Effect of climate finance on environmental quality: A global analysis

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Abstract

Climate finance is an increasingly sought-after instrument for reducing greenhouse gas emissions by financing adaptation and mitigation measures. There is a global commitment to achieve the Sustainable Development Goals (SDGs), particularly with regard to tackling climate change. The mobilization and use of climate finance could influence environmental quality. This paper focuses on analyzing the impact of climate finance on environmental quality in 111 countries worldwide over the period 2000-2019. This study uses the generalized method of moments (GMM) in panel data. The main results indicate a positive effect of climate finance on environmental quality, reflecting the theory of financial ecology. More specifically, climate finance targeting climate change mitigation measures has a significant effect on environmental quality. Member countries of the United Nations Framework Convention on Climate Change (UNFCCC) and private sector actors should implement strategies to monetize climate finance and invest heavily in mitigation and adaptation measures to improve environmental quality.

Keywords: Climate finance, CO2 emissions, ecological footprint, GMM, World.

JEL classifications : Q48 ; Q42 ; G0

1. Introduction

The world is currently experiencing major climatic phenomena, the main causes of which are due to human activities that emit greenhouse gasses (GHG). The production and consumption of fossil fuels (energy consumption in buildings, industry and transportation) are responsible for about 75% of global warming due to GHG emissions (IPCC, 2022). Agriculture is also responsible for a large proportion of emissions, partly because it is the main cause of global deforestation, but also because livestock farming, especially the rearing of ruminants, produces very high emissions of methane, a greenhouse gas whose effect is about 30 times greater than that of carbon dioxide (CO_2).

The latest IPCC report (2022) shows that the intensity of global warming will be particularly high in 2022, with temperatures 1.2 degrees above observed pre-industrial averages. The IPCC's projections show that temperatures could rise by up to 5 degrees compared to pre-industrial averages, 3.2 degrees below business-as-usual" scenarios and less than 2 degrees below the most optimistic scenarios.

This assessment and the scenarios developed illustrate the climate emergency and call on the world to act in an environmentally conscious manner. In view of the consequences of global warming for ecosystems and societies worldwide, mitigation and adaptation strategies are recommended. However, technical solutions (renewable energy, energy transition, energy efficiency, nuclear power, hydrogen, carbon capture) are proving ineffective on a global scale. New solutions include climate justice and solidarity, carbon sobriety and a significant reduction in greenhouse gas emissions at national and international level.

At the theoretical level, environmental concerns have been addressed and discussed (Georgescu-Roegen, 1971; Meadow et al., 1972; Cleveland et al., 1984, Stern, 2004). Since the work of Grossman and Krueger (1995), the impact of economic activities on the environment has been emphasized. Following the pioneering work of Kuznets (1955), they show that environmental quality should improve over time because economic development generates positive externalities for the environment. This thesis is obviously not shared by all economists. Piketty (2013), for example, criticizes Kuznets' linear vision of the environmental curve. For him, time and economic development do not systematically solve the environmental problem. The work of Nordhaus (2021) shows that the polluter pays principle must be applied effectively and without discrimination, an idea that is far from being fully implemented in American climate policy (Zenghelis, 2021). Nordhaus does not seem to accept the effectiveness of technological progress in improving the environment. He estimates that reducing emissions would be extremely expensive, costing between 2% and 6% of world income, if the internationally set targets were to be met. The author strongly advocates the idea of a single global carbon price that would rise over time. In doing so, he assumes a static reduction plan in which investors would choose the most efficient emissions reduction programs at the margin. Nobel laureate Nordhaus, like many other economists, believes that to encourage innovation, a sufficiently high carbon price should be introduced from the outset, focusing on the sectors where emissions reductions are most costly in order to encourage innovation where the potential for cost reductions is greatest.

Romer, on the other hand, supports the thesis of innovation in climate policy. He argues that the planet must increase its capacity to decarbonize the global economy at a lower cost. In his view, the evolution of the cost of reducing emissions will depend on innovation. Once a globally deployed integrated technology is sufficiently competitive, it can displace incumbents and completely transform the sector due to economies of scale in production and research. This debate shows that reducing greenhouse gas emissions on a global scale is of paramount importance. Improving the quality of the environment requires a reduction in emissions. However, this reduction comes at a cost. This includes the cost of innovation and environmentally friendly technological processes. For this reason, at the last Conferences of the Parties (COP 26 and COP 27), particular emphasis was placed on mobilizing resources to achieve the targets. The industrialized countries must keep their promise to mobilize 100 billion dollars per year for climate protection. However, the data projected by the IPCC (2022) shows that we would need to emit no more than 500 billion tons of additional CO2 to hope to stay below the 1.5 degree warming threshold. For the 2-degree target, the limit would be around 1,150 billion tons of CO2. These figures show the efforts that need to be made to mobilize financial resources for climate protection. Aware of the challenges associated with mobilizing resources, governments participating in COP 27 agreed to advance the global adaptation target that will be finalized at COP 28 and will feed into the first global assessment to improve the resilience of the most vulnerable populations. At COP 27, new pledges were made for the "Adaptation Fund" amounting to over 230 million dollars. Once mobilized, these funds will help vulnerable communities adapt to climate change through concrete adaptation solutions.

Climate finance therefore remains an essential prerequisite for low-carbon and climate-resilient development. Climate finance refers to the financial resources that are mobilized to finance mitigation and adaptation measures. In addition, there are the public financing commitments that industrialized countries have entered into under the United Nations Framework Convention on Climate Change (UNFCCC). Several funds were set up on the initiative of the UNFCCC. These include the Global Environment Facility (GEF), established in 1992, with two sub-funds: the Least Developed Countries Fund (LDCF) and the Special Climate Change Fund (SCCF), the Adaptation Fund (AF), the Green Climate Fund (GCF), which was established at the Durban Conference and became operational at the end of 2015, and the Climate Investment Funds (CIFs), established in 2008. Despite the wide range of funds available, the volume of resources mobilized for climate protection remains low. Given the urgency of climate change, viable finance and investment is needed to address climate change, reduce emissions, promote adaptation to the impacts already occurring and strengthen resilience. These climate investments could bring socio-economic and environmental benefits that far exceed the initial costs. Studies conducted before the Covid 19 pandemic have shown that investing in climate action would make an important contribution to building a sustainable economy. According to the World Bank in October 2019, the planet will need to spend significant funds on infrastructure over the next 15 years, amounting to around 90,000 billion dollars in 2030. However, it will be possible to offset these investments. It is becoming increasingly clear that the transition to a green economy can create new economic opportunities and new jobs. On average, an investment of 1 dollar generates 4 dollars in benefits. The New Climate Economy report (2018) concluded that ambitious climate action could generate $26,000 billion in direct economic benefits by 2030 compared to a business-as-usual scenario.

Several empirical studies have shown that climate finance improves environmental health by reducing greenhouse gas emissions (Jalil and Feridun, 2011; Gu and He, 2012). The study by Guo et al. (2022) in China shows that reducing carbon emissions is essential for achieving China's "peak carbon" and "carbon neutrality" targets. In addition, the study shows that green finance has a significant negative direct effect on carbon emissions, but the effect at the neighboring provincial level is obviously insignificant. The work of Shahbaz et al. (2013) shows that financial development could effectively promote technological innovation and environmental awareness to significantly reduce greenhouse gas emissions.

