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Does classification of green aid flows matter for environmental quality?

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Abstract
Climate change imposes an existential threat on the globe and has already had sizeable economic costs to countries. Environmental aid flows aim to alleviate the rising concerns of climate change in the developing world. Even though the existing literature has examined the effectiveness of green aid flows for reducing carbon dioxide emissions in the recipient countries, no existing study has examined the effectiveness of different classifications of green aid. Examining the green aid flows to 97 developing countries between 2002 and 2018, we find that all types of green aid significantly reduce carbon dioxide emissions; however, the aid flows targeting the environmental objectives are more effective in reducing carbon dioxide emissions compared to the aid flows that do not target environmental objectives or are not screened. The findings highlight that more aid should be screened and targeted for environmental objectives to increase the effectiveness of green aid flows in developing countries.

Keywords Green aid · Aid · CO_2 emissions · Panel data · Sustainable development

JEL Classification C12 · C13 · F35 · Q53 · Q54

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1 Introduction

Climate change imposes an existential threat on the globe and has already had sizeable economic costs to countries (Dell et al. 2012; Dellink et al. 2019), has led to reduced agricultural returns (see e.g., Lobell et al. 2011; Ray et al. 2015, 2019), increased forest fires (Flannigan et al. 2000; Seidl et al. 2017; Michetti and Pinar 2019), impacted health outcomes (Neira et al. 2014), among many others. Therefore, there has been increased global action to mitigate the negative consequences of climate change. Even though the 26th United Nations (UN) Climate Change Conference of the Parties (COP26), held in Glasgow in 2021, addressed the issues of climate change and urged countries to act to secure global net-zero emissions by 2050, the Global Energy Review report of international energy agency (IEA) estimates that carbon dioxide (CO_2) emissions increased by almost 5% in 2021 (IEA 2021).

The impacts of climate change have been recently evaluated by the working group of the Intergovernmental Panel on Climate Change and this report argued that the negative consequences of climate change have been disproportionately higher for developing countries (IPCC 2022). In other words, even though combat against climate change has been a priority for developed and developing world, developing and least developed countries were the ones that were hurt the most by climate change (see e.g., Collier et al. 2008; Tol 2018; Vinke et al. 2017). Therefore, there has been an increased emphasis on climate change adaptation and mitigation policies for the developing world (see e.g., Duguma et al. 2014; Huq et al. 2004; Mertz et al. 2009). One way of supporting the developing world in climate change and adaptation is climate change finance. For instance, Official development assistance (ODA) of the Organisation for Economic Co-operation and Development (OECD) started allocating aid to developing countries targeting the objectives of the Rio Conventions, and the climate finance provided by developed countries to developing countries reached 79.6 billion US dollars in 2019 (OECD 2021a).

Even though there has been an extensive evaluation of aid effectiveness for economic growth and poverty reduction (see e.g., Doucouliagos and Paldam 2009 for a review), certain studies examining the effectiveness of environmental aid flows to improve environmental quality have been emerged recently. The existing literature finds a mixed set of findings of the effect of green aid flows on environmental degradation (see Sect. 2 for the detailed literature review). Our paper aims to contribute to the literature that examines the relationship between green finance (aid) and CO_2 emissions. The existing literature examines the effect of aid flows on environmental pollution by either using aggregate aid flows (see e.g., Boly 2018; Farooq 2022; Mahalik et al. 2021; Sharma et al. 2019), or sector-related aid flows (see e.g., Li et al. 2021a; Mahalik et al. 2021); or aggregate aid flows in specific areas (see e.g., Wu et al. 2021). However, existing aid flows targeting the environment have been classified into four-scoring systems. The total aid flows targeting environment is divided into four categories. Green aid flows are put into two categories if the support “principally” or “significantly” targets the environmental objectives. The other two categories include aid flows that do not target the objective, but are screened or not screened (OECD 2021b for the details of the scoring system). The current studies have used aggregate flows without distinguishing for the scoring system; however, it is expected that aid flows are designed to meet the principal and significant objectives of environmental targets of the Rio convention (e.g., limiting anthropogenic emissions) so as to be more effective in reducing CO_2 emissions compared to that of aid flows that do not target the objectives or are not screened. Therefore, this paper aims to contribute to the existing literature by investigating whether aid classification (or categorization) has a varying effect on CO_2 reductions in the case of 97 developing countries, spanning the period 2002 to 2018 (see "Appendix A" for the list of countries used in this paper). Since we aim to investigate the impact of green finance on CO_2 emissions, this paper also evaluates the climate change mitigation effectiveness of the green finance (see e.g., Li et al. 2021a).

The remainder of the paper is organized as follows. The second section provides the literature on the effects of foreign aid on CO_2 emissions and the determinants of CO_2 emissions. The third section provides the details of data used and the empirical strategy followed. The empirical findings are presented in Sect. 4, while Sect. 5 concludes and provides policy recommendations.

