing countries is a new attempt to jointly address the challenge of climate change, which is conducive to give full play to the financial and technological advantages of developed countries, and mobilize more developing countries to participate in the process of climate governance, so as to

TABLE 3 | The impact of assistance behavior of climate-related development finance on carbon emissions of recipient countries under different climate vulnerabilities.

	CO ₂	CO ₂	energyCO ₂	energyCO ₂
	(1)	(2)	(3)	(4)
CRF*island	-0.2942 (0.2703)		-0.1530 (0.2427)	
CRF*nonisland		-0.8755*** (0.3032)		-0.8337*** (0.2762)
Control variable	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Region fixed effect	Yes	Yes	Yes	Yes
_cons	1.2875 (0.8153)	5.4659*** (1.1049)	1.9266*** (0.7322)	5.2343*** (1.0065)
N	1,480	3,266	1,480	3,266
F	7.3388	16.7354	6.7011	16.4168
r2_a	0.1059	0.1210	0.0933	0.1183

Note: *, **, *** are significant at the level of 10, 5 and 1%, respectively; In parentheses is the value of standard error.

promote the faster realization of the global carbon emission reduction target. Therefore, assistance of climate-related fund is necessary and effective at present.

Heterogeneity Analysis of the Impact of the Assistance Behavior of Climate-Related Development Finance on Carbon Emissions

Heterogeneity analysis of island countries and non-island countries. The essence of developed countries' assistance behavior in regard to climate-related development finance to developing countries is that they help developing countries jointly cope with the challenges brought about by climate change. Thoughtful analysis shows that the assistance behavior of climate-related development finance effectively reduced carbon emissions in developing countries, but whether this effectiveness fully meets the needs of developing countries requires further discussion. Based on this, this paper divides developing countries into island countries and non-island countries for analysis. The reason why developing countries are divided into island countries and non-island countries here is that this paper attempts to discuss whether climate assistance focuses on such countries threatened by sea-level rise, that is, island countries. Under the influence of climate change, island countries are more vulnerable to the threat of sea level rise and food crisis (Organization, 2008; Bijay et al., 2013). Therefore, from the theoretical perspective, climate assistance should focus more on such countries to help them improve their ability to deal with climate change. The island countries here are mainly composed of Small Island Developing States (SIDS) and other island countries.³

³Here, SIDS includes 43 small island developing States (some small island developing States have been eliminated due to the serious lack of data) and 11 other island developing States. The specific list is presented in detail in the appendix.

Through the comparison, the results (see Table 3) show that compared with island countries, assistance behavior of climate-related development finance had a positive impact on carbon emissions reduction of non-island countries. There was one unit of assistance behavior of climate-related development finance, and the total carbon dioxide equivalent of greenhouse gas emissions in non-island countries will be reduced by 87%, while energy consumption carbon emissions equivalent value will be reduced by 83%. And the above results passed the 1% significance level test (the *p*-values here are 0.004 and 0.003, respectively). Assistance behavior of climate-related development finance also had an inhibitory effect on the carbon emissions reduction of island countries, but the effect is not significant, indicating that the climate governance effect of island countries that are more urgent to deal with the challenge of climate change is not ideal under the background of climate assistance. This result also reflects that climate assistance should focus on island countries more affected by climate change in the future, that is, there is a deviation in the current direction of climate assistance behavior. The foresight report on small island developing States issued by the United Nations Environment Programme (UNEP) in 2014 pointed out that with global warming and the increase in the scale and frequency of natural disasters, 52 small island countries around the world face trillions of dollars of economic losses every year. Extreme climate promotes the rise of sea level, which directly increases the threat of flood and coastal erosion to urban tourism and the damage to infrastructure. The deviation of climate-related development finance direction to island countries makes such countries more passive in climate governance.

This paper combs the island countries and non-island countries involved, and finds that in terms of quantity, the number of island countries is 54, while the number of non-island countries is 119. This makes it easier for climate finance to focus on non-island countries. In addition, developed countries may have assistance preferences in the process of climate assistance, which is closely related to factors such as history, geopolitics, economic and trade relations. Due to relevant factors, island countries are generally not as concerned as other countries. Therefore, island countries may receive less attention in the climate-related development finance. This paper also combs the assistance financing and finds that the total amount of climate financing received by island countries was 38.96 billion dollars from 2000 to 2017. And the total amount of climate financing received by non-island countries was 308.75 billion dollars from 2000 to 2017. This also confirms the speculation that a larger number of non-island countries receive higher attention.

The positive impact of climate assistance on carbon emissions reduction of island countries is not significant. In order to make a more detailed analysis of the situation in the group of island countries and discuss the importance of climate-related development finance inflow, this paper takes island countries as the research object, and divides them into strong climate assistance island countries and weak climate assistance island countries according to the degree of assistance amount to analyze the carbon emissions reduction effect of climate assistance. Through the analysis, it is found that climate assistance has a

more significant impact on the carbon emissions reduction effect of island countries receiving more assistance. The results of total carbon emission and energy carbon emissions passed the significance level test of 5 and 10% respectively (p -values are 0.040 and 0.053, respectively). However, climate assistance has no positive effect on carbon emissions reduction in island countries with less assistance. Therefore, it can be considered that within the group of island countries, the inflow of assistance funds is indeed an important factor affecting the realization of the carbon emissions reduction targets of island countries, so it is necessary to increase the support for climate assistance to island countries. The specific results are shown in **Supplementary Appendix Table A1** of the appendix.

The purpose of climate assistance is to help developing countries in need of better climate governance. Facing the threat of climate change, island countries are more affected by the impact of sea level rise, food crisis and extreme weather on domestic economic development. Therefore, the flow direction and assistance effect of climate assistance fund should focus more on such countries. At present, the effect of climate assistance to island countries is not ideal. On the one hand, it shows that the flow of assistance funds is not inclined to the focus of such countries. On the other hand, it also shows that island countries need more investment in climate governance to produce the target effect. Study has shown that climate-related development finance flowing to developing countries accounts for only 4% of the reported total (Donner et al., 2016), which could be inferred that less funds flow to island countries. Therefore, it is worth discussing whether the direction of climate assistance needs to be adjusted in the future.

Heterogeneity analysis under different economic development levels. The differences in the economic development levels among countries indicate the different needs for aid recipients. Countries with low economic development levels may require more attention and assistance coping with the series of challenges related to climate change. Assistance is an important component of financing for such countries (Bourguignon and Platteau, 2021). Based on this, and in accordance with the list of the least developed countries released by the United Nations in 2014, this paper categorized developing countries into countries with a high degree of economic development and countries with a low degree of economic development,⁴ and then evaluated the assistance effect of recipient countries with different levels of economic development. The specific results are in **Table 4**.

It can be seen that compared with countries with low economic development level, climate assistance behavior had a significant inhibitory effect on carbon emissions of countries with high economic development level. Specifically, there was one unit of assistance behavior of climate-related development finance,

⁴Here, the least developed countries released by the United Nations in 2014 are regarded as countries with low economic development level, while the rest are regarded as countries with high economic development level. This paper takes this as the division standard of national economic level. Among them, there are 48 countries with low economic development level, and the specific list of countries is shown in the appendix.