While some empirical studies conclude that there is a reduction in greenhouse gas emissions, others come to mixed conclusions (Charfeddine and Ben Khediri, 2016; Hu and Wang, 2018). For them, access to finance increases fossil fuel consumption, which would contribute to higher GHG emissions. The relationship between green finance and environmental quality has not yet been sufficiently explored in the literature. Li et al. (2017) and Chen (2019) have used a computable general equilibrium model and a double-difference model, respectively, to show that green finance policy has a positive impact on carbon intensity on the one hand and influences corporate investment on the other. Very few studies have examined the relationship between climate finance and environmental quality (as measured by carbon emissions or ecological footprint). In light of the widespread mobilization of climate resources to reduce global warming caused by greenhouse gas emissions, it seems reasonable to ask the following question: What is the impact of climate finance on environmental quality worldwide? The aim of this article is to analyze the impact of climate finance on environmental quality worldwide. There are very few studies in the literature that have examined the impact of climate finance on environmental quality. In contrast to most contributions, this article has the advantage of looking at climate finance at a global level and taking into account the level of development of countries. It also captures both climate finance as a whole and the impact of each type of finance (mitigation and adaptation) on carbon reduction. In addition to the above, this study helps to inform international opinion on the need for climate finance in a world affected by the impacts of climate change.

The rest of the article is structured into three sections. The first section deals with the literature review, while the second section presents the materials and methods used. The third section analyzes and discusses the results obtained.

2. Theoretical and empirical literature

2.1 Theoretical literature

2.1.1. Ecological financial theory

Overall, ecological financial theory aims to understand how our economic and financial system can respond to the challenges of resilience and transition and how financial decisions can be embedded in their system of extra-financial constraints. It is therefore based on strong sustainability and places the bio- and geophysical constraints of sustainability at the forefront of capitalist logic. This implies a redirection of financial flows towards activities that are compatible with the Sustainable Development Goals (SDGs) and a qualitative change in the money cycle.

Ecological finance theory is essentially based on the concept of resilience. This concept, which according to Ulanowicz et al. (2009) originates from the life and earth sciences, was imported into the field of sustainable finance by Dron (2015). Through such a transfer, the author focuses on the self-regulating capacity of natural ecosystems while showing that current economic and financial systems lack this capacity. Ecological finance theory is also based on the concept of embeddedness developed by Polanyi (1944, 2001), which has been imported into the field of finance by authors such as Alijani & Karyotis (2016). In this vision, sustainability seeks to disrupt the criteria of social welfare and environmental constraints by re-embedding capitalism. Moreover, cybernetics has demonstrated a causal relationship between embeddedness and resilience. According to Simon (1962), any system can be represented as a series of interlocking subsystems. The author argues that the structure of a higher-level system, which is recognizable by its high complexity and the large amount of information it processes, can be broken down into elementary subsystems. Consequently, controlling the higher-level system based on the signals emitted by the subsystem leads to its collapse due to the loss of information. On the other hand, it would be an ontological error to control the superordinate system (the earth) on the basis of indicators generated by the financial subsystem (monetary signals).

When these different paradigms are considered in ecological financial theory, the order of priorities is reversed. It is no longer a question of ensuring that a green product is satisfactory from the investor's point of view, but of ensuring that the functioning of the financial system makes it possible to respond to the Anthropocene.

2.1.2. The classic "stick or carrot" theory of motivation

There are two main competing arguments for mobilizing the financial system to support the decarbonization of the economy. The first is the "price signal" approach, which aims to activate market participants' responses to risks and opportunities. The second logic aims to either redirect market participants through restrictions or incentives or, conversely, to expand or make them binding. In the innovation literature, the first logic is referred to as the "pull" force and the second as the "push" force of institutions (Rennings, 2000; Di Stefano et al., 2012; Grubb et al., 2014). The question, then, is whether funding should be primarily pulled or pushed, or a mixture of both. The answer to this question depends on how one understands the workings of economics and finance.

The role of finance in mitigating climate change is to stop funding "brown" measures and shift funding to "green" measures. The market pull associated with climate risk is therefore to create a price signal that tells market participants that it is no longer profitable or too risky to continue investing in brown assets, or that it is more profitable to invest in green activities. This signal can be achieved either through an efficient market that converts long-term physical risks and short-term transition risks into differences in the valuation of assets in the market, or through indirect policy or regulatory action in the underlying industries. Policy makers can intervene through the logic of pull in favor of market signals by focusing their actions on risk disclosure. They can also trigger the "push" logic to compensate for the inability of the price signal.

2.1.3. Creative destruction theory of Schumpeter

Faced with the new social and environmental paradigm, sustainable development seems to be a process of creative destruction that forces companies to adapt in order to meet the new expectations of civil society and respond to regulatory changes. Schumpeter's (1934) theory of creative destruction shows that finance can play an important role in the growth of a green niche. Indeed, entrepreneurial activity can be seen as a channel that attracts massive investment in new groups of promising technologies (niches). According to Perez (2012), times of crisis lead to the extinction of old, uncompetitive technologies and clear the way for technologies that are victorious in normal times. This theory suggests that the cost of investing in renewable energy falls over time, making carbon-intensive technologies less competitive. The financial sector, which has been responsible for financial crises through its excesses, will be forced by socially responsible investment to turn to a new, more responsible model that contributes to more responsible financial development by incorporating extra-financial and long-term considerations. Promoting green investments does not automatically replace or displace climate-relevant assets already in the system, even if it is no longer profitable to grow or invest in such technologies. Governance of the financial system based on the management of the whole system rather than niche growth therefore offers a vision that better addresses the multidimensional characteristics and complexity of the problem of decarbonizing the economy.

2.2. Empirical literature

Climate finance is a crucial mechanism to provide countries with the financial means to transition to sustainable, low-carbon development while adapting to the inevitable consequences of climate change. It is a crucial way to invest in climate change adaptation and resilience efforts in conflict- countries affected by conflict and climate-vulnerable countries exposure. Many countries are aware of its importance and are beginning to invest heavily in this area. According to Darasha (2021), green bond issuance in the Middle East reached $6.4 billion in mid-2021, with bonds issued in various currencies by regional and international banks and other financial institutions. These funds focus on the green recovery and the development of ESG assets. However, despite the rapid increase in green finance flows in virtually all regions of the world, there remains a significant investment gap that needs to be addressed in order to effectively manage a fair and sustainable energy transition, economic development and large-scale climate action. UNCTAD's World Investment Report estimates that there is a financing gap of around USD 2.5 trillion per year for the SDGs (UNCTAD, 2021). This funding gap is partly due to pledges made during the Conferences of the Parties (COP), particularly during COP 21 in Paris, that were not met. The climate sector needs massive funding to mitigate the effects of climate change and limit the ecological disaster. In this sense, Barua (2020) estimates that investments of several trillion dollars per year would be required to finance climate action and achieve the United Nations SDGs by 2030. This is supported by Adhikari et al. (2021), who argue that between 2030 and 2050, funding of 300-500 billion dollars per year would be required to build climate resilient infrastructure.

