

Country groups in global transnational environmental investments to achieve sustainable development goals

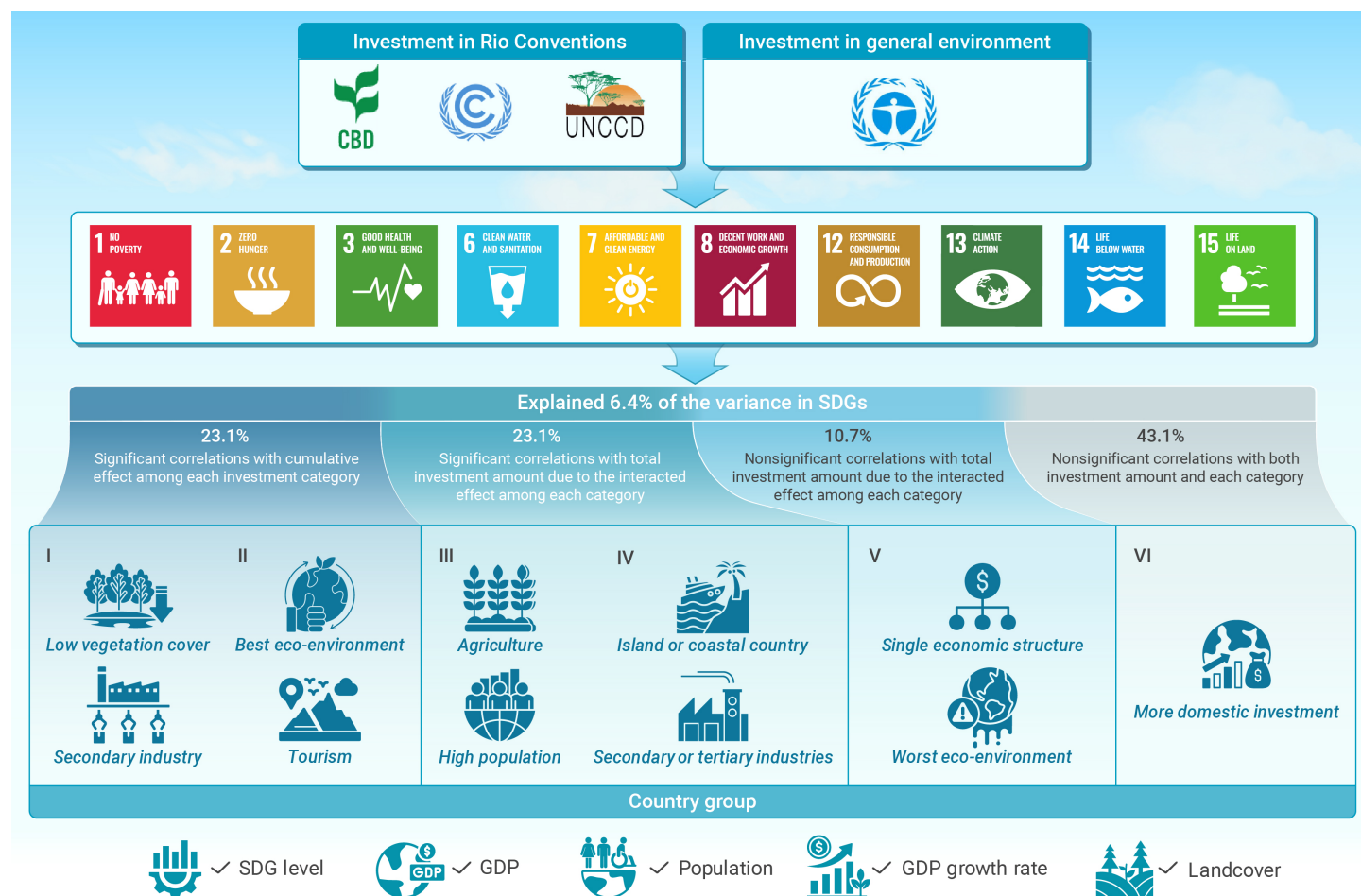
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Received: September 3, 2024; Accepted: April 23, 2025; Published Online: April 27, 2025; <https://doi.org/10.59717/j.xinn-geo.2025.100138>

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GRAPHICAL ABSTRACT



PUBLIC SUMMARY

- Transnational environmental investments explain 6% variance in SDGs across 130 countries.
- Investment impacts vary by socioeconomic status, resources, and funding, categorizing nations into six groups.
- Customized strategies per group are crucial to promote equity and accelerate SDG achievement by 2030.