TABLE 4 | The influence of assistance behavior of climate-related development finance on carbon emissions of recipient countries under different levels of economic development.

	CO ₂	CO ₂	energyCO ₂	energyCO ₂
	(1)	(2)	(3)	(4)
CRF*low	0.4892 (0.9123)		0.3889 (0.7368)	
CRF*high		-0.8168*** (0.2359)		-0.7072*** (0.2203)
Control variable	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Region fixed effect	Yes	Yes	Yes	Yes
_cons	1.6645* (0.9111)	3.7552*** (1.0987)	1.6552** (0.7358)	4.0854*** (1.0263)
N	1,336	3,410	1,336	3,410
F	8.0097	16.1591	8.4239	15.5222
r2_a	0.1328	0.1106	0.1411	0.1052

Note: *, **, *** are significant at the level of 10, 5 and 1%, respectively; In parentheses is the value of standard error.

and the total carbon dioxide equivalent of greenhouse gas emissions in countries with high economic development level will be reduced by 81%, while the carbon dioxide equivalent of energy consumption will be reduced by 70%. And the above results passed the 1% significance level test (the p -values here are all 0.001). However, the effect of climate assistance behavior on carbon emissions reduction in low economic development countries is not ideal. This result shows that climate-related development finance mainly flow to countries with high levels of economic development and insufficient investment in countries with low levels of economic development, indicating that the current direction of climate assistance has deviated. For countries with low economic development level, their coping ability is weak in the face of extreme weather and climate. In 2016, the World bank issued a relevant report pointing out that poverty makes relevant regions unable to resist natural disasters, and at the same time, the emergence of extreme climate will in turn exacerbate the problem of global poverty. It can be seen that it is necessary to pay attention to climate assistance to countries with low economic development level.

As the number of low-economy developing countries in this paper is only 48, the rest are high-economy developing countries. It can be considered that in terms of quantity, developing countries with high economy are more likely to get attention. To confirm this prediction, this paper further analyzed the amount of assistance funds received by these two types of countries, and found that low-economic developing countries received a total of 72.20 billion dollars in climate assistance funds from 2000 to 2017, while high-economic developing countries received 273.41 billion dollars. It is the high economic developing countries that have received more climate funding and attention, so their carbon emissions reduction effect is more significant than that of low economic developing countries.

For countries with low economic development, it is easier to drive economic development by sacrificing the environment and using cheaper fuels such as coal. At the same time, due to the low level of economic development, the funds invested in the field of

climate governance are also very limited. Therefore, the support of the climate-related development finance for the sustainable development of such countries needs to be greater. At present, the impact of climate assistance on carbon emissions reduction in countries with low economic development has not achieved positive results. It can be considered that the attention of climate-related development finance to such countries needs to be further improved, the existing direction of climate assistance should be adjusted, and the number of climate-related development finance for countries with low economic development should be increased, so as to improve the climate governance capacity of such economically vulnerable countries.

ANALYSIS ON THE RELATIONSHIP BETWEEN CLIMATE ASSISTANCE AND ENERGY STRUCTURE CHANGE

It can be seen from the above description that, the climate support behavior of developed countries significantly reduces the carbon dioxide emissions of developing countries. However, for developing countries, the way in which the climate-related development finance supports to achieve the carbon emission target needs further discussion. In other words, clarifying the intermediary transmission mechanism can contribute better grasping the focus and effects of climate-related fund in developing countries. This paper summarizes the specific sectors that have received the climate-related development finance, and found that the field of renewable energy power generation and non-renewable energy power generation is one of the key areas concerned by the climate-related development finance (renewable energy power generation and non-renewable energy power generation belong to transportation, energy and business services sectors), and the change of energy consumption has a great impact on carbon emissions. The success of a country's energy structure transformation is directly related to the realization of carbon emission reduction targets. Therefore, this paper attempts to explore whether climate assistance helps to optimize the energy structure of developing countries from the perspective of the change of energy structure.

Here, the proportion of coal power generation in the total power generation represents the fossil energy consumption in developing countries, and the renewable energy power generation (excluding hydropower) represents the development of renewable energy in developing countries. As the level of urbanization has a direct impact on energy demand, this paper analyzes the impact of climate assistance on energy development by adding the level of urbanization into the control variables. It can be seen in **Table 5** that columns (1)–(2) show the impact of climate assistance on the proportion of coal power generation in total power generation and renewable energy power generation in recipient countries. It can be seen that climate assistance behavior had not played an ideal effect in reducing fossil energy consumption of developing countries, but it promoted the development of renewable energy in developing countries and this result passed the 5% significance level test (the *p*-values here is 0.019).

TABLE 5 | Analysis on the relationship between climate assistance and energy structure change.

	Coalpower (1)	Renewables (2)	Coalpower (3)	Coalpower (4)
CRF	1.0599 (1.3119)	2.9393** (1.2552)		1.2913 (1.3170)
renewables			−0.0383* (0.0212)	
CRF *renewables				−0.0368* (0.0212)
Control variable	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Region fixed effect	Yes	Yes	Yes	Yes
_cons	−40.0572*** (14.5995)	−28.8609*** (9.9976)	−43.6053*** (14.2077)	−40.3344*** (14.5817)
N	871	2045	871	871
F	3.4923	14.9649	3.5784	3.4877
r2_a	0.0442	0.1546	0.0474	0.0466

Note: *, **, *** are significant at the level of 10, 5 and 1%, respectively; In parentheses is the value of standard error.

The reason for this result may be the price advantage of fossil energy and the impact of the development of technology to a certain extent. At present, developing countries mainly use fossil energy to promote economic development (Zhang et al., 2021), which has a large price advantage and market share. Therefore, coal consumption accounts for a large proportion in the development process (Zhang et al., 2018). Under this background, it will take a long time to achieve the “coal withdrawal” process and more external attention and investment are needed to promote the decline of coal consumption in developing countries. Further, with the economic development and the support of climate-related development finance for the development of many sectors, the scientific and technological level of developing countries has been further improved. For renewable energy, its development needs to be supported by capital (Wen et al., 2022) and technology. In this situation, renewable energy in recipient countries is bound to develop rapidly. The high dependence of recipient countries' economic development on fossil energy has brought great challenges to their climate and environmental governance. The consumption of fossil energy dominated by coal is the source of urban air pollution and temperature rise. The frequent occurrence of extreme weather such as high temperature, heat wave and extreme precipitation in cities shows that climate governance is urgent. To fundamentally reverse this phenomenon, it is necessary to accelerate the reduction of developing countries' dependence on fossil energy and vigorously promote the development of renewable energy.

Climate assistance has not achieved the desired effect on the decline of coal consumption in recipient countries, but has played a positive role in the development of renewable energy. Then, could the development of renewable energy help to reduce the proportion of coal consumption? In other words, it is worth discussing whether the development of renewable energy will play a catalytic role in the “coal withdrawal” process of recipient countries. Based on this, this paper further analyzes the

impact of the development of renewable energy on the change of coal consumption in developing countries.