Faced with the worrying problem of climate change, several studies have tried to understand the impact of green finance on the Sustainable Development Goals. Most of these studies are of Chinese origin. Qi et al. (2014) examined the relationship between CO2 emissions and renewable energy development between 2010 and 2020, and the authors concluded that renewable energy generation plays a positive role in reducing CO2 emissions in the short term. This research has the advantage of showing how policy makers would do well to consider the impact of offsetting the low costs of current policies when designing complementary or alternative policies to bring renewable electricity into the generation mix. In the same dynamic and based on annual data covering the period 1980 to 2014, Chen et al. (2019) used the ARDL bound test approach and proved that any increase in the use of green energy leads to a decrease in carbon dioxide emissions in both the short and long term. Compared to previous studies, the long time period and the model used by the authors guarantee a much more robust result. Wang (2022) uses the same approach to analyze annual data from 2007 to 2019 to determine how green energy can help China achieve its decarbonization target. The results show that the development of green energy can reduce carbon dioxide emissions in the long term. This paper has two main contributions. First, it chooses the relationship between China's carbon dioxide emissions and renewable energy consumption as the starting point, which is innovative in a way. Second, based on the finding that China's renewable energy consumption has a restraining effect on carbon dioxide emissions, it proposes how to achieve the government's existing targets for carbon dioxide emission intensity under the scenario of adjusting the economic development speed. Lin et al. (2022) investigated the impact of green finance on the reduction of carbon emissions between 2007 and 2018.

Using a dynamic spatial Durbin model, the study shows that green finance contributes to the reduction of carbon emissions. In contrast to previous studies that only considered raw data, the authors' strong contribution is that they have constructed an index system for evaluating green finance that contains five indicators and uses the entropy weighting method. Zhu et al. (2022) examined the role of green energy resources in reducing CO2 emissions by focusing on fossil fuels in rural China between 2007 and 2018 and concluded that the development of green energy resources has a significant long-term impact on environmental protection in the country's rural areas. The authors have made an important contribution by demonstrating that IPAT theory is applicable to their study.

Lin and Qiao (2022) investigated how green energy can be integrated into people's lifestyles to reduce their environmental impact. It turned out that green electricity at a reasonable price could encourage people to use it and thus reduce carbon emissions in China. However, according to the authors, the government should strive to invest heavily in the green energy sector in order to provide the population with cheap green electricity, which in turn prevents the recourse to carbon emissions. Dong et al. (2022) used the STIRPAT approach to investigate carbon reduction and found a negative correlation between the use of green electricity and carbon emissions. Their study highlights policy proposals to reduce carbon emissions by adjusting income distribution, formulating targeted policies in different countries and promoting technological innovation. For Abbasi et al. (2022), who used annual data from 1980 to 2018 to compare the impact of green and fossil energy resources on climate change in China using the dynamic ARDL method, the use of green energy has a positive impact on reducing CO2 emissions in the short and long term. These earlier studies show the channels through which climate finance can improve environmental quality. Investing in renewable energy is a serious option to significantly reduce greenhouse gas emissions.

Wang et al. (2023) have investigated energy-related net carbon dioxide emissions. The empirical results confirm the positive role of green energy development on the country's industrial production. The innovations of this article compared to previous studies are twofold. First, the authors use a decomposition method that includes carbon sources and sinks. In addition, the causes of energy-related net CO2 emissions in China in the period 2010-2018 are identified. Zhang et al. (2023) also confirmed the positive effect of green energy resources on the expansion of agricultural land in China. The policy of expanding agricultural land can be strengthened by using renewable energy resources. Sun et al. (2023) used data from 2010 to 2021 to investigate the impact of green finance and the use of renewable energy on carbon dioxide emissions in China and its provinces. Their research shows that green finance reduces pollution at the provincial level. In fact, a 1% increase in renewable energy consumption led to a 0.103% decrease in carbon dioxide emissions. Based on their findings, the authors suggest that policy makers should incentivize a cleaner environment. Lin et al. (2023) analyzed the sources of carbon dioxide emissions in 25 Chinese provinces between 2007 and 2020, divided them into energy structure, economic development, energy efficiency and industrial structure, and used a two-stage LMDI method to investigate the linear and non-linear relationships between green finance and carbon dioxide emissions using spatial measurement methods. The results suggest that green finance is an effective means of reducing carbon emissions, particularly through its influence on energy structure, energy efficiency and industrial structure.

More recently, Zuhal and Göcen (2024) used spectral Granger causality analysis symmetrically and asymmetrically to analyze the relationship between renewable energy consumption, CO2 emissions, and economic growth for 1973:M01-2022:M06 in the United States. The results show that renewable energy consumption is essential for increasing sustainable economic growth and environmental quality in the United States. The symmetric causality test shows a bidirectional causality relationship between CO2 emissions, renewable energy consumption and economic growth. The asymmetric causality shows that there is a bidirectional causality between positive and negative shocks to CO2 emissions, renewable energy consumption and economic growth. Yang and Peng (2024) discuss the causality between the Green Financial Reform and Innovation (GFRI) policies and carbon emission intensity in China. They apply a time-varying difference-in-differences (DID) model to evaluate the impact of the GFRI experimental zone policy on carbon emission intensity. They conclude that the GFRI trial zone policy drastically reduces the intensity of carbon emissions and that this effect is more pronounced in cities with a high share of credit and bond financing. Furthermore, the effect of GFRI trial zone policies on reducing carbon emissions intensity is weaker in cities with a high number of environmental sanctions and fiscal pressure. This study is original as it discusses the heterogeneity of impacts and the parallel-serial mediation effect of this experimental zoning policy. Diallo (2024) uses the instrumental variable estimator for Sub-Saharan Africa to show that renewable energy consumption improves environmental quality. However, this cannot be achieved without massive green financing. Added to this would be the development of green technologies that would influence current production methods and make them more environmentally friendly.

As far as we know, no empirical study has challenged the basic assumptions about the positive relationship between climate finance and environmental quality. Even though the impact of green finance on environmental quality seems proven, the current level of finance is not sufficient to achieve significant results. Developing countries are the most vulnerable to the impacts of climate change and need green finance to develop adaptation and mitigation strategies. This study aims to enrich the debate by examining climate funds for adaptation on the one hand and mitigation on the other, to determine which fund is more effective depending on a country's level of development.