Country groups in global transnational environmental investments to achieve sustainable development goals

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Received: September 3, 2024; Accepted: April 23, 2025; Published Online: April 27, 2025; <https://doi.org/10.59717/j.xinn-geo.2025.100138>

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Citation: Zhou C., Feng X., Maestre F., et al. (2025). Country groups in global transnational environmental investments to achieve sustainable development goals. *The Innovation Geoscience* 3:100138.

Transnational environmental investments aim to narrow the gap among developing countries in achieving sustainable development goals (SDGs). Despite their importance, how these investments are associated with SDG performance is largely unknown. Using data for 10 SDGs and 130 countries, we analyzed transnational environmental investments toward achieving SDGs globally. We found significant positive correlations between such investments and individual or composite SDG indicators. Transnational environmental investments accounted for 6.4% of the variance in SDG performance, correlating with the achievement of sustainable development in 56.9% of countries. These correlations, however, varied across countries, which we identified and categorized into six main country groups based on socioeconomic and natural resource contexts and in the amount of investment received. Our results indicate that policies should focus on enhancing environmental investments, balancing the distribution of investments among countries, and optimizing the trade-offs associated with investing and achieving SDGs within each country group. Our research provides novel insights into the potential of transnational environmental investment to promote equity among countries and accelerate progress toward sustainable development by 2030.

INTRODUCTION

Sustainable development remains an ambitious goal in the face of ongoing climate change, land degradation, and biodiversity loss worldwide, thus requiring urgent and immediate global action.^{1,2} The “2030 Agenda for Sustainable Development”, a framework of 17 goals, 169 targets, and 247 indicators, was adopted by the UN General Assembly in 2015 to promote the sustainable growth of the global economy while protecting the planet from degradation.^{3,4} Much progress has been made in determining how socioeconomic (e.g., national development policies and international trade) and technological (e.g., clean energy and carbon sequestration) advances may influence sustainable development.⁵⁻⁷ However, environmental protection measures have been found to restrict socioeconomic development due to the high short-term cost of industrial transformation and the exacerbation of inequality and poverty by improperly designed environmental policies, halting progress toward achieving SDGs.⁷

The Rio Conventions, including the United Nations Framework Convention on Climate Change (UNFCCC), the Convention on Biological Diversity (CBD), and the United Nations Convention to Combat Desertification (UNCCD), aim to promote a sustainable planet for future generations by achieving global agreement on key environmental goals.^{2,8} In response to these goals, both domestic and international environmental investments (e.g., Global Environment Facility (GEF)⁹) have been made and contribute directly to capacity building and the development of national strategies and programs to conserve biodiversity and address climate change.⁸ Although national efforts to invest in environmental goals have achieved limited progress,¹⁰ international investments are being recognized as an increasingly important tool for achieving multiple SDGs.^{11,12} Annually, public financial service providers invest approximately \$128 billion in transnational environmental initiatives,¹¹ with

the primary objective of assisting developing countries in addressing environmental challenges, reducing poverty, and advancing national development strategies. These investments play a crucial role in bridging the gaps among countries and supporting the achievement of SDGs.⁸