We can see from column (3) that the development of renewable energy helps to reduce the proportion of coal consumption. Specifically, the development of renewable energy will increase by 1 unit, and the proportion of coal power generation will decrease by 0.0383 units, and this results have passed the 10% significance level test (the p -value here is 0.071). In other words, the development of renewable energy has a significant substitution effect on coal. In this paper, the above relationship is tested again under the background of climate assistance. It is found that the development of renewable energy in recipient countries also has a positive substitution for coal under the background of climate assistance. In conclusion, it can be seen that climate assistance reduced carbon emissions by promoting the development of renewable energy in recipient countries and promoting the positive transformation of their energy structure on this basis. The specific results are shown in column (4).

From the above results, it can be seen that under the background of climate assistance, renewable energy in recipient countries has developed rapidly, which has a positive impact on promoting the transformation of energy structure. But it can't be ignored that the process of "coal withdrawal" in recipient countries is still facing great challenges and pressure. In order to more clearly reflect the current situation of fossil energy consumption in developing countries, this paper sorts out the proportion of fossil energy consumption in the total energy consumption and the total consumption of hard coal in developing countries.

From the summary of this article, the average consumption proportion of fossil energy in developing countries shows a slow fluctuating upward trend, but the consumption proportion has declined in some years. From the numerical point of view, the proportion of fossil energy consumption exceeds 50%. From the total consumption of hard coal in developing countries, it can be seen that the consumption of hard coal has shown an upward trend since 2000, peaked in 2015, and then began to decline in 2016. To sum up, developing countries are still heavily dependent on fossil energy, but there is a trend and possibility to reduce fossil energy consumption. Therefore, under the climate assistance background, how to better promote the overall "coal withdrawal" process in developing countries and realize the greater substitution of renewable energy for fossil energy become the key to solve the problem of climate governance in developing countries. The specific results are shown in **Supplementary Appendix Figure A1** and **Supplementary Appendix Figure A2** of the appendix.

DISCUSSION

Impact of Climate-Related Development Finance on Science and Technology Development in Developing Countries

Climate assistance has a positive impact on the development of renewable energy in developing countries, so the way to achieve

this result is worthy of in-depth discussion. As the development of renewable energy requires high technology, the level of science and technology could be regarded as the key to the development of renewable energy (Geng and Ji, 2016). And after sorting out the key areas of climate assistance, this paper found that climate-related development finance of developed countries pay special attention to the education field of developing countries (this field is included in department of education, health and infrastructure). Education is the basic support for a country's scientific research and development, which helps to improve the quality of human capital and promote the realization of scientific and technological innovation (Dakhli and De, 2004; Wu, 2006; Xu et al., 2006). The inflow of climate-related development finance into the field of education can be regarded as support for the scientific and technological development of the recipient country. Therefore, the research on the current situation of science and technology development in recipient countries under climate assistance will help this paper further understand the reasons for the rapid development of renewable energy.

Based on this background, from the perspective of science and technology, this paper attempts to deeply explore the impact of climate-related development finance on the scientific and technological level of developing countries, so as to better identify the key factors promoting the positive transformation of energy structure. This paper selects the number of scientific researchers in developing countries as the proxy variable of scientific and technological level. In addition, because the impact of different types of climate-related development finance may be different, this paper analyzes the impact of the development of total climate-related development finance (*totalfund*), adaptive climate-related development finance (*adapt*) and mitigation climate-related development finance (*mitigate*) on technology development respectively. As shown in **Table 6**.

From columns (1)–(2), it can be seen that climate-related development finance helps to promote the increase of the number of scientific researchers in recipient countries, indicating that climate-related development finance has a positive impact on promoting the improvement of scientific and technological level of recipient countries (the p -values here are 0.013 and 0.065, respectively). Columns (3)–(6) show impact of the adaptation and mitigation climate-related development finance on the number of scientific researchers in the recipient country. Whether from the regression coefficient or significant results, the development of the adaptation climate-related development finance has a more positive impact on the increase of the number of scientific researchers in the recipient country (the p -values here are 0.034 and 0.095, respectively). In other words, compared with the mitigation climate-related development finance, the development of adaptive climate-related development finance plays a greater role in promoting the technological progress of recipient countries. In conclusion, the increase of climate-related development finance can indeed have a positive impact on the improvement of scientific and technological level in developing countries, and technological progress plays an important supporting role in the development of renewable energy.

TABLE 6 | Impact of climate-related development finance on science and technology development in developing countries.

	Researcher (1)	Researcher (2)	Researcher (3)	Researcher (4)	Researcher (5)	Researcher (6)
totalfund	0.0093** (0.0037)	0.0082* (0.0044)				
adapt			0.0271** (0.0128)	0.0239* (0.0143)		
mitigate					0.0099** (0.0044)	0.0076 (0.0050)
Control variable	No	Yes	No	Yes	No	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Region fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
_cons	5.4651*** (0.0687)	6.7689*** (1.3894)	5.4607*** (0.0688)	6.6317*** (1.3805)	5.4646*** (0.0688)	6.5871*** (1.3811)
N	702	457	702	457	702	457
F	12.5080	11.5704	12.3777	11.5271	12.4081	11.4918
r2_a	0.1411	0.3258	0.1386	0.3247	0.1392	0.3237

Note: *, **, *** are significant at the level of 10, 5 and 1%, respectively; In parentheses is the value of standard error.

Therefore, it can be considered that the impact of climate assistance on renewable energy in developing countries is mainly achieved by promoting the improvement of local technological level.

It is necessary to promote inflow of climate-related development finance into field of education in developing countries, and the development of adaptive climate-related development finance is indispensable. To fundamentally promote the transformation of the economic development model of developing countries and gradually reduce their dependence on fossil energy dominated by coal, it needs to vigorously improve the utilization efficiency of energy (Sarkar and Singh, 2010) and the substitution of renewable energy, which all need to be based on the improvement of technical level. The sustainable development of cities needs to balance the relationship between economy and environment, and technological innovation is the key to achieve the balance between the two. On the premise of ensuring the level of economic development, the improvement of technical level can improve energy utilization efficiency, promote the reduction of fossil energy consumption, lay a technical foundation for the development of renewable energy, and finally achieve the goal of environmental protection. Therefore, to promote the improvement of urban climate and environment in developing countries and reduce the frequency of extreme weather, so as to maintain the sustainable development model, we need to fundamentally improve the technical level. The development of education can provide a strong foundation for the training of scientific researchers and the improvement of technical level in a country. Therefore, paying attention to the investment in education in developing countries and guiding the climate-related development finance to flow more into the field of education is the fundamental policy to promote the sustainable transformation and development of developing countries in the long term.