3. Methodology

The aim of this paper is to analyze the impact of climate finance on environmental quality. The main challenge is to establish a causal link between climate finance and environmental quality. One of the challenges is to attribute environmental outcomes exclusively to climate finance. Environmental quality is influenced by a variety of factors, including natural processes, socio-economic conditions and other policy interventions. Separating the specific effects of climate finance from these confounding factors requires rigorous research methods and careful data analysis. In addition, there may be a time lag between the provision of climate finance and the actual realization of environmental improvements. Certain environmental benefits, such as carbon sequestration or ecosystem restoration, may take years or even decades to materialize. In such cases, it becomes difficult to distinguish the contribution of climate finance from other concurrent efforts. To address this problem, we use the Generalized Method of Moments (GMM) developed by Arellano and Bond (1991). This method is widely used in the literature, including studies such as Schlenker, Hanemann, and Fisher (2006), who assess the impact of climate change on agriculture in the United States, Chen, Chen, and Xu (2016), who examine the relationship between climate variables such as temperature and precipitation and agricultural outcomes such as yields and crop yields, Zhou, Zhu, and Luo (2022), who assess the impact of fintech and green finance on promoting green growth, Zhang et al. (2021), who examine the relationship between public R&D spending, green economic growth and energy efficiency, and Zhao et al. (2021), who examine the impact of energy poverty on CO2 emissions. Similar research approaches are taken by Lee et al. (2022) to analyze the impact of climate finance flows on CO2 emissions, Kablan and Chouard (2022) to assess the impact of renewable energy subsidies on CO2 emissions in recipient countries, Mahalik et al. (2021) to assess the effectiveness of total foreign aid and foreign energy aid inflows on environmental quality in India, and Bhattacharyya et al. (2016) to examine the impact of energy-related environmental aid on CO2 and SO2 emissions in recipient countries. Due to its applicability to other estimation methods and its ability to provide "effective" estimates, the Generalized Method of Moments (GMM) is one of the most widely used techniques in the contemporary econometric literature. Arellano and Bond (1991) advocate the GMM estimator, which incorporates lagged endogenous variables as explanatory factors, as particularly advantageous for analyzing panel data. This approach provides more consistent and robust results, even in the presence of arbitrary heteroscedasticity. The dependent variable responds to changes in one or more independent variables, but gradually adjusts over time to establish a long-run equilibrium. When dealing with panel data, GMM goes beyond ordinary least squares (OLS) and two-stage least squares (2SLS) estimates to capture the entire system of equations observed in panel studies. Compared to cross-sectional differences and stabilization estimators, GMM is well suited to capture the dynamic nature of panel data. Wooldridge (2002) provides strong empirical support for GMM models as a superior tool for analyzing panel data and confirms their suitability for panels with unobserved effects. The pioneering work of Arellano and Bond (1991) has shown the robustness of GMM estimates even under weak assumptions. A notable advantage emphasized by Wooldridge (2002) is the ability of GMM to handle many parameters. This property proves particularly valuable in cases where the models lack external variables, such as when estimating the relationship between climate finance and environmental quality variables.

Thus, the GMM model can be expressed as follows:

$$\boldsymbol{CO2_{it} = \alpha_0 + \beta_1 CO2_{i,t-1} + \beta_2 CF_{i,t} + \beta_3 X_{i,t} + \delta_i + \varphi_t + \varepsilon_{i,t}} \qquad \textbf{Eq. (1)}$$

The subscripts *i* and *t* represent the country's index and the time period, respectively. Based on available data, the panel dataset is unbalanced and contains 111 countries (both developed and developing countries) from 2000–2019. Following the practice in the relevant empirical literature, the effect of business cycles on equation (1) variables has been smoothed using non-overlapping sub-periods of 5-year average data. These non-overlapping sub-periods include 2000–2004, 2005–2009, 2010–2014, and 2015–2019. $\boldsymbol{\alpha_0}$, $\boldsymbol{\beta_1}$, $\boldsymbol{\beta_2}$ and $\boldsymbol{\beta_3}$ and are coefficients that would be estimated. $\boldsymbol{\delta_i}$ are countries' time invariant countries' specific effects; $\boldsymbol{\varphi_t}$ are time dummies that act for global shocks that affect all countries' CO2 emissions (in tons per capita) path simultaneously. $\boldsymbol{\varepsilon_{i,t}}$ is an error term. We provide in Appendix A the description and source of all variables in equation (1) and Table 1 displays the standard descriptive statistics on these variables.

In equation (1), $\boldsymbol{CO2_{it}}$ represents the carbon dioxide emissions per capita of country *i* during year *t.* The one-period lag of this variable has been included in equation (1) to capture the potentially state-dependent nature of CO2 emissions. In other words, this accounts for the fact that CO2 emission levels at any given time may be influenced by the emission levels of previous periods. This dynamic is important for obtaining consistent estimates of the other parameters in the model and for better understanding the temporal evolution of CO2 emissions. Bond, (2002) argued that even if the coefficient of the lagged dependent variable(s) is not the primary coefficient of interest in the analysis, allowing for dynamics in the underlying process can be crucial for obtaining consistent estimates of the other parameters in the model. For the core explanatory variable $\boldsymbol{CF_{it}}$, we employ the ratio of three categories of climate funds (overall climate funds, climate mitigation funds, and climate adaptation funds) to the GDP of the recipient country to quantify climate finance. Term $\boldsymbol{X_{it}}$ is a set of control variables that affect carbon emissions, including foreign direct investment (FDI), population of beneficiary countries (POP), value-added of the industry (IVA), energy intensity (IE), GDP per capita (GDP) and democratic institutions as control variables.

4. Data and Descriptive Statistics

4.1. Data

To assess the of climate finance, we use a comprehensive panel dataset covering 111 developed and developing countries over the period 2000-2019. The chosen time frame is primarily due to the limited data on climate finance in developing countries before the 2000s. Our main variables are climate finance (independent variable) and CO2 emissions (in tons per capita) (dependent variable). Following previous research (Bhattacharyya et al. 2016; Chen and Lee, 2020; Lee et al., 2022; Bayramoglu et al., 2023), we quantify climate finance as the ratio of three different categories of climate funds (global climate funds, mitigation funds and climate adaptation funds) to the GDP of the beneficiary country. This measure is derived using data on official development assistance and other resource flows from countries to bilateral and multilateral development assistance providers compiled by the OECD Development Assistance Committee (DAC).

Our primary dependent variable, carbon dioxide emissions (in tons per capita), comes from the World Development Indicators (WDI). As for the control variables, it is of utmost importance to gain a comprehensive understanding of the factors that influence environmental quality. The theoretical framework decomposes environmental impacts into population, wealth and technology. Based on the literature on the determinants of environmental quality, we select the following control variables: Population of the beneficiary country (POP), Value Added Industry (VAI), Foreign Direct Investment (FDI), Energy Intensity (EI) and Democratic Institutions.

The correlation between population growth and environmental quality can be ambiguous, with both positive and negative associations. Two arguments support this relationship. First, a larger population can negatively affect environmental quality through increased energy consumption and carbon emissions (Su et al., 2021). Second, rapid urbanization due to population growth can facilitate infrastructure development, improve the efficiency of public facilities and promote industrial agglomeration, thereby reducing energy consumption and contributing to emission reduction (Guo et al. 2020). We expect a positive correlation between industrial value creation and environmental quality. While higher economic growth and industrialization often lead to an increase in carbon emissions, a thriving industry can also play a role in reducing pollutant emissions, responsible waste management and the conservation of natural resources (Li and Lin, 2015; Carfora and Scandurra, 2019; Wang and Wang, 2019; Li et al., 2022). In line with Su, Umar and Gao (2022), foreign direct investment (FDI) is expected to correlate positively with environmental quality, as developing countries often require external support for costly emission reductions, climate change mitigation and environmental protection measures (Wang and Chen, 2014). We expect a negative correlation with energy intensity (IE), as countries that rely heavily on energy-intensive sources may face challenges in implementing renewable energy investments through climate finance (Cornillie and

Fankhauser, 2004). Finally, democratic institutions are expected to have a positive relationship, as democracies tend to have robust legal frameworks and institutions that promote regulation and environmental protection (Farzin and Bond, 2006; Li and Reuveny, 2006; Fredriksson and Wollscheid, 2007; Bernauer and Koubi, 2009; Mak Arvin and Lew, 2011). Democratic institutions such as a free press and civil society offer citizens the opportunity to voice their environmental concerns, leading to stronger policy responses.

Detailed definitions of each variable used in this article and the corresponding sources are compiled in the appendix of this document.