2 Literature review

The existing literature recently investigated the role of the foreign finance (aid) on CO_2 emissions. The first stream of the literature has found that green aid flows led to decreased CO_2 emissions. Using climate change mitigation aid flows to the three most carbon-intensive sectors (energy, transport and industry) to 86 countries between 2003 and 2014, Li et al. (2021a) demonstrate that aid flows to these sectors reduce CO_2 emissions only in countries with strong institutional quality. Similarly, using the aid flows for energy generation and supply by renewable sources, as well as the flows of funds targeted at biosphere protection to developing countries, Carfora and Scandurra (2019) document that these aid flows reduce greenhouse gas (GHG) emissions. In contrast, using aid flows data for 52 recipient countries from 1980 to 2016, and the mediation models, Wu et al. (2021) highlight that aid flows directly reduce CO_2 emissions, as well as indirectly through the substitution of clean energy for traditional fossil energy. In the same line, using aggregate aid flows data, Sharma et al. (2019) show that total foreign aid leads to reduced CO_2 emissions in Nepal. Other studies also find that aid flows reduce CO_2 emissions (see Mahalik et al. 2021 for the effect of total foreign aid on CO_2 emissions for India; Farooq 2022 for 49 Asian countries; Boly 2018 for 112 countries when multilateral aid flows are used; Pinar 2023 for 92 countries). However, another strand of the literature either finds no significant or a negative effect of green aid on environmental degradation. For instance, using data for 128 countries over the period 1971–2011, Bhattacharyya et al. (2018) examine the effect of energy-related aid on CO_2 and SO_2 emissions and find no significant impact with the exception of countries located in Europe and Central Asia. On the other hand, Mahalik et al. (2021) illustrate that energy-related aid flows to India lead to increased CO_2 emissions. Similarly, Bertheau and Lindner (2022) found that foreign aid allocated to the energy sector led to increased harmful fossil fuel capacities in Southeast Asia. Using total foreign aid flows for 112 developing countries between 1980 and

2013, Boly (2018) shows that bilateral aid flows have no significant effect on pollution reduction.

A wide body of literature examines the determinants of CO_2 emissions per capita. One of the most examined hypotheses is the environmental Kuznets curve (EKC), which expects that the environmental degradation will increase along with the initial economic growth at lower levels of development, but after surpassing a certain development level, economic growth would lead to environmental improvement (see e.g., Grossman and Krueger 1991, 1995; Panayotou 1993), resulting in an inverted U-shaped relationship between economic development and environmental degradation. Even though most of the studies provide support for the EKC hypothesis (e.g., Apergis 2016; Churchill et al. 2018; Dogan and Seker 2016; Jeffords and Thompson 2019; Kasioumi 2021; Kasioumi and Stengos 2023; Sarkodie and Ozturk 2020; Sinha and Shahbaz 2018, among many others)), some studies found N-shaped relationship between pollution and economic development (e.g., Balsalobre-Lorente et al. 2017; Özokcu and Özdemir 2017) and some other studies find no support for the EKC hypothesis (e.g., Al-Mulali et al. 2015; Inglesi-Lotz and Dogan 2018; Ozcan et al. 2018). The readers are referred to Sarkodie and Strezov (2019) for a detailed review of the EKC hypothesis. One of the key inputs of the production is energy consumption, and the existing literature also examines the role of energy consumption for the CO_2 emissions as part of the EKC hypothesis (Al-Mulali et al. 2015; Destek and Sarkodie 2019; Karahasan and Pinar 2021; Sarkodie and Ozturk 2020; Shahbaz et al. 2020; Usman et al. 2019, among many others).

Other important factors that are found to be important for environmental degradation are foreign direct investment (FDI) flows and trade activities. The so-called pollution haven hypothesis (PHH) has been extensively examined, which argues that both FDI and trade flows in developing countries are due to their weak environmental regulations, while leading to increased environmental degradation in these countries. Most of the existing studies find a positive association between FDI flows and CO_2 emissions (see e.g., Sapkota and Bastola 2017; Hanif et al. 2019; Nawaz et al. 2021; Salehnia et al. 2020; among others). On the other hand, another strand of the literature shows a negative effect of FDI flows on CO_2 emissions, known as the pollution halo effect, as FDI flows lead to increased use of advanced technologies and improved management practices (see e.g., Huang et al. 2017; Wang et al. 2019; Zhu et al. 2016). Ahmad et al. (2021) find support for pollution haven or halo effects depending on the Chinse province examined (see also Apergis et al. 2023 for the effect of bilateral FDI flows on CO_2 emissions). Similar to the findings regarding the effects of FDI flows on environmental quality, the effect of trade on environmental quality provides mixed findings. One strand of the literature found that trade openness led to improved technology use and knowledge spillovers, known as the technique effect, and reduces CO_2 emissions (see e.g., Shahbaz et al. 2012, 2013; Koc and Bulus 2020). Another strand of literature argues that trade openness increases economic activity and leads to increased CO_2 emissions (see e.g., Ahmed et al. 2017; Cai et al. 2018; Chen et al. 2022; Dou et al. 2021; Li et al. 2021b; Rahman et al. 2021).