Through the above analysis, it can be seen that different types of climate-related development finance have different results in supporting local technology development. Compared with the

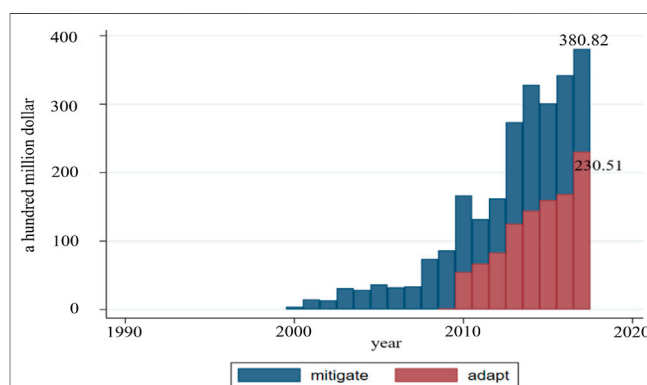


FIGURE 4 | Development comparison of mitigation and adaptation climate-related development finance. Data source: official website of Organization for Economic Co-operation and Development (OECD) (<https://www.oecd.org/>).

mitigation climate-related development finance, the effect of the adaptive climate-related development finance is more significant. In view of this result, this paper makes a comparative analysis on the development trend of these two types of climate-related development finance, trying to clarify the relationship between this result and the development of assistance amount, that is, does the positive effect of adaptive climate assistance also mean that this type of assistance amount is higher? So as to clarify whether there is a deviation from the current assistance direction. The specific results are shown in **Figure 4**.

It can be seen that the mitigation climate-related development finance has been paid attention to since 2000, and has shown a rapid upward trend. By 2017, the amount of assistance in this field has exceeded 38 billion US dollars. The development of adaptive climate assistance started late and the development speed is relatively slow. In 2017, the amount of assistance received in this field was about 23 billion dollars. Combined with the results in **Table 6**, it is not difficult to find that the field of adaptive climate has received less attention, but it has a better positive

TABLE 7 | Impact of different types of climate-related development finance on changes in carbon emissions and renewable energy in recipient countries.

	CO ₂	CO ₂	energyCO ₂	energyCO ₂	Renewables	Renewables
	(1)	(2)	(3)	(4)	(5)	(6)
adapt	-0.0905* (0.0505)		-0.0845* (0.0458)		0.4988*** (0.1191)	
mitigate		-0.0268 (0.0200)		-0.0291 (0.0181)		0.3945*** (0.0466)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Region fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
_cons	3.3555*** (0.7463)	3.3627*** (0.7416)	3.5219*** (0.6769)	3.5242*** (0.6734)	3.2775* (1.7586)	2.6191 (1.7332)
N	4,698	4,746	4,698	4,746	4,698	4,746
F	21.1712	21.4604	20.5012	20.8488	16.2511	18.0664
r2_a	0.1059	0.1065	0.1017	0.1028	0.0747	0.0855

Note: *, **, *** are significant at the level of 10, 5 and 1%, respectively; In parentheses is the value of standard error.

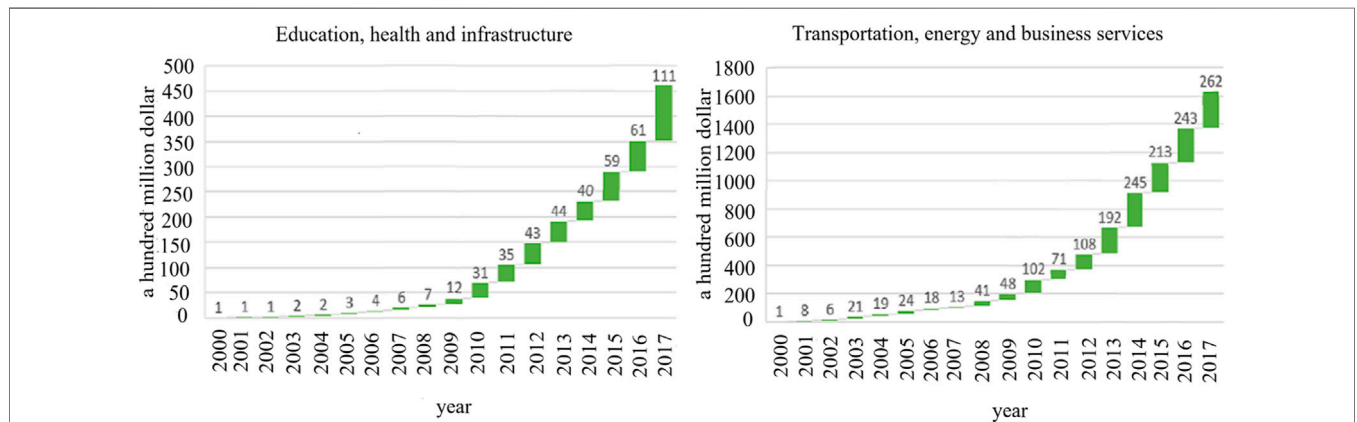


FIGURE 5 | Support of climate-related development finance for sectors I and II. Data source: official website of Organization for Economic Co-operation and Development (OECD) (<https://www.oecd.org/>).

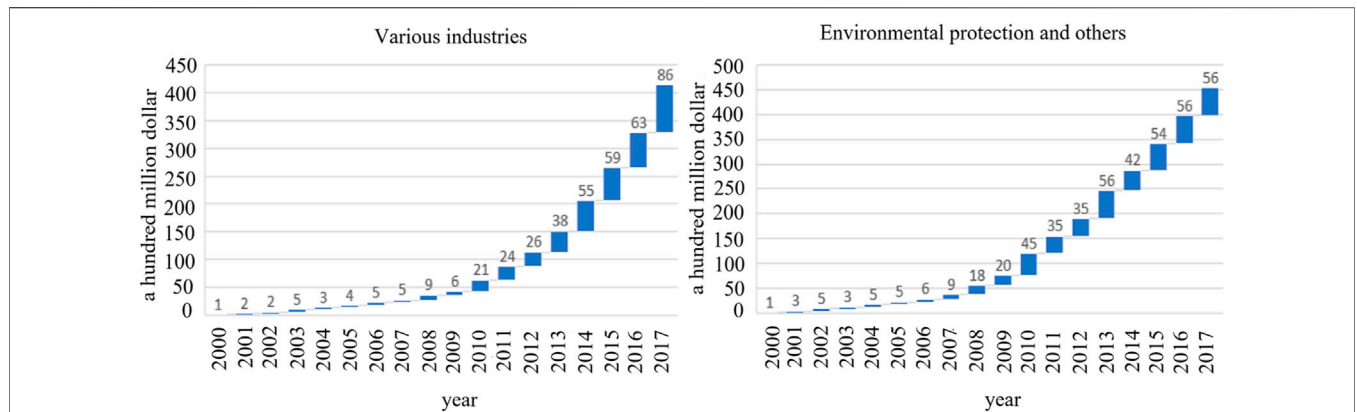
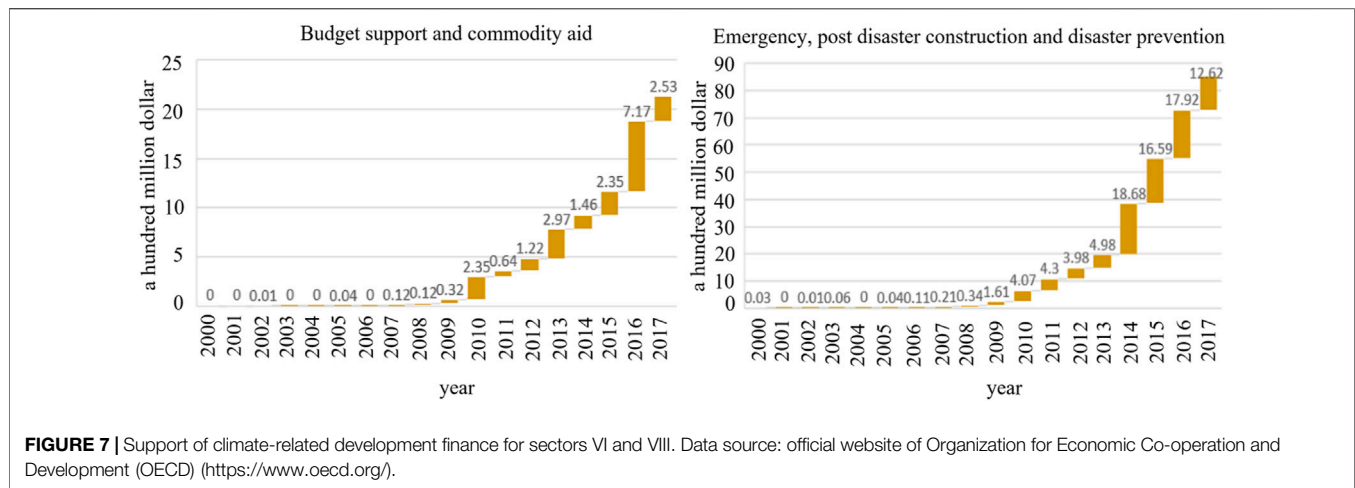