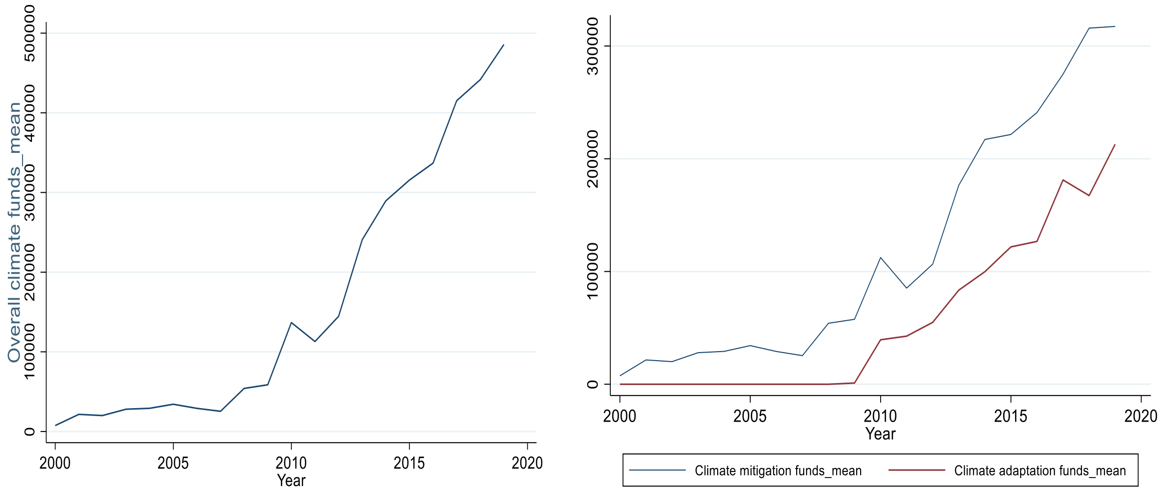
4.2. Descriptive Statistics

Table 1 provides descriptive statistics for the key variables used in the subsequent analysis, encompassing the full sample of 111 developed and developing countries.

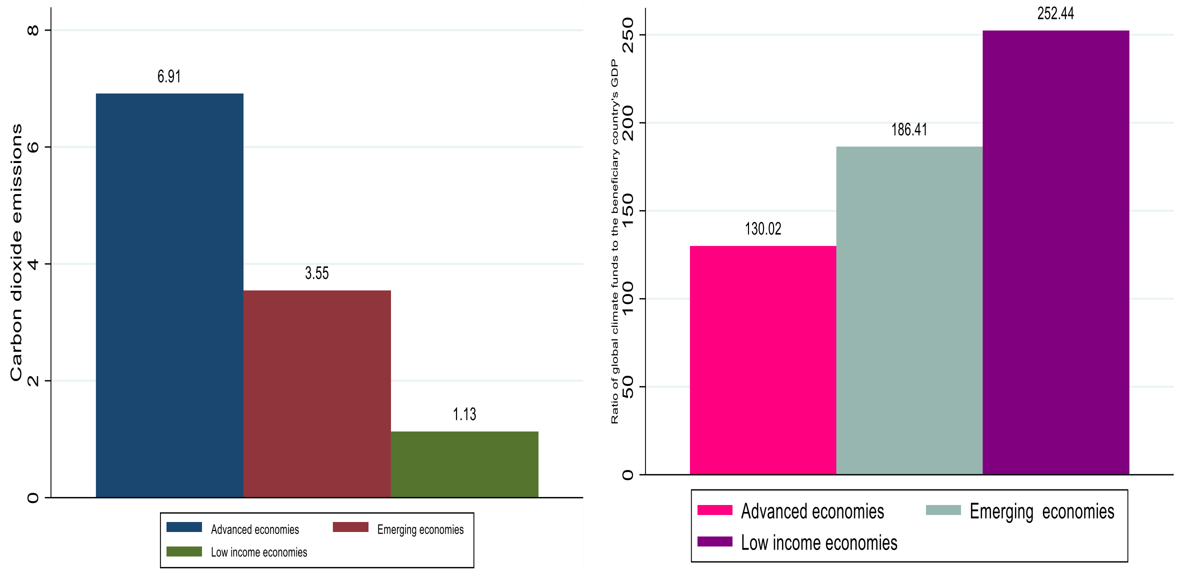
Table1: Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
CO2 emissions	2445	2.168	2.645	.02	23.052
Tot CF cons	2452	175010.1	510621.3	.157	10518610
Mitigation cons	2452	128227.82	402042.99	0	7725543.3
Adaptation cons	2452	62157.516	170051.41	0	3127471.4
Foreign direct investment	2355	4.428	6.338	-37.173	103.337
Population density	2445	122.786	179.387	1.584	1681.693
Polity2	2016	2.898	5.81	-10	10
GDP per capita	2392	3940.152	3751.935	255.1003	22879.51
Energy intensity level	2435	5.518	3.46	1.03	27.14

The observed characteristics of our sample indicate a considerable degree of heterogeneity between variables, including CO2 emissions. This heterogeneity is particularly pronounced for the climate finance variables, with the exception of energy intensity (EI). In addition, our results show that donors clearly emphasize the climate change mitigation channel, which is reflected in the significantly higher average allocation to climate change mitigation compared to climate change adaptation. Both categories also show remarkable heterogeneity in terms of total bilateral aid. After calculating global climate funds, this study provides a time trend chart of average global climate funds from 2000 to 2019 (see Figure 1). To distinguish between the two categories of climate funds, namely climate mitigation funds and climate adaptation funds, Figure 2 also presents time trend charts for both categories of climate funds. From this figure, it can be seen that the average global climate funds show a clear upward trend from 2000 to 2019, indicating a gradual improvement in climate finance. As for the two (02) categories of climate funds, the curve of climate adaptation funds shows the clearest downward trend. The financing of mitigation measures seems to be more important than the financing of adaptation measures. It is noteworthy that the trend of the climate adaptation funds curve does not change significantly in the period 2000-2008 and is almost zero, indicating that no climate adaptation funds were allocated to the beneficiary countries during this period.



<u>Fig1:</u> Overall climate funds, climate mitigation and climate adaptation funds



<u>Fig1:</u> Carbon dioxide emissions and Ratio of global climate funds to beneficiaries

5. Empirical findings and discussion

Table 2 shows the results of estimating the model using the two-stage dynamic panel system GMM estimator proposed by Blundell and Bond (1998). This sophisticated method provides us with two valuable advantages. First, it allows us to include lagged carbon emissions in the control variables, effectively combating the inherent inertia often associated with carbon emissions, such as carbon dioxide emissions. Second, this approach skillfully deals with the challenge of lacking valid external instruments to estimate the causal impact of climate finance on carbon emissions while controlling for the Nickell bias that occurs in dynamic fixed-effects panels. To mitigate potential issues with the non-stationarity of certain variables that could be indicative of carbon dioxide emissions and reduce the risk of spurious regressions, given the 20-year period of analysis from 2000 to 2019, we take a prudent approach by dividing our panel data into five non-overlapping sub-periods of four years each. This strategic move allows us to obtain more robust estimates by using annual averages. The validity of this econometric approach is underpinned by statistical tests, as both the null hypotheses of the Sargen/Hasen test and the AR(2) test are validated. To streamline the instruments in the regression analyzes, we follow the approach recommended by Roodman (2006) by consolidating the instrument matrix. In addition, the presence of a positive coefficient for the lagged dependent variable emphasizes an inertia effect and thus justifies the dynamic panel specification. Columns (1 to 3) show separate estimates for each climate finance indicator: total climate finance, climate mitigation finance and climate adaptation finance. Remarkably, column (1) shows that the coefficient for climate finance has a negative significance at the 1% level, indicating that climate finance significantly reduces carbon dioxide emissions in the beneficiary countries and thus makes a significant contribution to improving environmental quality. Specifically, climate finance is found to reduce carbon dioxide emissions by 0.18 percentage points. In addition, the results show some persistence of carbon dioxide emissions over time, as evidenced by a positive and significant coefficient of 0.84 for lagged carbon dioxide emissions in equation (1). The effects of mitigation finance appears to be more pronounced than that of adaptation finance (which, remarkably, turns out to be statistically insignificant - see column 3). Specifically, adaptation finance is concerned with the process of adapting to current or expected climate change and its effects, while mitigation finance aims to reduce resource use, emissions per unit of output and greenhouse gas emissions (IPCC, 2014).