The level of urbanization has been integrated into the analysis of environmental degradation. One strand of literature finds that urbanization leads to increased energy efficiency and innovation, subsequently, decreasing environmental degradation (see e.g., Charfeddine and Mrabet 2017; Liobikienė and Butkus 2019); whereas, another strand of the literature argues that urbanization leads to increased energy consumption and therefore hampers environmental quality (Al-Mulali and Ozturk 2015; Dauda et al. 2021; Pata 2018; Sheng and Guo 2016; Wang et al. 2018).

3 Data and empirical strategy

3.1 Data and variables

In line with the existing literature, we use CO_2 emissions per capita as a proxy for environmental degradation (Bhattacharyya et al. 2018; Farooq 2022; Mahalik et al. 2021; Sharma et al. 2019, among others). The data on CO_2 emissions per capita are obtained from the World Development Indicators of the World Bank. By contrast, the variable with the main interest in this paper is aid flows with environmental targets. During the Earth Summit in Rio de Janeiro in 1992, the countries committed to helping developing countries in the implementation of the Rio Conventions. Therefore, the OECD-DAC statistical department has been keeping a record of aid flows to the developing countries that aim to target Global Environmental Objectives. We use total aid flows to the developing countries that aim to tackle environmental goals (OECD 2021c). The four-scoring system has been used to identify aid flows to the developing countries. These are mainly marked as targeting the environment as a (i) "principal" objective, or (ii) "significant" objective, or alternatively the aid flows did, or (iii) not target the objective, but screened, or (iv) not screened (OECD 2021b for the details of the scoring system). In this paper, we test whether different aid classifications have a varying effect on CO_2 emissions in developing countries. After eliminating the data with missing observations, we end up with 97 countries with a yearly balanced panel data set between 2002 and 2018 (see "Appendix A" for the country list). This green aid flows data are part of the Official development assistance (ODA) of the OECD, which targets the socioeconomic welfare of developing countries. Therefore, we consider only 97 developing countries as part of our analysis as green aid is only allocated to developing countries.

In the empirical setting, we examine the effects of the overall aid flows targeting the environment (AID-T); aid flows classified to meet the principal objective of Rio Conventions (AID-P); aid flows that meet the significant objective of Rio Conventions (AID-S); aid flows that do not target the Rio Convention objectives, but screened (AID-NTBS); and aid flows that are not screened (AID-NS). For the robustness of the analysis, aid data is used in two forms: (i) different types of green aid flows are divided by the total population, and (ii) different types of green aid flows are presented as a percentage of GDP.

We also account for the standard control variables, along with the existing literature discussed in Sect. 2. To test the EKC hypothesis, we also include GDP per capita (measured in constant 2010 US$), and the square of GDP per capita. We also control for energy consumption per capita (measured in kg oil equivalent), trade openness (measured as the sum of the imports and exports as a percentage of GDP), net inflows of foreign direct investment (measured as a % of GDP), and urban population

Table 1 Descriptive statistics

Variables	Mean	Median	SD	Range
CO_2 emissions per capita	2.13	1.30	2.46	16.01
GDP per capita	3748.96	2902.77	3334.66	17,780.50
Energy consumption per capita	938.61	653.26	1031.64	7953.24
Trade openness	75.25	69.48	34.80	311.19
FDI (% of GDP)	4.52	2.94	6.75	140.49
Urbanization	50.68	49.31	19.40	86.65
AID—P (% of GDP)	0.17	0.06	0.38	8.92
AID—S (% of GDP)	0.35	0.11	0.67	11.05
AID—NTBS (% of GDP)	1.61	0.72	2.55	26.13
AID—NS (% of GDP)	0.35	0.09	0.78	12.40
AID—T (% of GDP)	2.49	1.41	3.34	29.31
AID—P per capita	3.90	1.02	13.01	322.66
AID—S per capita	5.62	2.06	12.87	276.62
AID—NTBS per capita	24.90	12.96	39.39	484.76
AID—NS per capita	4.96	1.58	10.38	149.97
AID—T per capita	39.39	23.08	54.60	655.76

(measured as a percentage of the total population). All the data for control variables, except energy consumption, is obtained from the World Development Indicators of the World Bank. Total energy consumption data are available up to 2014 in the World Bank Development Indicators, henceforth, we obtained the total energy consumption from the U.S. Energy Information Administration.[1] Table 1 shows certain summary statistics. On average, the percentage of the green aid targeting environmental objectives principally or significantly takes a smaller percentage of total aid flows (i.e., 0.17 and 0.35% of the GDP), compared to the aid that does not target environmental objectives, but screened (i.e., 1.61% of the GDP).

3.2 Empirical strategy

The goal is to explore the role of environmental aid in CO_2 emissions per capita. To this end, the model specification yields:

$$\begin{aligned} CO2_{i,t} = {} & c_1 EAID_t + c_2 GDPY_{i,t} + c_3 GDPY_{i,t}^2 + c_4 EC_{i,t} + c_5 TO_{i,t} + c_6 URB_{i,t} \\ & + c_7 FDI_{i,t} + \alpha_i + \beta_t + b_0 + v_{i,t} \end{aligned} \tag{1}$$

where CO_2 is carbon emissions per capita, GDPY is GDP per capita, $GDPY^2$ is GDP per capita squared, EC shows energy consumption per capita, TO denotes trade openness, URB denotes urbanization, and FDI is foreign net direct investment inflows.