FIGURE 6 | Support of climate-related development finance for sectors III and IV. Data source: official website of Organization for Economic Co-operation and Development (OECD) (<https://www.oecd.org/>).



impact on the technological development of developing countries. Therefore, whether more attention needs to be paid to adaptive climate is worth discussing.

Analysis on the Impact of Different Types of Climate-Related Development Finance and Assistance Received by Different Sectors

In view of the large differences in the scale of climate-related development finance flowing into the two fields of climate adaptation and climate mitigation, this paper analyzes the carbon emission reduction results and the development impact of renewable energy brought by the two types of climate-related development finance, and tries to compare the effectiveness of the results brought by the current focus on the fields of climate adaptation and climate mitigation to better evaluate the development status of the two types of climate assistance. The specific results are shown in **Table 7**.

Columns (1)—(4) show the impact of these two types of climate-related development finance on carbon emissions of recipient countries. It can be seen that the development of these two types of climate-related development finance helps to reduce carbon emissions of recipient countries, but the emissions reduction effect brought by adaptive climate assistance is more significant, and the result passed the 10% significance level test (the p -values here are 0.073 and 0.065, respectively). From columns (5)—(6), it can be seen that these two types of climate-related development finance have a positive role in promoting the development of renewable energy in recipient countries (the p -values here are 0.000), but by comparing the regression coefficient, it is found that the promotion effect of adaptive climate assistance is better. Combined with **Figure 4**, this paper believes that under the background of more mitigation climate-related development finance, its impact on carbon emissions reduction and renewable energy development is not as good as that brought by the adaptation climate-related development finance. In the face of extreme weather in cities, it is particularly important to adapt to the climate. In order to cope with possible floods, the construction of urban coastline and the improvement of urban infrastructure are an important part of adapting to the climate. At the same time, in order to reduce the adverse effects of extreme

drought, rational allocation of urban water and agricultural irrigation water is also a typical way to adapt to climate change. Better adaptation to the climate is conducive to the sustainable development of all cities. So the current attention to adaptive climate assistance should be further improved (Pauw, 2021).

The support of climate-related development finance is the basis for promoting climate governance and the development of specific recipient sectors in recipient countries. Therefore, it is very necessary to study the preference and direction of fund inflow. From the perspective of different types of climate assistance, we have carried out a detailed analysis of the trend of fund inflow and its impact on carbon emissions reduction. And does the fund have a certain preference and focus on the inflow of different sectors? Based on this, this paper analyzes the current focus of climate-related development finance on key sectors. Due to the large difference in the amount of climate assistance received by recipient departments, this paper presents it through two figures. The specific results are shown in **Figure 5**, **Figure 6** and **Figure 7**.

Through comparison, it can be seen that the four sectors “Education, health and infrastructure,” “Transportation, energy and business services,” “Various industries” and “Environmental protection and others” receive more climate-related development finance, and the development of climate-related development finance is faster, especially the two sectors “Education, health and infrastructure” and “Transportation, energy and business services” receive more attention. The two sectors “Budget support and commodity aid” and “Emergency, post disaster construction and disaster prevention” received less attention. It can be seen that climate assistance is more focused on environmental related sectors at present, such as transportation and energy. Therefore, there is no deviation in the current direction of climate assistance in support of specific sectors.

CONCLUSION

Taking developing countries as the research object, this paper uses the differences-in-differences method (DID) to identify the

causality of the impact of climate assistance behavior in developed countries on carbon emissions in developing countries. Through the research, it is found that climate assistance could significantly reduce the carbon emissions level of recipient countries, indicating that the promotion of climate assistance is necessary. First, this paper proves the conclusion that climate assistance behavior helps to reduce the carbon emissions level of recipient countries through DID method, that is to say, climate assistance behavior has been affirmed. Second, from the perspective of the quantity of climate financing, this paper further analyzes the carbon emissions reduction effects of the two types of climate financing to illustrate the significance of climate finance flows to recipient countries. Finally, it can be seen from **Figure 2** that the scale of climate financing shows an expanding trend. Combined with the previous analysis, this paper believes that the existence and scale expansion of climate financing have a positive impact on the realization of carbon emissions reduction targets of recipient countries. However, the impact of this result on island types and recipient countries with low level of economic development has not achieved the desired effect. The positive impact of climate assistance on carbon emissions reduction in recipient countries is mainly realized by promoting the transformation of energy structure in target countries. Furthermore, climate-related development finance plays a positive role in promoting the technical level of recipient countries, especially the development of the adaptive climate-related development finance. Meanwhile, compared with the mitigation climate-related development finance, adaptation climate-related development finance has a more positive effect on carbon emissions reduction and renewable energy development. In addition, the climate-related development finance is mostly directed to the fields of transportation, energy and education at present.

This paper systematically analyzes the current situation, impact effects and existing problems of the “South-North cooperation” climate governance model, in order to provide reference for the rational adjustment and improvement of the direction of climate assistance in the future, and provide empirical support for further improving the enthusiasm of climate assistance in developed countries and guiding more developing countries to participate in the process of global climate governance. The frequent occurrence of extreme weather caused by climate change poses a great threat to the economic development and ecological protection of countries all over the world. In the face of extreme weather and climate, countries need to strengthen financial and technical cooperation and jointly contribute wisdom in exploring diversified and effective climate governance models. The specific conclusions are as follows:

First, climate assistance can significantly reduce the total carbon emissions equivalent of greenhouse gases and carbon emissions equivalent of energy consumption in recipient countries, and this result does not change in the analysis of carbon emissions per capita and carbon emissions per unit GDP. For the achievement of carbon emissions reduction target, it has a better effect on non-island countries and countries with high degree of economic development. The existence of climate

assistance is meaningful, and the assistance of developed countries to climate governance in developing countries should be further promoted, including the amount of investment in the climate-related development finance and the scope of developing countries assisted. Further increasing the amount of developed countries’ investment in climate assistance and expanding the scope of benefits can better supplement the funding gap for climate governance in developing countries, and lay a foundation and provide a bridge for mobilizing more countries to participate in climate governance. At the same time, the direction of climate assistance should be adjusted, focusing on island countries and countries with low economic development that are more urgent to deal with the challenge of climate change, and giving more attention and financial support to these two types of countries to help regions with more dangerous situations better deal with climate change.