It can be seen that most of the estimates for these three separate estimates reach statistical significance with regard to the control variables. Industrial value added and foreign direct investment are positively associated with carbon dioxide emissions. The coefficients for industrial value added (IVA) are significantly positive, suggesting that increasing industrialization increases carbon dioxide emissions, which is consistent with (Lee et al., 2022). Advancing industrialization leads to rapid use of fossil fuels such as coal, oil and natural gas to power machinery, factories and vehicles. This intensive use of fossil fuels increases carbon dioxide emissions (Li and Lin, 2015; Li et al., 2022). This can be attributed to the fact that countries with higher levels of industrialization are more resistant to policies in favor of renewable energy production because these policies imply structural changes in their well-developed industrial structures and economies. Well-established industries may have made significant investments in existing infrastructure, making the transition more difficult and costly (Carfora and Scandurra, 2019; Wang and Wang, 2019). We also find that foreign direct investment (FDI) has a significant and positive impact on carbon dioxide emissions, which is consistent with previous research on FDI and environmental quality (Levinson and Taylor, 2008; Wang and Chen, 2014). According to the "pollution oasis" hypothesis, foreign investment relocates polluting industries to developing countries where environmental regulations are less stringent, leading to an increase in CO2 emissions (Bommer, 1999; Cole, 2003; Ozatac et al., 2017). Foreign direct investment brings with it capital and technology that promotes economic growth and industrialization, which is often accompanied by increased use of fossil fuel resources, thus increasing CO2 emissions. In addition, multinational companies can transfer less advanced and more polluting technologies to developing countries. Finally, foreign direct investment can encourage local companies to adopt similar practices in order to attract more investment, which can also lead to higher emissions if these practices are associated with high fossil fuel consumption.

Table 2. Effects of climate finance on carbon dioxide emissions.

Dependent variable	**Carbon dioxide emissions**		
Regressions	**[1]**	**[2]**	**[3]**
Carbon dioxide emissions (Lag1)	0.9570***	0.9713***	0.9304***
	(0.1301)	(0.1125)	(0.0909)
Climate finance	-0.1734***		
	(0.0577)		
Mitigation finance		-0.0888**	
		(0.0377)	
Adaption finance			-0.0153
			(0.0497)
Industry, value added	0.2007*	0.1919*	0.2263*
	(0.1079)	(0.0995)	(0.1327)
Population density	-0.0294	-0.0296	-0.0504
	(0.0579)	(0.0487)	(0.0652)
Foreign direct investment (% of GDP)	0.1017**	0.0818**	0.0389
	(0.0453)	(0.0401)	(0.0485)
Polity2	0.0021	0.0014	-0.0054
	(0.0100)	(0.0093)	(0.0118)
Energy intensity	-0.7947	-0.6844	-1.1152
	(0.7357)	(0.5232)	(0.9158)
GDP per capita	-0.2109	-0.1422	-0.1296
	(0.3388)	(0.2595)	(0.2983)
Intercept	3.1229	2.0951	2.6302
	(3.8110)	(2.8440)	(3.9165)
Observations	**411**	**411**	**411**
Countries	**111**	**111**	**111**
Instruments	**22**	**24**	**21**
Hansen	**0.2724**	**0.3013**	**0.1355**
AR1	**0.0991**	**0.0845**	**0.07**
AR2	**0.5202**	**0.834**	**0.8116**

*Note: Robust Standard Errors are in parenthesis. The variables "GDP per capita ", "Population density ", "Foreign direct investment (% of GDP)", "Energy intensity», have been considered as endogenous across all model specifications. The variables "Industry, value added ", and "*Polity2*" have been considered as exogenous. Standard errors in parentheses * p < 0.10, ** p < 0.05, *** p < 0.01*

Robustness

In this section, we primarily focus on testing the robustness of our results by using alternative samples, including additional controls, and exploring alternative definitions for both dependent and explanatory variables.

Alternative Sample

We begin our robustness analysis by scrutinizing the susceptibility of our findings to sample selection. We make four adjustments to the sample. First, we exclude the period of climate finance from 2000 to 2008 from the calculation of total climate finance. This period is characterized by a lack of adaptation finance in many countries, potentially leading to an underestimation of the impact of climate finance on environmental quality. We then account for outliers by excluding the top (bottom) 5% of countries with high (low) levels of climate finance within their governance. Finally, to mitigate the inherent heterogeneity of countries in our sample, we omit developed countries from our dataset and aim for a more uniform sample, especially in terms of income levels. The results presented in columns [1] to [4] of Table 3 are consistent with our main findings. In short, our conclusions are not affected by any single category of climate finance, nor by anomalies or income differences.

<u>Tableau 3</u> Alternative Sample

Dependent variable	**Carbon dioxide emissions**			
Regressions	[1] Climate finance excluding the year 2002 to the year 2008.	[2] Excluding bottom 5% climate finance	[3] Excluding top 5% climate finance	[4] Excluding Advanced economies
Carbon dioxide emissions (Lag1)	0.7830***	0.9536***	0.9941***	0.9298***
	(0.1618)	(0.1249)	(0.1267)	(0.0999)
Climate finance	-0.3150***	-0.1709***	-0.1992***	-0.0885**
	(0.0938)	(0.0573)	(0.0608)	(0.0428)
Industry, value added	0.1663	0.1414*	0.1865*	0.0880
	(0.1739)	(0.0838)	(0.1078)	(0.0794)
Population density	0.0181	0.0130	-0.0441	-0.0236
	(0.0771)	(0.0502)	(0.0523)	(0.0430)
Foreign direct investment (% of GDP)	0.2076***	0.1207***	0.1006**	0.0602
	(0.0761)	(0.0451)	(0.0472)	(0.0476)
Polity2	-0.0020	0.0083	0.0046	0.0014
	(0.0120)	(0.0092)	(0.0098)	(0.0076)
Energy intensity	-0.1459	-0.2967	-1.0160*	-0.4982
	(1.0951)	(0.6536)	(0.5887)	(0.3425)
GDP per capita	0.0804	-0.1246	-0.3198	-0.0902
	(0.4793)	(0.3306)	(0.2964)	(0.2175)
Intercept	0.9301	1.8461	4.8283	1.9359
	(5.3047)	(3.6078)	(3.2449)	(2.2181)
Observations	**316**	**394**	**398**	**382**
Countries	**110**	**109**	**111**	**103**
Instruments	**20**	**21**	**20**	**27**
Hansen	**.3584**	**.1146**	**.3176**	**.2063**
AR1	**.0836**	**.0936**	**.0855**	**.0142**
AR2	**.9004**	**.358**	**.4722**	**.4636**