Despite recognition at the highest political level of the importance of transnational environmental investments to achieve SDGs,¹¹ whether these investments directly contribute to sustainable development is still unknown. Recent research has raised concerns about the potential trade-offs, cascading effects, and synergies among various environmental and socioeconomic objectives, particularly in the context of initiatives aimed at achieving environmental goals.⁵⁻⁷ For example, some studies have highlighted the potential negative impact of climate change mitigation efforts on the livelihoods of those who depend on activities such as wood/forage harvesting and agriculture for their income.¹³ Other studies have shown that differences in levels of national development, such as those associated with resource abundance, population, livelihoods, and the wealth gap, restrain progress toward achieving the global SDGs.¹⁴⁻¹⁶ Although the importance of increasing transnational investment for sustainable development has been widely acknowledged,¹¹ the potential impacts of such investments in different countries have not yet been examined using a standardized approach. Previous research on this topic has been constrained by variations across countries in terms of the benefits, main objectives, and constraints of sustainable development in response to transnational investments.¹⁷ The absence of a standardized evaluation framework has created uncertainty about the potential of transnational environmental investments for solving global sustainable development challenges. This potential may not be fully realized if environmental investments are solely tested and evaluated at regional and/or national scales.¹¹ In the worst-case scenario, the lack of adequate evaluation and design of environmental investments or projects may undermine the credibility of transnational environmental assistance, limit the promotion of global transnational environmental investment and assistance programs, erode donor confidence, and divert efforts away from achieving global environmental goals.¹⁸

To fill existing knowledge gaps regarding the impacts of transnational environmental investment, here, we address three main questions: (i) are current transnational environmental investments significantly associated with the global achievement of the SDGs, and if so, how?; (ii) have transnational environmental investments helped promote equity and fairness when achieving sustainable development among countries, and if not, for what reasons?; and (iii) what should we do to better contribute to the achievement of the SDGs with transnational environmental investments?

To address these questions, we gathered data from the Development Assistance Committee's Creditor Reporting System (DAC CRS) of the Organization for Economic Cooperation and Development (OECD).¹⁹ We focused on the 130 developing countries that received these investments, including official development assistance and other official flows, from 2002 to 2018. These statistics offer a comprehensive overview of international environmental investment to achieve the Rio Convention goals, such as biodiversity conservation, climate change adaptation and mitigation, and combating desertification, as well as general environmental objectives such as improv-

A Transnational investment in global environment goal

Investment in Rio Conventions



✓ Biodiversity investment

The biodiversity investment targets the Convention on Biological Diversity, which objectives are the conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of the benefits arising from commercial and other utilization of genetic resources.



✓ Climate change adaptation & mitigation investment

The climate change investment targets United Nations Framework Convention on Climate Change, which sets an overall framework for intergovernmental efforts to tackle the challenge posed by climate change, including climate change mitigation and adaptation.



✓ Desertification investment

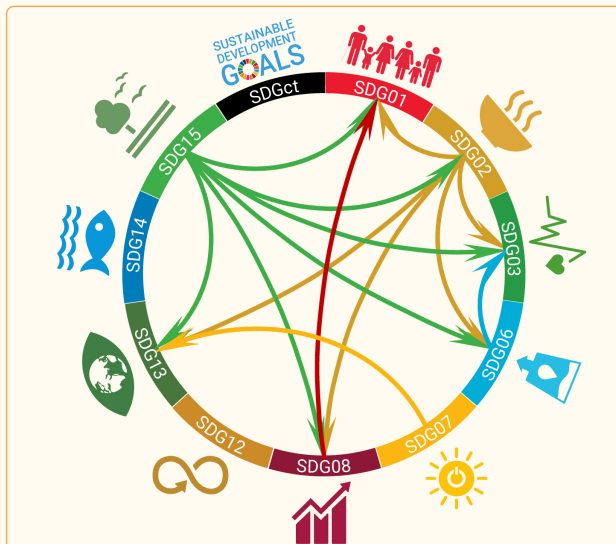
The desertification investment targets United Nations Convention to Combat Desertification, which aims to combat desertification and mitigate the effects of drought in countries experiencing serious drought and/or desertification, through effective actions at all levels, supported by international co-operation and partnership arrangements.

Investment in general environment



Environment investment covers a wide range of activities focused on achieving the objectives of the Rio Conventions, as well as other initiatives aimed at promoting environmental sustainability. Its primary goal is to improve the physical and/or biological environment of a recipient country, area, or target group. This involves taking specific actions to integrate environmental concerns into various development objectives through institution building and capacity development. In other words, environment investment encompasses a variety of efforts aimed at enhancing environmental sustainability and ensuring that development activities are carried out in a way that supports the long-term health of the planet.