[1] The data set could be obtained from https://www.eia.gov/international/data/world.

EAID denotes environmental aid, and we include different types of environmental aid to the estimations one at a time (i.e., AID-T, AID-P, AID-S, AID-NTBS and AID-NS as a percentage of GDP and per capita). The model allows for both country and time fixed effects, α_i and β_t, respectively, and b_0 is the constant term. In a panel country framework, the disturbances $v_{i,t}$ are uncorrelated. They are assumed to be independently distributed across countries with a zero mean. To avoid the presence of potential endogeneity issues, we estimate the dynamic panel data model using the General Method of Moments (GMM) method recommended by Arellano and Bover (1995) and Blundell and Bond (1998). The presence of endogeneity potentially could come through reverse causality between carbon emissions and any of the covariates. For instance, Azam et al. (2016) provide evidence that carbon emissions have a significant positive impact on economic growth in the cases of China, Japan, and the US, while it has a negative effect in the case of India. Similar results are reached by Zou and Zhang (2020) based on panel data from 30 regions in China. Similarly, it has also been found causality running from CO_2 emissions to FDI inflows and CO_2 emissions to trade openness (Shao et al. 2019). Therefore, to account for the potential endogeneity of the covariates, we use the GMM estimation and use lagged values of the covariates as instrumental variables (see e.g., Apergis and Pinar 2021; Hove and Tursoy 2019; Li et al. 2021a, b; Mahadevan and Sun 2020; among others, for the use of GMM methods).

In addition, the empirical analysis will make use of panel causality introduced by Dumitrescu and Hurlin (2012). This test can be used when T > N (with T being the number of observations and N the number of countries considered) which is our case here. The corresponding Wald statistic is defined as: $Z_{N,T} = \sqrt{\frac{N}{2K}}\left(W_{N,T} - K\right)$, where K is the number of lags in the corresponding vector autoregression (VAR) model, and:

$$W_{N,T} = \frac{1}{N}\sum_{i=1}^{N} W_{i,T} \tag{2}$$

where $W_{i,T}$ stands for the individual Wald statistical values for cross-section units.

4 Empirical analysis

The unit root tests are essential for determining whether we should use levels or first differences of the covariates in the GMM estimations. However, to determine which set of unit root tests (i.e., first- or second-generation) are suitable for our analysis, we investigate the degree of residual cross-sectional dependence in the first step of the empirical analysis. The previous literature generally used first-generation unit root tests to test for the stationarity, assuming cross-sectional independence; however, most macro-level data is usually cross-sectionally dependent (Pesaran 2015). Therefore, we first explore the degree of residual cross-sectional dependence. To this end, the cross-sectional dependence (CD) statistic by Pesaran (2004) is employed. The results are reported in Table 2 and uniformly reject the null hypothesis of cross-section indepen-

Table 2 Cross dependence tests

Variables	CD test	p-value
CO_2 emissions per capita	8.92	0.01
GDP per capita	8.36	0.00
GDP per capita squared	9.45	0.00
Energy consumption per capita	7.44	0.00
Trade openness	8.93	0.01
FDI (% of GDP)	7.85	0.00
Urbanization	7.15	0.00
AID—P (% of GDP)	9.07	0.00
AID—S (% of GDP)	10.84	0.00
AID—NTBS (% of GDP)	9.42	0.00
AID—NS (% of GDP)	11.92	0.00
AID—T (% of GDP)	10.51	0.01
AID—P per capita	9.74	0.00
AID—S per capita	11.63	0.00
AID—NTBS per capita	10.07	0.00
AID—NS per capita	9.85	0.00
AID—T per capita	9.52	0.00

The test is based on the sum of correlation coefficient squares among cross sectional residuals. This test, which is asymptotically standard normal

dence, suggesting that all of the variables are cross-sectionally dependent.

Next, a second-generation panel unit root test is employed to determine the degree of integration of the respective variables. The Pesaran (2007) panel unit root test does not require the estimation of factor loading to eliminate cross-sectional dependence. The null hypothesis is a unit root for the Pesaran (2007) test. The results are presented in Table 3. They indicate that all variables are stationary in their first differences. Therefore, based on these unit root results, the first differences of the covariates are used in the GMM estimations.

Table 4 reports the baseline empirical results using the static GMM estimations. Columns (1) through (10) display the estimates when all controls are included, while each column corresponds to the ten definitions of the environmental aid variable. The first five columns define the aid variable as a percentage of GDP, while the five remaining columns include the aid variable defined in per capita terms. Firstly, we highlight the relevant diagnostics. In all cases, we test for the serial correlation in the error term by using the Arellano-Bond test. The AR (2) test results suggest that the null hypothesis is rejected, indicating no second-order serial correlation. Furthermore, difference-in-Hansen is the test of the validity of GMM instruments and the test of overidentification is based on the Hansen J statistic. In particular, the diagnostics reject the null hypothesis of difference-in-Hansen tests, thus, supporting the validity of the instruments considered.