*Note: Robust Standard Errors are in parenthesis. The variables "GDP per capita ", "Population density ", "Foreign direct investment (% of GDP)", "Energy intensity», have been considered as endogenous across all model specifications. The variables "Industry, value added ", and "*Polity2*" have been considered as exogenous. Standard errors in parentheses * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$*

Potential Omitted Variables

We continue our robustness check by examining the sensitivity of our results to additional control variables. Following the literature on climate finance and environmental quality, we include four different categories of additional control variables. The first category includes a number of economic variables: Measures such as the rate of economic growth, financial openness, trade globalization, and/or trade openness provide insights into the economic environment in which climate finance operates. For example, a resilient economy can skillfully absorb and implement climate finance to improve the environment. In column [2], we present our primary model and extend it by including annual GDP growth. The integration of this variable into the second stage is justified by the potential correlation between income growth and the variables previously examined, particularly GDP per capita. While the results in column [3] imply a notable and statistically significant impact of this variable on climate finance, its main effect is shown in column [2]. Consequently, the inclusion of income growth does not lead to significant changes in the results of our analyzes. The second category includes demographic and social variables such as urbanization rate, human capital and forest cover (as a percentage of total land area). These variables are used to decipher the impact of changing population dynamics on the effectiveness of climate finance.

For example, urbanized populations may require different strategies to improve environmental quality than rural areas. The third category includes technological and infrastructural aspects: Control variables related to the adoption of renewable energy, energy-efficient technologies, and infrastructure development show how technological advances driven by climate finance influence the trajectory of environmental quality improvement. The fourth category comprises policy and institutional variables, including environmental regulations, the quality of governance and the existence of climate-related policies. See the Appendix for a detailed description of these variables. The results in columns [2]- [13] of Table 4 show that the integration of these variables leads to results that are consistent with our initial findings.

Tableau 4. Potential Omitted Variables

Dependent variable	**Carbon dioxide emissions**													
Regressions	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]
Carbon dioxide emissions	0.9777***	0.9726***	0.9155***	0.9815***	0.9827***	0.9951***	0.9511***	0.9964***	0.9704***	0.9694***	0.9697***	0.9696***	0.9770***	0.9752***
	(0.1287)	(0.1128)	(0.0534)	(0.1127)	(0.1170)	(0.1004)	(0.1367)	(0.0972)	(0.1328)	(0.1051)	(0.1200)	(0.1188)	(0.1179)	(0.1115)
Climate change	-0.1937***	-0.1946***	-0.1575**	-0.1885***	-0.1620***	-0.1691***	-0.1424***	-0.2026***	-0.1974***	-0.1813***	-0.1920***	-0.2014***	-0.1935***	-0.1869***
	(0.0599)	(0.0675)	(0.0717)	(0.0595)	(0.0562)	(0.0534)	(0.0496)	(0.0611)	(0.0614)	(0.0548)	(0.0609)	(0.0631)	(0.0600)	(0.0607)
Industry, value added	0.1692*	0.1221	0.0618	0.1689*	0.0828	0.1410	0.0416	0.1126	0.1682*	0.1466*	0.1683*	0.1875*	0.1338	0.1570
	(0.1011)	(0.1266)	(0.1115)	(0.0960)	(0.1105)	(0.0983)	(0.0966)	(0.1126)	(0.1007)	(0.0876)	(0.1013)	(0.1043)	(0.0949)	(0.0957)
Population density	0.0972**	0.0705	0.0634	0.0978**	0.0217	0.0686*	0.0990**	0.0716	0.1055**	0.0822**	0.0983**	0.0977**	0.0885**	0.1019**
	(0.0430)	(0.0523)	(0.0503)	(0.0428)	(0.0556)	(0.0380)	(0.0401)	(0.0448)	(0.0496)	(0.0400)	(0.0423)	(0.0415)	(0.0419)	(0.0428)
Foreign direct investment (% of GDP)	-0.0336	-0.0585	-0.0263	-0.0355	-0.0556	-0.0377	-0.0205	-0.0566	-0.0287	-0.0348	-0.0300	-0.0268	-0.0473	-0.0432
	(0.0562)	(0.0655)	(0.0451)	(0.0503)	(0.0657)	(0.0483)	(0.0476)	(0.0530)	(0.0614)	(0.0462)	(0.0522)	(0.0508)	(0.0558)	(0.0535)
Polity2	0.0041	0.0044	0.0001	0.0044	0.0045	0.0027	0.0173**	0.0085	0.0048	-0.0004	-0.0010	-0.0024	0.0033	0.0039
	(0.0101)	(0.0097)	(0.0089)	(0.0103)	(0.0097)	(0.0084)	(0.0079)	(0.0096)	(0.0096)	(0.0116)	(0.0127)	(0.0116)	(0.0108)	(0.0108)
Energy intensity	-0.8509	-0.9430	-0.3871*	-0.8051*	-1.0340**	-0.7598*	-0.4815	-0.7052	-0.7988	-0.5956	-0.7642	-0.7536	-0.7927	-0.7807*
	(0.6221)	(0.6854)	(0.2162)	(0.4385)	(0.4081)	(0.4074)	(0.5521)	(0.5639)	(0.7005)	(0.5115)	(0.4618)	(0.4712)	(0.4882)	(0.4327)
GDP per capita	-0.2593	-0.2525		-0.2635	-0.3151	-0.2670	-0.2129	-0.4219	-0.2381	-0.2272	-0.2359	-0.2498	-0.3074	-0.2887
	(0.3053)	(0.3007)		(0.2386)	(0.2086)	(0.2144)	(0.2473)	(0.2753)	(0.3330)	(0.2247)	(0.2522)	(0.2544)	(0.2826)	(0.2303)
GDP growth		0.0281**	0.0267**											
		(0.0120)	(0.0102)											
Urbanization				-0.0137										
				(0.0232)										
Trade globalization					0.3151*									
					(0.1766)									
Financial openness						0.0430								
						(0.0272)								
Renewable energy consumption							-0.0936							
							(0.1155)							
Using the Internet								0.2003**						
								(0.0882)						
Forest area									-0.0203					
									(0.0688)					
Regulatory Quality										0.1378				
										(0.1220)				
Political Rights											-0.0198			
											(0.0299)			
Rule of Law												0.0178		
												(0.0138)		
Human Capital													0.4301	
													(0.2909)	
Telecommunication Infrastructure														0.3855
														(0.3837)
Observations/countries	411/111	411/111	411/111	411/111	405/109	399/107	409/110	408/111	411/111	411/111	411/111	410/111	409/110	409/110
Inst	20	21	22	22	22	22	19	19	21	22	22	22	22	22
Hansen	.2891	.2549	.2078	.375	.2646	.3647	.1053	.1512	.2847	.3441	.3645	.3971	.3645	.3931
AR1	.0893	.0652	.0621	.0857	.084	.0938	.1029	.1081	.0909	.1053	.0881	.091	.0892	.0865
AR2	.4682	.5168	.5805	.4598	.5642	.4716	.4128	.4756	.4562	.4719	.4671	.4577	.4704	.3941

Alternative definition of the dependent variable

In this section, we examine alternative estimates for the measurement of our dependent variable, carbon dioxide emissions. We begin the analysis by replacing carbon dioxide emissions (i.e. our indicator of environmental quality) with the Ecological Footprint (an important measure for assessing environmental sustainability and the extent of humanity's ecological overshoot). The results of these alternative specifications are summarized in columns [1]- [2] of Table 6. The results indicate that changing the definition of the dependent variable does not change our results, as the coefficients retain their positive and statistically significant character.