B Interactions between SDGs



C Features of national development



✓ SDG level



✓ GDP



✓ Population



✓ GDP growth rate



✓ Landcover

Figure 1. Components used in analyzing the association between transnational environmental investment and the achievement of Sustainable Development Goals (SDGs) across countries. (A) Transnational environmental investment categories analyzed for each SDG. (B) Interactions among SDGs at the national level associated with transnational environmental investment (represented by arrows). (C) Major national development features considered in the study. Transnational environmental investments are primarily investments in the Rio Conventions, and they include biodiversity, climate change adaptation and mitigation, and desertification investments, as well as investments in general environmental objectives. Each of these investment categories has a distinct association with sustainable development at the national level because of the interactions between the SDGs and the characteristics of countries. SDGct = composite SDG (averaged from 10 SDG scores; see Materials and Methods), SDG01 = no poverty, SDG02 = zero hunger, SDG03 = good health and wellbeing, SDG06 = clean water and sanitation, SDG07 = affordable and clean energy, SDG08 = decent work and economic growth, SDG12 = responsible consumption and production, SDG13 = climate action, SDG14 = life below water, and SDG15 = life on land.

ing physical and biological environments and integrating environmental concerns with development objectives. This approach provides a unified view of the current investment aimed at achieving environmental goals across multiple countries (Figure 1A).²⁰ We selected and studied 10 SDGs that are directly relevant to environmental investments, as they provide measurable indicators for assessing the relationship between transnational environmental investments and SDGs. Although we acknowledge that transnational environmental investments may also be correlated with other SDGs, we primarily used these measurable indicators to provide quantitative results considering the availability of data. We examined both their associations with transnational environmental investments and the interactions between the SDGs and national socioeconomic development factors (Figure 1B; see Materials and Methods). We interpret these associations as evidence of the impact of transnational environmental investments on sustainable development. To simplify the presentation of our findings, we use terms such as “impact” and “contribution” to express directional relationships. We believe that this interpretation is supported by existing knowledge on the relationships between environmental investments and individual SDGs,⁵ as well as by the nature of our study design, which evaluates the correlation between transnational environmental investments and the degree of achievement of SDGs. We then assessed the correlations between transnational environmental investments and the level of sustainable development across countries based on the natural and socioeconomic characteristics of these countries and on the

amount of investment received (Figure 1C). This is a key step toward achieving equity and fairness in transnational environmental investments and supporting policies that improve the effectiveness of achieving SDGs.

MATERIALS AND METHODS

Quantifying transnational environmental investment

Transnational investment assistance targeting global environmental goals was obtained from the DAC CRS database.²⁰ We chose this dataset to ensure that our results were based on the most comprehensive and reliable data sources currently available. Data included in the DAC CRS database are collected by the OECD and cover external development financing aimed at achieving environmental goals and Rio Declaration objectives; these include (i) biodiversity markers (introduced in 1998), (ii) climate change adaptation (introduced in 2010) and mitigation (introduced in 1998; see Supplemental Texts for detailed information on these transnational environmental investments), (iii) desertification (introduced in 1998), and (iv) the general environment (introduced in 1992), as well as the total investment amount (sum of principal, significant, screened not targeted, and not screened investments). The first four indicators correspond to the main targets of the Rio Declaration, as derived from the CBD, the UNFCCC, and the UNCCD.² The final indicator includes the majority of activities targeting the objectives of the Rio Conventions under the DAC definition of “aid to the environment”, defined as activities that are “intended to produce an improvement in the physical and/or

biological environment of the recipient country, area, or target group concerned" or that "include specific action to integrate environmental concerns with a range of development objectives through institution building and/or capacity development".

Rio markers apply to international development aid financing, including official development assistance (ODA), which has been mandatory to report since 2006, and other official flows (OOFs) of funds that do not meet ODA criteria, which began on a voluntary basis in 2010. ODA is defined as flows to countries and territories on the DAC List of ODA recipients and to multilateral institutions that are supported by official agencies (including state and local governments) or by their executive agencies. Each transaction is administered to promote the economic development and welfare of developing countries as the main objectives and is concessional in character, conveying a grant element in some form. OOFs are defined as transactions by the official sector with countries on the DAC List of ODA recipients that do not meet the conditions for eligibility as ODA, either because they are not primarily aimed at development or because they have a grant element of less than 25%. For each activity reported to the DAC CRS, donors indicate whether it targets the environment or the Rio Conventions (biodiversity, climate change mitigation, climate change adaptation, and desertification). A scoring system of three values is used, in which aid activities labeled as targeting the environment are classified as the principal objective, a significant objective, or a minor objective. Please see the Supplemental Information for a detailed description of ODA and OOF funds.