Table 3 Unit root tests

Variables	Levels	First differences
CO_2 emissions per capita	– 1.271	– 7.344***
GDP per capita	– 1.448	– 6.985***
GDP per capita squared	– 1.519	– 7.549***
Energy consumption per capita	– 1.233	– 8.992***
Trade openness	– 1.195	– 7.540***
FDI (% of GDP)	– 1.166	– 8.714***
Urbanization	– 1.258	– 6.853***
AID—P (% of GDP)	– 1.463	– 8.709***
AID—S (% of GDP)	– 1.225	– 7.664***
AID—NTBS (% of GDP)	– 1.349	– 7.451***
AID—NS (% of GDP)	– 1.528	– 7.983***
AID—T (% of GDP)	– 1.254	– 8.073***
AID—P per capita	– 1.561	– 6.832***
AID—S per capita	– 1.447	– 7.235***
AID—NTBS per capita	– 1.251	– 7.984***
AID—NS per capita	– 1.367	– 7.994***
AID—T per capita	– 1.543	– 8.854***

A constant is included in the Pesaran (2007) tests. The results are reported under the null hypothesis of stationarity. Critical values are: – 2.40 at 1%, – 2.22 at 5%, and – 2.14 at 10%. The Pesaran results are reported at lag = 4. ***: $p \leq 0.01$

Our findings remain consistently similar across all specifications. More specifically, the estimates clearly document a negative and statistically significant impact of environmental aid on CO_2 emissions per capita across the panel of countries under consideration. Overall, we find that all types of environmental aid flows negatively affect CO_2 emissions per capita; however, the magnitude of the aid flows principally targeting the environmental objectives is the highest among all types of sub-category green aid flows. For instance, if the growth of the environmental aid targeting environmental objectives principally (i.e., ΔAID—P) increases by one unit as a percentage of GDP, CO_2 emissions per capita decreases by 0.0673. On the other hand, growth in environmental aid significantly targeting environmental objectives (i.e., ΔAID—S), not targeting objectives, but screened (i.e., ΔAID—NTBS) and not screened (i.e., ΔAID—NS) increases by one unit as a percentage of GDP, CO_2 emissions per capita decreases by 0.0639, 0.0611, and 0.0583, respectively. When the aid variable is defined in per capita terms, we also observe a similar trend where the magnitude of the coefficient of green aid is higher when aid targets the environmental objectives principally or significantly compared to non-screened aid flows. In other words, our findings demonstrate that the environmental aid that targets objectives principally or significantly leads to more reduction in CO_2 emissions. Therefore, more aid allocation in these categories would contribute achieving reduction in CO_2 emissions in developing countries.

Table 4 Static GMM estimates

Aid variable used	ΔAID—P	ΔAID—S	ΔAID—NTBS	ΔAID—NS	ΔAID—T	ΔAID—P	ΔAID—S	ΔAID—NTBS	ΔAID—NS	ΔAID—T
Variables	1	2	3	4	5	6	7	8	9	10
ΔEAID—(% of GDP)	− 0.0673***	− 0.0639***	− 0.0611***	− 0.0583***	− 0.0714***					
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]					
ΔEAID per capita						− 0.0655***	− 0.0618***	− 0.0584***	− 0.0552***	− 0.0686***
						[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
ΔGDP per capita	− 0.0209***	− 0.0196***	− 0.0181***	− 0.0169***	− 0.0248***	− 0.0211***	− 0.0175***	− 0.0162***	− 0.0138**	− 0.0274***
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.02]	[0.00]
ΔGDP per capita squared	0.0461***	0.0419***	0.0378***	0.0412***	0.0392***	0.0429***	0.0407***	0.0448***	0.0432***	0.0492***
	[0.00]	[0.00]	[0.00]	[0.00]	[0.01]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
ΔEnergy consumption per capita	0.0371***	0.0352***	0.0340***	0.0327***	0.0410***	0.0318***	0.0282**	0.0254**	0.0219**	0.0349***
	[0.00]	[0.00]	[0.00]	[0.01]	[0.00]	[0.01]	[0.02]	[0.03]	[0.05]	[0.00]
ΔTrade openness	0.0441***	0.0425***	0.0419***	0.0396***	0.0473***	0.0452***	0.0426***	0.0421***	0.0386***	0.0502***
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
ΔFDI	− 0.0417***	− 0.0395***	− 0.0372***	− 0.0366***	− 0.0467***	− 0.0409***	− 0.0389***	− 0.0351***	− 0.0329***	− 0.0448***
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
ΔUrbanization	0.0591***	0.0568***	0.0535***	0.0518***	0.0625***	0.0560***	0.0538***	0.0509***	0.0491***	0.0588***
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
Constant	0.128	0.136	0.122	0.131	0.114	0.116	0.125	0.130	0.135	0.132

Table 4 (continued)