Second, climate assistance helps to promote the transformation of energy structure in recipient countries. Specifically, it promotes the development of renewable energy in recipient countries and significantly promotes the substitution of renewable energy for coal consumption, which provides important support for developing countries to achieve carbon emission reduction targets. But it could not be ignored that direct impact of climate assistance in promoting the process of “coal withdrawal” in recipient countries is still very limited. At present, the consumption of fossil energy in developing countries is still large, but it shows a downward trend. Under this background, climate assistance should increase investment and subsidies in renewable energy and other clean energy in developing countries and improve their market competitiveness and price advantage to accelerate their substitution for fossil energy. And helping developing countries improve the utilization efficiency of fossil energy represented by coal, reduce their dependence on coal, and then promote the process of “coal withdrawal.”

Third, climate-related development finance helps to improve the scientific and technological level of developing countries, especially the development of the adaptive climate-related development finance, which makes it possible to promote the development of renewable energy and the transformation of energy structure in developing countries. The amount and development speed of mitigation climate-related development finance are higher than that of the adaptation climate-related development finance, but the latter has a better impact on carbon emission reduction and renewable energy development. In addition, the inflow sectors of climate-related development finance are mainly concentrated in transportation, energy, education and other sectors, indicating that there is no deviation in the assistance direction focusing on specific sectors. At present, the amount of the two types of climate-related development finance should be appropriately adjusted, and more attention should be paid to climate adaptation assistance. For developing countries, especially those that are particularly urgent to deal with the climate crisis, better adaptation to climate change in a certain period of time is more meaningful to ensure their lives and promote economic development. At the same time, increase the inflow of climate assistance funds to developing countries in the fields of transportation, energy and education, promote the

development of sectors related to the environment, and vigorously supporting the development of education will help lay the foundation for the progress of science and technology in developing countries.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

NL: Conceptualization, Methodology, Formal analysis, and Writing—original draft. BS: Conceptualization, Methodology, Formal analysis, and Writing—original draft. LW: Data curation, Visualization, and Writing—original draft. RK:

REFERENCES

- Acaravci, A., and Ozturk, I. (2010). On the Relationship between Energy Consumption, CO₂ Emissions and Economic Growth in Europe. *Energy* 35, 5412–5420. doi:10.1016/j.energy.2010.07.009
- Akram, R., Chen, F., Khalid, F., Ye, Z., and Majeed, M. T. (2020). Heterogeneous Effects of Energy Efficiency and Renewable Energy on Carbon Emissions: Evidence from Developing Countries. *J. Clean. Prod.* 247, 119122. doi:10.1016/j.jclepro.2019.119122
- Andric, I., Muammer, K., and Sami, G. A. (2019). A Review of Climate Change Implications for Built Environment: Impacts, Mitigation Measures and Associated Challenges in Developed and Developing Countries. *J. Clean. Prod.* 20, 83–102. doi:10.1016/j.jclepro.2018.11.128
- Arsum, P. A., Philip, E. A., Van, B., Fenda, A. A., Akiwumi, B., and Kenyon, C. L. (2020). Impacts of Climate Change on the Tourism Sector of a Small Island Developing State: A Case Study for the Bahamas. *Environ. Dev.* 37 (5964), 100556. doi:10.1016/j.envdev.2020.100556
- Betzold, C., and Weiler, F. (2017). Allocation of Aid for Adaptation to Climate Change: Do Vulnerable Countries Receive More Support? *Int. Environ. Agreements* 17, 17–36. doi:10.1007/s10784-016-9343-8
- Bijay, P., Filho, W. L., and Schulte, V. (2013). “Understanding the Links between Climate Change and Disaster Management in Pacific Island Countries,” in *Climate Change Management* (Berlin, Heidelberg: Springer), 55–69. doi:10.1007/978-3-642-31110-9_4
- Bourguignon, F., and Platteau, J. P. (2021). Aid Allocation: The Role of External Discipline. *Int. Econ.* doi:10.1016/j.inteco.2021.06.008
- Brunner, S., and Enting, K. (2014). Climate Finance: a Transaction Cost Perspective on the Structure of State-To-State Transfers. *Glob. Environ. Change* 27, 138–143. doi:10.1016/j.gloenvcha.2014.05.005
- Chen, L., Wang, W. T., Zhu, L. C., and Zhang, D. W. (2019a). The Role and Development of Green Climate Fund in the Global Climate Governance System. *Progressus Inquisitiones de Mutatione Clim.* 15, 326–334. doi:10.12006/j.issn.1673-1719.2018.138
- Chen, L., Zhang, D. W., and Zhu, L. C. (2019b). Global Climate Financing Situation and Prospect. *Environ. Prot.* 1, 33–38.
- Clark, R., Reed, J., and Sunderland, T. (2018). Bridging Funding Gaps for Climate and Sustainable Development: Pitfalls, Progress and Potential of Private Finance. *Land Use Policy* 71, 335–346. doi:10.1016/j.landusepol.2017.12.013
- Dakhli, M., and De Clercq, D. (2004). Human Capital, Social Capital, and Innovation: a Multi-Country Study. *Entrepreneurship Reg. Dev.* 16, 107–128. doi:10.1080/08985620410001677835

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fenvs.2021.778254/full#supplementary-material>