To obtain the investment data for each Rio marker, we downloaded relevant data directly from the OECD page tool (<https://stats.oecd.org/Index.aspx?DataSetCode=crs1#>) then, the corresponding score, sector, donor, and amount type were determined. We first selected the data for five Rio markers classified in the principal objective class. The dataset used in our analysis included information on the total amount of investment provided by all donors to each recipient country in constant prices reported in US Dollars for the year 2018. Since a single activity may correspond to multiple goals, such as climate change mitigation and biodiversity, the three Rio Conventions were considered interrelated and mutually reinforcing. Hence, investments that correspond to a single Rio marker were chosen because they best reflect the characteristics of that investment category. The total financing amount, which integrates all investments except those for repeated goals, included investment data for all scores.

To identify sectors for each investment category under the corresponding Rio marker, we selected all sectors: social infrastructure and services, economic infrastructure and services, production sectors, multisector/cross-cutting, commodity aid/general program assistance, action relating to debt, humanitarian aid, administrative costs of donors, refugees in donor countries, and unallocated/unspecified. These data reflect investments made in different sectors to achieve environmental goals in the corresponding areas. We also used data from all donors to reflect the overall characteristics of the investment (in constant 2018 US dollars).

To derive our indicators of transnational environmental investment assistance, which were limited by the availability of SDG indicators, we used statistical data from 130 countries between 2002 and 2018.

Quantifying the SDGs and target indicators

We selected the SDG indicators related to ecology and the environment from among the 247 indicators specified by the Interagency and Expert Group on SDG Indicators.²¹ We sourced the specific indicators and data used from SDG data and the World Development Indicators of the World Bank (WDI),¹⁹ as well as the sustainable development target indicators of the World Food and Agriculture Organization (FAO).²² To select SDG indicators, we followed two criteria: (1) they are related to the environment and are directly affected by environmental policies, and (2) available data series cover at least 40 countries and are longer than 12 years. To ensure that the selected indicators were not affected by multicollinearity, we used the variance inflation factor (VIF) to assess the covariance between them. We excluded any indicators found to have a VIF greater than 10 from our final selection. For instance, we included SDG13.02.02.EN.ATM.METH.AG.KT. CE (agricultural methane emissions measured in thousands of metric tons of CO₂ equivalent) but excluded SDG13.02.02.EN.ATM.METH.AG. ZS (agricultural methane emis-

sions as a percentage of total emissions). The final indicator system encompassed 10 SDGs, 20 targets, and 37 matching indicators (Table S1). Since the combination of different targets and measurement indicators under the same SDG can reflect different dimensions of that goal, we used the average of these indicator scores as the target score for each SDG in cases with multiple indicators. We calculated the composite SDG score (SDGct) as the average of the ten target scores, which represents the overall performance in achieving all assessed SDGs.

Additional data used

Land cover change data were obtained from the European Space Agency's Climate Change Initiative Land Cover (ESA CCI-LC) product, which is part of the European Space Agency's CCI Land Cover Climate Research Data Package (CRDP).²³ The main data source of the ESA CCI-LC from 2000–2013 was SPOT-VEGETATION data products,²⁴ and the main data source from 2013–2015 was PROBA-V data products.^{24,25} The ESA CCI-LC uses the Land Cover Classification System (LCCS) developed by the FAO to define land cover types. Statistical data from the ESA CCI-LC were derived from FAO statistics for each country.²² Additionally, we used the total population, GDP, and GDP growth rate as socioeconomic development indicators. These variables were obtained from the WDI database.²⁶