Aid variable used	ΔAID—P	ΔAID—S	ΔAID—NTBS	ΔAID—NS	ΔAID—T	ΔAID—P	ΔAID—S	ΔAID—NTBS	ΔAID—NS	ΔAID—T
	[0.19]	[0.17]	[0.23]	[0.18]	[0.29]	[0.18]	[0.22]	[0.18]	[0.17]	[0.18]
Diagnostics										
Country fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
R2-adjusted	0.83	0.79	0.73	0.75	0.87	0.84	0.80	0.75	0.73	0.85
Number of instruments	17	16	19	18	17	17	18	20	19	18
AR(2)	[0.46]	[0.42]	[0.49]	[0.40]	[0.53]	[0.50]	[0.47]	[0.45]	[0.46]	[0.52]
Hansen Overidentification	[0.95]	[0.95]	[0.93]	[0.91]	[0.98]	[0.98]	[0.95]	[0.92]	[0.94]	[0.99]
Difference-in-Hansen	[0.99]	[0.99]	[0.98]	[0.98]	[0.99]	[0.99]	[0.98]	[0.97]	[0.98]	[0.99]

Columns (1) through (10) display the estimates when all controls are included, while each column corresponds to the ten definitions of the environmental aid variable. The number of lags was determined through the Akaike criterion. The first five columns define the aid variable as percentage of GDP, while the five remaining columns include the aid variable defined in per capita terms. The GMM instruments are collapsed to avoid over-proliferation following Roodman (2009). AR(2) is the test for auto-correlation of order 2 in first-differenced errors. Difference in Hansen is the test of validity of GMM instruments in the level equation. The test of overidentification is based on the Hansen J statistic. The null hypothesis is that the instruments are valid (i.e., uncorrelated with the error term), and that the exclusions restrictions are valid (i.e., the instruments are correctly excluded from the second-stage equation). **: $p \leq 0.05$, ***: $p \leq 0.01$

In terms of the remaining controls, the estimates clearly document that energy consumption, trade openness and urbanization exert a positive and statistically significant impact on CO_2 emissions per capita. In contrast, FDI has a negative impact on carbon emissions. The effects of the GDP per capita and the squared term of GDP per capita turns out to be negative and positively, respectively, which offers evidence of an U-shaped relationship between income and environmental pollution. This finding highlights that the increase in GDP per capita leads to decrease in CO_2 emissions initially but then leads to an increase in CO_2 emissions. This finding is in line with the studies that highlight an N-shaped relationship between income and environmental pollution (see e.g., Balsalobre-Lorente et al. 2017; Karahasan and Pinar 2021; Özokcu and Özdemir 2017). In other words, increases in trade openness, urbanization and energy consumption lead to increased CO_2 emissions, which are in line with the existing literature (Al-Mulali and Ozturk 2015; Ahmed et al. 2017; Cai et al. 2018; Destek and Sarkodie 2019; Dauda et al. 2021; Dou et al. 2021). In other words, increase in trade openness leads to an increased economic activity and therefore increases CO_2 emissions in developing countries. In contrast, growth in FDI flows to developing countries leads to decreased CO_2 emissions, which confirms the pollution halo effect, as FDI flows lead to an increased use of advanced technologies and improved management practices (see e.g., Huang et al. 2017; Wang et al. 2019; Zhu et al. 2016).

5 Robustness analysis

5.1 The dynamic model

This section repeats the baseline analysis (Table 4), but this time, the dynamic version of Eq. (1) is considered in which certain lags of all the covariates are allowed. The number of lags has been determined through the Akaike criterion. The new findings are reported in Table 5 and provide robust support to those reported previously. Based on the Akaike criterion, the estimations include lagged GDP per capita, trade openness and FDI growth levels in the estimation compared to the estimations reported in Table 4. Overall, all types of environmental aid flows negatively affect CO_2 emissions per capita, but the magnitude of the coefficients of aid targeting environmental objectives principally (columns 1 and 6) and significantly (columns 2 and 7) are larger than those of the coefficients of aid not targeting objectives, but screened (columns 3 and 8) and not screened (columns 4 and 9). Furthermore, the coefficients of the lagged GDP per capita, trade openness and FDI growth levels are also significant and the signs of the lagged coefficients of these variables are similar to those reported in Table 4. Overall, the findings are consistent with the dynamic GMM estimations.

5.2 Panel non-causality test

In this part, to examine that the direction of the causality between green aid flows and CO_2 emissions, the panel non-causality test developed by Dumitrescu and Hurlin (2012) is performed. Under the null hypothesis, it is assumed that there is no individual