Tableau 6 Alternative definition of the dependent variable

Dependent variable	**Carbon dioxide emissions**	**Total Ecological Footprint** (GHA per person)
Regressions	**[1]**	**[2]**
Carbon dioxide emissions (Lag1)	0.9777***	
	(0.1287)	
Total Ecological Footprint (GHA per person) (Lag1)		0.8711***
		(0.2104)
Climate finance	-0.1937***	-0.1836**
	(0.0599)	(0.0818)
Industry, value added	0.1692*	0.0698
	(0.1011)	(0.1204)
Population density	0.0972**	0.4931**
	(0.0430)	(0.2334)
Foreign direct investment (% of GDP)	-0.0336	0.0201
	(0.0562)	(0.0495)
Polity2	0.0041	0.0101
	(0.0101)	(0.0078)
Energy intensity	-0.8509	0.0736
	(0.6221)	(0.1992)
GDP per capita	-0.2593	-0.0544
	(0.3053)	(0.1954)
Constant	3.7471	0.2190
	(3.3500)	(1.4995)
Observations	**411**	**411**
Countries	**111**	**111**
Instruments	**20**	**13**
Hansen	**.2891**	**.1721**
AR1	**.0893**	**.0091**
AR2	**.4682**	**.2016**

*Note: Robust Standard Errors are in parenthesis. The variables "GDP per capita ", "Population density", "Foreign direct investment (% of GDP)", "Energy intensity", have been considered as endogenous across all model specifications. The variables "Industry, value added ", and "*Polity2*" have been considered as exogenous. Standard errors in parentheses * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$*

Conclusion and policy implications

At a time when citizen engagement and responsibility are of paramount importance, this article examines in detail the relative impact of global climate finance and mitigation and adaptation funds on per capita CO2 emissions. Using panel data covering a wide range of developed and developing countries from 2000 to 2019, this analysis incorporates variables such as per capita income, recipient country population, industrial value added, foreign direct investment, energy intensity and democratic institutions as important additional factors in the carbon emissions equation. This empirical approach, which differs significantly from the prevailing studies, gives our study a unique quality and enriches the literature on economics and energy policy. Using the generalized method of moments, the empirical results suggest a substantial reduction in CO2 emissions through global climate funds. Industrial value added and foreign direct investment remain consistently high in the long run. The robustness of these results is validated by a series of tests that include alternative definitions of the dependent variable, changes in the sample and additional controls. Consequently, increased climate finance is effective in reducing carbon dioxide emissions. Subsequent tests for heterogeneity show that our results are sensitive to the level of economic development, with their significance increasing over time. This comprehensive study highlights the intricate interplay between climate finance and emissions reduction, which has profound implications for sound policy formulation to mitigate global climate change.

The empirical conclusions outlined above have crucial policy implications for an effective climate change mitigation strategy at the global economic level. The study highlights the positive effects of climate change mitigation on environmental quality, in contrast to the non-significant effects of climate change adaptation. From a climate policy perspective, the results suggest that governments should prioritize higher contributions from mitigation funds over adaptation funds in order to effectively implement long-term initiatives to improve environmental quality. Given the potential of climate finance to preserve natural environmental quality, these funds should be used more efficiently for profitable clean energy projects. This redirection aims to reduce CO2 emissions and thereby avert the harmful effects of climate change on humans and other species. Given the significant impact of increased industrial value creation on CO2 emissions, a proactive policy is needed. Encouraging industry to adopt environmentally friendly technologies and enforcing strict emission standards are crucial steps. The introduction of carbon pricing mechanisms serves as an incentive to reduce emissions, while investments in carbon capture research and sustainable materials promote innovative solutions. Implementing the principles of a circular economy minimizes waste and emissions while promoting sustainable supply chains. Joint international efforts enhance emission reduction targets and promote global cooperation. Equally important is supporting communities affected by industrial change. Promoting innovation and entrepreneurship in clean technologies drives sustainable economic growth. This comprehensive approach recognizes the interaction between industrial expansion and carbon emissions and increases the effectiveness of climate change mitigation initiatives. Since foreign direct investment often comes at the expense of the natural environment, we recommend that governments impose strict international environmental regulations on foreign companies that have a greater impact on the environment. Alternatively, governments can encourage the market entry of foreign multinationals that internalize negative externalities such as pollution through environmentally friendly and energy-efficient technologies. To achieve this qualitative change, governments must make efforts and change their attitudes, followed by the cooperation of citizens.

Given these mixed results, this article strongly recommends continued research on climate finance and environmental quality to improve compliance with environmental policies and the implementation of renewable energy strategies to reduce carbon emissions.

This study covers 111 developed and developing countries and is limited by a 20-year analysis period, from 2000 to 2019, due to data availability. Despite the many strengths of this document, there are still opportunities for more in-depth research. First, while our study looks at the direct effect of climate financing on environmental quality, it does not consider the mechanisms through which this financing operates. We therefore recommend that future research explore these potential channels. Furthermore, in the current debate on the availability of climate funds, non-linear analysis could be considered to determine the funding threshold at which these funds become truly effective.

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Appendix A. Definition and sources of variables.

Variables	Descriptions	Sources
CO_2 emissions	CO_2 emissions (metric tons per capita)	World Development Indicators (WDI), World Bank
Total Ecological Footprint	Total Ecological Footprint of Consumption (GHA per person)	World Development Indicators (WDI), World Bank
Climate finance	the ratio of three distinct categories of climate funds (global climate funds, climate mitigation funds, and climate adaptation funds) to the beneficiary country's GDP	OECD Development Assistance Committee (DAC).
Mitigation finance	Climate mitigation funds	OECD Development Assistance Committee (DAC).
Adaptation finance	climate adaptation funds	OECD Development Assistance Committee (DAC).
Foreign direct investment	It includes domestic and foreign liabilities such as currency and money deposits, securities other than shares, and loans.	WDI
Population density	population of beneficiary countries (POP)	WDI
Polity2	Democracy index,	Polity.V
Energy intensity level	The percentage of population with access to electricity.	WDI
GDP per capita	GDP Per capita	WDI
GDP growth	The annual percentage growth rate of GDP at market prices is based on constant local currency (average).	WDI
Urbanization	Urban population (% of total population)	WDI
Financial openness	Financial openness	Kaopen(2020)
Trade globalization	Trade globalization	KOF (Dreher, 2006a; Gygli et al., 2019)
Renewable energy consumption	Renewable energy consumption (% of total final energy consumption)	WDI
Using the internet	Individuals using the Internet (% of population).	WDI
Forest area	Forest area (% of land area)	WDI
Regulatory quality	Regulatory Quality, Estimate	WDI
Political Rights	Political Rights	WDI
Rule of law	Rule of Law	World Development Indicators (WDI), World Bank
Human capital	Human Capital Index	International Centre for Tax and Development
Telecommunication Infrastructure	Telecommunication Infrastructure	World Development Indicators (WDI), World Bank