Data normalization

We normalized the SDG indicators and transnational environmental investment data based on minimum-maximum values (ranging from 0 to 100)²⁷ as follows:

$$\text{Normalized Country indicator} = \frac{\text{Country indicator} - \text{minimum global value}}{\text{maximum global value} - \text{minimum global value}} \times 100 \quad (1)$$

where *NormalizedCountryindicator* is the standardized indicator, *Countryindicator* is the indicator before normalization, *minimumglobalvalue* is the minimum value, and *maximumglobalvalue* is the maximum of the indicator in the 130 countries evaluated during the 2002–2018 period. Accounting for temporal and cross-country variations in the indicators, we aggregated the values of each indicator across all countries and time periods. This allowed us to establish lower and upper limits for normalization purposes.^{5,6} When a larger indicator data value represented worse performance (e.g. SDG01.02.01 Poverty headcount ratio at national poverty line (% of population)), we reversed the SDG indicators after normalization as follows:

$$\text{Reversed SDG indicator} = 100 - \text{Normalized SDG indicator} \quad (2)$$

where *Reversed SDG indicator* is the reversed indicator, *Normalized SDG indicator* is the indicator after normalization.

Statistical analyses

We employed regression analysis to assess the correlation between transnational environmental investment and SDG achievement across different countries. To do this, we established a regression framework that simultaneously considers the association of the environmental investment assistance, the combined effect of contextual indicators, and the interaction among SDGs with the change in SDG scores (our dependent variable). We did not consider the inverse relationship between transnational environmental investment and SDGs since the environmental investment data we used originated from transnational investments outside of the domestic country and therefore may not have a direct association with the domestic country's SDG achievement. As a result, we used transnational environmental investment as an independent variable rather than a dependent variable. Due to sample size limitations, we represented contextual indicators based on the SDG score in the previous year. The specific model utilized is as follows:

$$\Delta \text{SDG} = k_1 \cdot \text{SDG}_{\text{last}} + k_2 \cdot \text{INV} + k_3 \cdot \text{RT} + c \quad (3)$$

where ΔSDG represents the change in SDG score between the current year and the previous year, SDG_{last} represents the SDG score from the previous year considering the possible effects of the country's economy, society, and natural environment, *INV* is the total investment or investment amount per

category from other countries, RT represents the relevant SDG scores considering the possible effects of interactions among SDGs at the national level associated with transnational environmental investment (Figure 1C), c is a constant term, and k_1 , k_2 , and k_3 are the regression coefficients. The regression coefficients represent the difference in the correlation of a specific type of investment with different SDGs considering that transnational environmental investment projects have multiple goals and overlapping indicators. For a regression coefficient to be included in the analysis, a p value less than 0.05 and a confidence interval within the limits of the regression model were required. With this approach, we analyzed the associations between transnational environmental investment projects and SDGs considering various factors that may affect these relationships.

To explore the global contributions and associations of transnational environmental investments to SDGs from 2002 to 2018, stepwise regression was performed for 130 countries using the regression framework outlined earlier. The total relative contribution of transnational environmental investment to the SDGs, represented by the proportion of explained variance in SDGs attributable to transnational environmental investment, was calculated as the difference in R^2 values between regression models with and without the environmental variable in each country (Equation 3 with and without variable INV, respectively). Then, a similar stepwise regression was performed to analyze the correlation of transnational environmental investments within different categories to SDGs. To achieve this, the variable "environmental" was represented as a combination of all five types of transnational environmental investments, as well as a combination of any four types of investments, and the corresponding regression models were built for each category separately. The contribution of an additional transnational environmental investment category to SDGs, represented the proportion of explained variance in SDGs attributable to this additional transnational environmental investment category, was calculated by taking the difference in the R^2 values of the two regression models. The advantage of this approach, when compared to performing regression analyses for each type of transnational environmental investment individually, is that it effectively considers the cross-sectional effect among different investment categories on SDGs. By using this method, we were able to gain a comprehensive understanding of the associations between transnational environmental investments and SDGs in different countries, across various investment categories, and over time.