Table 5 Dynamic GMM estimates

Aid variable used	ΔAID—P	ΔAID—S	ΔAID—NTBS	ΔAID—NS	ΔAID—T	ΔAID—P	ΔAID—S	ΔAID—NTBS	ΔAID—NS	ΔAID—T
Variables	1	2	3	4	5	6	7	8	9	10
ΔEAID—(% of GDP)	− 0.0644***	− 0.0594***	− 0.0584***	− 0.0562***	− 0.0665***					
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]					
ΔEAID per capita						− 0.0653***	− 0.0622***	− 0.0593***	− 0.0546***	− 0.0663***
						[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
ΔGDP per capita	− 0.0194***	− 0.0178***	− 0.0170***	− 0.0157***	− 0.0216***	− 0.0198***	− 0.0180***	− 0.0160***	− 0.0129**	− 0.0242***
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.03]	[0.00]
ΔGDP per capita (− 1)	− 0.0091**	− 0.0074**	− 0.0066**	− 0.0061**	− 0.0129***	− 0.0098**	− 0.0083**	− 0.0062**	− 0.0053*	− 0.0132***
	[0.02]	[0.03]	[0.04]	[0.04]	[0.01]	[0.02]	[0.03]	[0.04]	[0.05]	[0.00]
ΔGDP per capita squared	0.0429***	0.0395***	0.0370***	0.0399***	0.0426***	0.0408***	0.0382***	0.0404***	0.0419***	0.0464***
	[0.00]	[0.00]	[0.00]	[0.00]	[0.01]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
ΔEnergy consumption per capita	0.0365***	0.0343***	0.0329***	0.0317***	0.0405***	0.0302***	0.0274**	0.0241**	0.0205**	0.0314***
	[0.00]	[0.00]	[0.00]	[0.01]	[0.00]	[0.01]	[0.02]	[0.03]	[0.05]	[0.00]
ΔTrade openness	0.0426***	0.0411***	0.0407***	0.0384***	0.0436***	0.0428***	0.0410***	0.0406***	0.0370***	0.0463***
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
ΔTrade openness (− 1)	0.0318***	0.0293***	0.0262***	0.0217***	0.0174**	0.0302***	0.0272***	0.0239***	0.0214***	0.0341***
	[0.00]	[0.00]	[0.00]	[0.00]	[0.01]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
ΔFDI	− 0.0381***	− 0.0357***	− 0.0334***	− 0.0318***	− 0.0426***	− 0.0397***	− 0.0356***	− 0.0326***	− 0.0302***	− 0.0418***

Table 5 (continued)

Aid variable used	ΔAID—P	ΔAID—S	ΔAID—NTBS	ΔAID—NS	ΔAID—T	ΔAID—P	ΔAID—S	ΔAID—NTBS	ΔAID—NS	ΔAID—T
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
ΔFDI (− 1)	− 0.0165**	− 0.0133**	− 0.0102**	− 0.0084*	− 0.0189**	− 0.0144**	− 0.0127**	− 0.0094**	− 0.0076*	− 0.0183**
	[0.03]	[0.04]	[0.05]	[0.06]	[0.02]	[0.03]	[0.04]	[0.05]	[0.07]	[0.02]
Δurbanization	0.0560***	0.0531***	0.0502***	0.0475***	0.0584***	0.0543***	0.0521***	0.0492***	0.0477***	0.0571***
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
Diagnostics										
Country fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
R2-adjusted	0.86	0.82	0.75	0.79	0.88	0.86	0.83	0.77	0.76	0.89
Number of instruments	24	27	25	27	24	26	30	24	25	24
AR(2)	[0.48]	[0.47]	[0.54]	[0.45]	[0.56]	[0.52]	[0.51]	[0.48]	[0.50]	[0.55]
Hansen Overidentification	[0.96]	[0.96]	[0.95]	[0.94]	[0.99]	[0.99]	[0.97]	[0.93]	[0.96]	[0.99]
Difference-in-Hansen	[0.99]	[0.99]	[0.99]	[0.99]	[0.99]	[0.99]	[0.98]	[0.98]	[0.99]	[0.99]

Columns (1) through (10) display the estimates when all controls are included, while each column corresponds to the ten definitions of the environmental aid variable. The number of lags was determined through the Akaike criterion. The first five columns define the aid variable as percentage of GDP, while the five remaining columns include the aid variable defined in per capita terms. The GMM instruments are collapsed to avoid over-proliferation following Roodman (2009). AR(2) is the test for auto-correlation of order 2 in first-differenced errors. Difference in Hansen is the test of validity of GMM instruments in the level equation. The test of overidentification is based on the Hansen J statistic. The null hypothesis is that the instruments are valid (i.e., uncorrelated with the error term), and that the exclusions restrictions are valid (i.e., the instruments are correctly excluded from the second-stage equation). **: $p \leq 0.05$, ***: $p \leq 0.01$

causality relationship from one variable to another exists. This hypothesis is denoted as the Homogeneous Non-Causality (HNC) hypothesis. Under the alternative hypothesis, it is assumed that there is a causal relationship from one variable to another for a subgroup of individuals and the coefficients may differ across groups.

The causality results are reported in Table 6. According to them, we can highlight the presence of univariate causality at the 1% level, running from all types of environmental aid to CO_2 emissions per capita. Therefore, environmental aid significantly affects CO_2 emissions per capita levels, but CO_2 emissions per capita of developing countries do