- Dong, F., Dai, Y., Zhang, S., Zhang, X., and Long, R. (2019). Can a Carbon Emission Trading Scheme Generate the Porter Effect? Evidence from Pilot Areas in China. *Sci. Total Environ.* 653, 565–577. doi:10.1016/j.scitotenv.2018.10.395
- Donner, S. D., Kandlikar, M., and Webber, S. (2016). Measuring and Tracking the Flow of Climate Change Adaptation Aid to the Developing World. *Environ. Res. Lett.* 11, 054006. doi:10.1088/1748-9326/11/5/054006
- Dumisani, C. (2016). Moving Past the Rhetoric: Policy Considerations that Can Make Sino-African Relations to Improve Africa's Climate Change Resilience and the Attainment of the Sustainable Development Goals. *Adv. Clim. Change Res.* 7, 253–263. doi:10.1016/j.accre.2016.11.002
- Ferdousi, F., and Qamruzzaman, M. (2017). Export, Import, Economic Growth, and Carbon Emissions in Bangladesh: a Granger Causality Test under VAR (Restricted) Environment. *Manage. Cities Reg. Chapters.* doi:10.5772/intechopen.70782
- Ferraro, P. J., and Pattanayak, S. K. (2006). Money for Nothing? A Call for Empirical Evaluation of Biodiversity Conservation Investments. *Plos Biol.* 4, e105. doi:10.1371/journal.pbio.0040105
- Geddes, A., Schmid, N., Schmidt, S. T., and Steffen, B. (2020). The Politics of Climate Finance: Consensus and Partisanship in Designing green State Investment banks in the United Kingdom and Australia. *Energy Res. Soc. Sci.* 69, 101583. doi:10.1016/j.erss.2020.101583
- Geng, J. B., and Ji, Q. (2016). Technological Innovation and Renewable Energy Development: Evidence Based on Patent Counts. *Ijgenvi* 15, 217. doi:10.1504/ijgenvi.2016.076945
- Guggisberg, S. (2019). Funding Coastal and marine Fisheries Projects under the Climate Change Regime. *Mar. Pol.* 107, 103352.1–103352.10. doi:10.1016/j.marpol.2018.11.015
- Ha, S., Hale, T., and Ogden, P. (2016). Climate Finance in and between Developing Countries: an Emerging Opportunity to Build on. *Glob. Pol.* 7, 1. doi:10.1111/1758-5899.12293
- Halsnæs, K. (1996). The Economics of Climate Change Mitigation in Developing Countries. *Energy Policy* 24, 917–926. doi:10.1016/s0301-4215(96)80357-0
- Hargrove, A., Qandeel, M., and Sommer, J. M. (2019). Global Governance for Climate justice: A Cross-National Analysis of CO₂ Emissions. *Glob. Transitions* 1, 190–199. doi:10.1016/j.glt.2019.11.001
- Hu, Y.-c., Zhou, W., and Yuan, T. (2018). Environmental Impact Assessment of Ecological Migration in China: a Survey of Immigrant Resettlement Regions. *J. Zhejiang Univ. Sci. A.* 19, 240–254. doi:10.1631/jzus.a1600669
- Keho, Y. (2016). What Drives Energy Consumption in Developing Countries? the Experience of Selected African Countries. *Energy Policy* 91, 233–246. doi:10.1016/j.enpol.2016.01.010

- Khan, M., Robinson, S.-a., Weikmans, R., Ciplet, D., and Roberts, J. T. (2020). Twenty-Five Years of Adaptation Finance through a Climate justice Lens. *Clim. Change* 161, 251–269. doi:10.1007/s10584-019-02563-x
- Kosmo, M. (1989). Commercial Energy Subsidies in Developing Countries Opportunity for Reform. *Energy Policy* 17, 244–253. doi:10.1016/0301-4215(89)90049-9
- Kovacevic, R. (2004). The Position of Developing Countries in International Trade. *Ekonomika* 49, 65–97. doi:10.2298/eka0462065k
- Li, X., Zhou, Y., Asrar, G. R., Imhoff, M., and Li, X. (2017). The Surface Urban Heat Island Response to Urban Expansion: A Panel Analysis for the Conterminous United States. *Sci. Total Environ.* 605–606, 426–435. doi:10.1016/j.scitotenv.2017.06.229
- Li, N., Shi, B., and Kang, R. (2021). Information Disclosure, Coal Withdrawal and Carbon Emissions Reductions: A Policy Test Based on China's Environmental Information Disclosure. *Sustainability* 13, 9758. doi:10.3390/su13179758
- Liang, Y. C., and Cao, Y. K. (2015). Analysis on the Market Framework of Carbon Emission Trading System in Australia. *World For. Res.* 2, 86–90. doi:10.13348/j.cnki.sjlyyj.2015.02.012
- Liu, Y. (2009). Exploring the Relationship between Urbanization and Energy Consumption in China Using ARDL (Autoregressive Distributed Lag) and FDM (Factor Decomposition Model). *Energy* 34, 1846–1854. doi:10.1016/j.energy.2009.07.029
- McCulloch, N., Moerenhout, T., and Yang, J. (2021). Fuel Subsidy Reform and the Social Contract in Nigeria: A Micro-economic Analysis. *Energy Policy* 156, 112336. doi:10.1016/j.enpol.2021.112336
- Nong, D., Simshauser, P., and Nguyen, D. B. (2021). Greenhouse Gas Emissions vs CO₂ Emissions: Comparative Analysis of a Global Carbon Tax. *Appl. Energ.* 298, 117223. doi:10.1016/j.apenergy.2021.117223
- Nonhebel, S., and Moll, H. C. (2008). The Relationship between Household Expenditures and Environmental Impact. *Energ. Environ. Stud.*, 1–8.
- Organization, A. (2008). Climate Change and Food Security in Pacific Island Countries. *Clim. Change Food Security Pac. Isl. Countries* 40, 301–313. doi:10.1002/9783527665334.ch1
- Ornsaran, P. M., Robbert, B., and Victor, C. (2020). What Makes Internationally-Financed Climate Change Adaptation Projects Focus on Local Communities? A Configurational Analysis of 30 Adaptation Fund Projects. *Glob. Environ. Change* 61, 102035. doi:10.1016/j.gloenvcha.2020.102035
- Ouyang, X., and Lin, B. (2014). Impacts of Increasing Renewable Energy Subsidies and Phasing Out Fossil Fuel Subsidies in China. *Renew. Sustain. Energ. Rev.* 37, 933–942. doi:10.1016/j.rser.2014.05.013
- Pauw, W. P. (2021). The Adaptation Finance gap Can Only Be Closed by Limiting the Adaptation Costs. *One Earth* 4, 1352–1355. doi:10.1016/j.oneear.2021.09.002
- Pickering, J., Skovgaard, J., Kim, S., Roberts, J. T., Rossati, D., Stadelmann, M., et al. (2015). Acting on Climate Finance Pledges: Inter-agency Dynamics and Relationships with Aid in Contributor States. *World Dev.* 68, 149–162. doi:10.1016/j.worlddev.2014.10.033
- Pickering, J., Betzold, C., and Skovgaard, J. (2017). Special Issue: Managing Fragmentation and Complexity in the Emerging System of International Climate Finance. *Int. Environ. Agreements* 17, 1–16. doi:10.1007/s10784-016-9349-2
- Pour, S. H., Wahab, A. K. A., Shahid, S., Asaduzzaman, M. d., and Dewan, A. (2020). Low Impact Development Techniques to Mitigate the Impacts of Climate-Change-Induced Urban Floods: Current Trends, Issues and Challenges. *Sustain. Cities Soc.* 62, 102373. doi:10.1016/j.scs.2020.102373
- Purdon, M. (2017). Neoclassical Realism and International Climate Change Politics: Moral Imperative and Political Constraint in International Climate Finance. *J. Int. Relat. Dev.* 20, 263–300. doi:10.1057/jird.2013.5
- Qi, S. Z., and Wang, B. B. (2013). Initial Quota Allocation of Carbon Trading: a Comparative Analysis of Models and Methods. *Wuhan Univ. J. (Philos. Soc. Sci.)* 5, 19–28.
- Rehman, A., Rauf, A., Ahmad, M., Chandio, A. A., and Zhang, D. Y. (2019). The Effect of Carbon Dioxide Emission and the Consumption of Electrical Energy, Fossil Fuel Energy, and Renewable Energy, on Economic Performance: Evidence from Pakistan. *Environ. Sci. Pollut. Res.* 26, 21760–21773. doi:10.1007/s11356-019-05550-y
- Román, V. M., Arto, I., Ansuategi, A., and Galarraga, I. (2019). The Economic Implications of Tied Aid and Local Content Requirements for Climate Finance. *Clim. Change Econ.* 11, 2050002. doi:10.1142/s2010007820500025
- Román, V. M., Arto, I., and Ansuategi, A. (2016). The Geographic Distribution of the Economic Impact of Climate Finance. Working Papers. 5, BC3.
- Rondinelli, D. A., and Kasarda, J. D. (1992). Foreign Trade Potential, Small enterprise Development and Job Creation in Developing Countries. *Small Business Econ.* 4, 253–265. doi:10.1007/bf00388621
- Sam, B. (2014). Subnational Climate justice? Adaptation Finance Distribution and Climate Vulnerability. *World Dev.* 58, 130–142. doi:10.1016/j.worlddev.2014.01.014
- Sarkar, A., and Singh, J. (2010). Financing Energy Efficiency in Developing Countries—Lessons Learned and Remaining Challenges. *Energy Policy* 38, 5560–5571. doi:10.1016/j.enpol.2010.05.001
- Sarkodie, S. A., and Strezov, V. (2018). Economic, Social and Governance Adaptation Readiness for Mitigation of Climate Change Vulnerability: Evidence from 192 Countries. *Sci. Total Environ.* 15, 150–164. doi:10.1016/j.scitotenv.2018.11.349
- Scandurra, G., Romano, A., Carfora, A., and Ronghi, M. (2017). *Climate Finance as an Instrument to Promote the green Growth in Developing Countries*. Berlin: Springer-Verlag.
- Scandurra, G., Thomas, A., Passaro, R., Bencini, J., and Carfora, A. (2020). Does Climate Finance Reduce Vulnerability in Small Island Developing States? an Empirical Investigation. *J. Clean. Prod.* 256, 120–330. doi:10.1016/j.jclepro.2020.120330
- Shi, B. B., Wu, L., and Kang, R. (2021). Clean Development, Energy Substitution, and Carbon Emissions: Evidence from Clean Development Mechanism (CDM) Project Implementation in China. *Sustainability* 13, 860. doi:10.3390/su13020860
- Simon, D. D., Milind, K., and Sophie, W. (2016). Measuring and Tracking the Flow of Climate Change Adaptation Aid to the Developing World. *Environ. Res. Lett.* 11, 054006. doi:10.1088/1748-9326/11/5/054006
- Song, D. Y., and Xia, T. X. (2019). Performance Evaluation of Carbon Trading Pilot Policy in China. *Stat. Decis.* 11, 157–160. doi:10.13546/j.cnki.tjyj.2019.11.037
- Stein, P., Goland, T., and Schiff, R. (2010). *Two Trillion and Counting: Assessing the Credit gap for Micro, Small, and Medium-Size Enterprises in the Developing World*. Washington DC: World Bank.
- Sudmant, A., Colenbrander, S., Gouldson, A., and Chilundika, N. (2017). Private Opportunities, Public Benefits? the Scope for Private Finance to Deliver Low-Carbon Transport Systems in Kigali, Rwanda. *Urban Clim.* 20, 59–74. doi:10.1016/j.uclim.2017.02.011
- Sun, X., and Zhang, K. M. (2014). Empirical Analysis on the Influencing Factors of Carbon Emission Intensity in China. *Stat. Res.* 31, 61–67. doi:10.3969/j.issn.1002-4565.2014.02.009
- Syed, M. R. (2019). Structural Analogy in Development and Climate Aid: The Case of Bangladesh. *J. Dev. Pol. Pract.* 4, 89–116. doi:10.1177/2455133318812983
- Urpelainen, J. (2012). Strategic Problems in North–South Climate Finance: Creating Joint Gains for Donors and Recipients. *Environ. Sci. Pol.* 21, 14–23. doi:10.1016/j.envsci.2012.03.001
- Vandenbergh, P. M. (2018). Keyword: Motivating Private Climate Governance: the Role of the Efficiency gap. *Ark. L. Rev.* 71 (2), 1.
- Vernon, L. (2006). Potential Impacts of Climate Change on Agricultural Land Use Suitability: Lupinus. *Department Agric.*
- Wang, K. M. (2011). The Relationship between Carbon Dioxide Emissions and Economic Growth: Quantile Panel-type Analysis. *Qual. Quant.* 47, 1337–1366. doi:10.1007/s11135-011-9594-y
- Weikmans, R., and Zaccai, E. (2017). An Analysis of justice Conceptions in Climate Change Adaptation Aid. *Dev. Durable Territ.* 8 (1). doi:10.4000/developpementdurable.11668
- Wen, J., Okolo, C. V., Ugwuoke, I. C., and Kolani, K. (2022). Research on Influencing Factors of Renewable Energy, Energy Efficiency, on Technological Innovation. Does Trade, Investment and Human Capital Development Matter? *Energy Policy* 160, 112718. doi:10.1016/j.enpol.2021.112718
- Wu, Y. M. (2006). Application of Spatial Econometric Model in Provincial R & D and Innovation. *J. Quant. Tech. Econ.* 23 (5), 74–85+130. doi:10.3969/j.issn.1000-3894.2006.05.009