Table 6 Dumitrescu and Hurlin panel Granger non-causality test results

Null hypothesis	*p*-value
Principal Aid targetting Rio Convention as % of GDP	
Environmental aid does not cause carbon emissions	[0.00]
Carbon emissions does not cause environmental aid	[0.28]
Significant Aid targetting Rio Convention as % of GDP	
Environmental aid does not cause carbon emissions	[0.00]
Carbon emissions does not cause environmental aid	[0.33]
Aid not targetting Rio Convention but screened as % of GDP	
Environmental aid does not cause carbon emissions	[0.00]
Carbon emissions does not cause environmental aid	[0.21]
Aid not screened as % of GDP	
Environmental aid does not cause carbon emissions	[0.00]
Carbon emissions does not cause environmental aid	[0.27]
Total environmental aid—Sum of the previous four definitions	
Environmental aid does not cause carbon emissions	[0.00]
Carbon emissions does not cause environmental aid	[0.39]
Principal Aid targetting Rio Convention (per capita)	
Environmental aid does not cause carbon emissions	[0.00]
Carbon emissions does not cause environmental aid	[0.18]
Significant Aid targetting Rio Convention (per capita)	
Environmental aid does not cause carbon emissions	[0.00]
Carbon emissions does not cause environmental aid	[0.24]
Aid not targetting Rio Convention but screened (per capita)	
Environmental aid does not cause carbon emissions	[0.00]
Carbon emissions does not cause environmental aid	[0.30]
Aid not screened (per capita)	
Environmental aid does not cause carbon emissions	[0.00]
Carbon emissions does not cause environmental aid	[0.16]
Total environmental aid—Sum of the previous four definitions (per capita)	
Environmental aid does not cause carbon emissions	[0.00]
Carbon emissions does not cause environmental aid	[0.42]

not significantly affect the green aid allocation. In other words, the non-causality tests confirm the causal link running from the environmental aid to CO_2 emissions per capita and support our findings with the GMM estimations.

6 Conclusion and policy implications

Climate change imposes a wide range of negative consequences on developing countries. To combat and alleviate the negative implications of climate change, developed countries and international organizations have been allocating environmental aid to developing countries. These green aid flows to developing countries have been rated in terms of their targets: (i) targeting environmental objectives principally; (ii) targeting environmental objectives significantly; (iii) green aid that does not target objectives, but screened; and (iv) not screened.

In this paper, we found that the aid classification mattered by using two different estimation methods, GMM estimation and non-causality tests, and green aid flows to 97 developing countries between 2002 and 2018. In particular, we found that the magnitude of the impact of the reduction of the CO_2 emissions was relatively higher if aid was classified as principally or significantly targeting the environmental objectives than those not targeted, nor screened. Our findings were also robust to the inclusion of the standard set of control variables and our analysis also tackled potential endogeneity problems.

Even though all types of green aid flows matter for reducing CO_2 emissions per capita, the green aid that targets the environmental objectives does a better job in reducing CO_2 emissions. Therefore, international organizations and developed countries (i.e., donors) should place more aid classified to target environmental objectives principally or significantly to increase the effectiveness of the green aid. Furthermore, beyond the negative impact of green aid on CO_2 emissions, we also found that the change in FDI reduces CO_2 emissions, and the increase in urbanization leads to increased CO_2 emissions. Therefore, developing countries should promote policies that foster FDI flows because FDI flows lead to increased use of advanced technologies and improved management practices (see e.g., Huang et al. 2017; Wang et al. 2019; Zhu et al. 2016) and reduce CO_2 emissions. Furthermore, developing countries should promote smart cities with efficient energy use during urbanization to improve energy efficiency and reduce CO_2 emissions.

There are some limitations of the study and potential future research areas. Firstly, our analysis covers yearly data up to 2018 due to data availability, and future studies could evaluate the implications of green finance for pollution in developing countries in recent years by analyzing a recent data set. Secondly, this paper examined the impact of green finance on CO_2 emissions in developing countries; however, a future study could also evaluate the impact of green finance on renewable energy adaptation and energy efficiency.

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Declarations

Conflict of interest The authors declare no competing interests.

Ethics approval and consent to participate This article does not contain any studies with human participants or animals performed by any of the authors.

Consent for publication All authors agreed to publish the article.

Appendix A

Countries included in the empirical analysis

Albania, Algeria, Angola, Antigua and Barbuda, Argentina, Armenia, Azerbaijan, Bangladesh, Belarus, Belize, Benin, Bhutan, Bolivia, Bosnia and Herzegovina, Botswana, Brazil, Burkina Faso, Burundi, Cabo Verde, Cameroon, Central African Republic, Chad, Chile, China, Colombia, Congo Dem. Rep., Congo Rep., Costa Rica, Cote d'Ivoire, Dominica, Dominican Republic, Ecuador, Egypt, El Salvador, Eswatini, Fiji, Gabon, Gambia, Georgia, Ghana, Grenada, Guatemala, Guinea, Guinea-Bissau, Haiti, Honduras, India, Indonesia, Iran, Iraq, Jamaica, Jordan, Kazakhstan, Kenya, Kyrgyz Republic, Lebanon, Liberia, Libya, Madagascar, Malaysia, Mali, Mauritania, Mauritius, Mexico, Mongolia, Morocco, Mozambique, Myanmar, Namibia, Nepal, Nicaragua, Niger, Nigeria, Pakistan, Panama, Paraguay, Peru, Philippines, Rwanda, Senegal, Sierra Leone, South Africa, Sri Lanka, Sudan, Tanzania, Thailand, Togo, Tunisia, Turkey, Turkmenistan, Uganda, Ukraine, Uruguay, Uzbekistan, Vietnam, Zambia, Zimbabwe.

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