- Xu, Y. S., and Liu, Q. (2018). Status Quo and prospect of the Global Climate Adaptation Finance. *J. Cent. Univ. Finance Econ.* 8, 25–36.
- Xu, G. Y., and Song, D. Y. (2010). Empirical Study on Environmental Kuznets Curve of Carbon Emission in China - Based on Provincial Panel Data. *China Ind. Econ.* 5, 37–47.
- Xu, H. L., Qi, P., and Zhu, S. J. (2006). Trade Openness, Human Capital and Total Factor Productivity: An Empirical Analysis Based on China's Inter Provincial Panel Data. *The J. World Econ.* 29 (12), 3–1096.
- Yau, R., and Chen, G. H. (2021). Assessing Energy Subsidy Policies in a Structural Macroeconomic Model. *Energ. Econ.* 103, 105509. doi:10.1016/j.eneco.2021.105509
- Ye, Y. (2014). Climate Finance, Africa and China's Role. *Afr. East-asian Aff.* 1, 36–57. doi:10.7552/0-1-120
- Zhang, Y. Q., Liu, C. J., Li, K., and Zhou, Y. (2018). Strategy on China's Regional Coal Consumption Control: A Case Study of Shandong Province. *Energy Policy* 112, 316–327. doi:10.1016/j.enpol.2017.10.035
- Zhang, H. R., Zhang, R. X., Li, G. M., Li, W., and Choi, Y. (2020). Has China's Emission Trading System Achieved the Development of a Low-Carbon Economy in High-Emission Industrial Subsectors? *Sustainability* 12, 1–20. doi:10.3390/su12135370
- Zhang, G. X., Nuruzzaman, M., and Su, B. (2021). Nexus between Household Energy Consumption and Economic Growth in Bangladesh (1975–2018). *Energy Policy* 156, 112420. doi:10.1016/j.enpol.2021.112420
- Zhang, P. (2016). Study on the Demand of Climate Finance for Developing Countries Based on Submitted INDC. *Adv. Clim. Change Res.* 7, 99–104. doi:10.1016/j.accre.2016.05.002

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