To further analyze the associations between transnational environmental investments and SDGs, we used the coefficients obtained from the regressions involving a portfolio of the five types of investments to determine the sign of the focal type investment and contribution to different SDGs. These analyses were performed separately for each SDG and transnational environmental investment category. In addition, we analyzed the contributions of transnational environmental investments to the SDGs, as well as the corresponding correlations and signs, for each category separately. By combining changes in the amount of transnational environmental investment and the interactive relationships among different investment categories, we were able to explore the main reasons for the limited correlation between transnational environmental investment and SDGs. Through these analyses, we gained a nuanced understanding of the relationships between transnational environmental investments and SDGs and identified factors that can limit the effectiveness of these investments. These insights can inform future efforts to increase the positive effect of transnational environmental investments on sustainable development.

Based on the above analysis, we classified countries into six groups based on their total transnational environmental investments and investments in individual categories in relation to SDGs (see below). By doing so, we highlighted the interrelationships between the associations of transnational environmental investments in different categories with the same target across the different countries evaluated.

Uncertainty and sensitivity analysis

To ensure the robustness of our models, we conducted sensitivity tests to evaluate the impact of different model specifications on our results. Specifically, we calculated the relative effect of each category of transnational environmental investment on the SDGct by comparing the R^2 values of regression models with and without the environmental variable, and only one cate-

gory of transnational environmental investment was considered in a given run. We then compared the results obtained using this approach with the results from the approach described in the previous section.

We examined the temporal contribution of each category of transnational investment to the SDGct and the ratios of positive and negative correlations of each category of transnational investment to the SDGct. The results of our sensitivity tests, shown in Figure S1, indicate that the two approaches yielded similar results. The average relative contribution of each category of transnational investment to the SDGct was relatively consistent between the two approaches, with an average difference of 0.6–2.1%. Overall, these results suggest that our main findings are robust to different model specifications. However, we did observe a slight increase in the proportion of countries with a positive correlation between transnational environmental investments and SDGct when using the alternative approach (Figure S1B1 v.s. B2). This difference is likely because the approach used in our analysis accounts for the cross-sectional effect among other categories of investment and the environmental variable on SDGct, while the tested approach lacked these factors. This may have magnified the relative contribution of each category of investment and the proportion of positive correlations.

We conducted an additional analysis to assess the impact of different combinations of SDG target scores on our results. We examined all possible combinations of SDG target scores for different numbers of targets included in the calculation of SDGct and analyzed the correlation between each transnational environmental investment and SDGct accordingly (see Supplemental Information). Our findings suggest that as the number of SDG targets included in the calculation increases, the uncertainty or variation in the relative contribution of each transnational environmental investment to SDGct, as well as the proportions of positive and negative correlations, decreases (see Figure S2). These results underscore the importance of considering multiple SDG targets when evaluating the correlation between transnational environmental investment and sustainable development.

Country groups of transnational environmental investment to achieve SDGs

We categorized countries based on the sign and significance of the correlations between environmental investments and SDGs to better understand how the environmental and socioeconomic characteristics of countries receiving these investments influence correlation trends. We used total environmental investment and each category of investment in the context of SDGct to categorize countries as follows: Category 1, for which total environmental investment is significantly correlated with national SDGct and each category of investment is nonsignificantly correlated with national SDGct; Category 2, for which both total environmental investment and all categories of investment are significantly correlated with national SDGct; Category 3, for which total environmental investment is nonsignificantly correlated with national SDGct and all categories of investment are significantly correlated with national SDGct; and Category 4, for which both total environmental investment and all categories of investment are nonsignificantly correlated with national SDGct.

Next, we further divided countries for which SDGct was significantly correlated with total environmental investment (categories 1 and 2) into those with positive or negative correlations based on the sign of the regression coefficient for total environmental investment. Category 1 was then subdivided into two country groups: country group I, for which SDGct was positively correlated with total environmental investment, and country group II, for which SDGct was negatively correlated with total environmental investment. Similarly, category 2 was subdivided into country group III, for which SDGct was positively correlated with total environmental investment, and country group IV, for which SDGct was negatively correlated with total environmental investment. Category 3 was designated as country group V, and category 4 was labeled as country group VI. By using this approach, we categorized countries into six groups, as shown in Figure S3 and Table S2.

We then analyzed the amount of transnational environmental investment received by countries in each group considering the socioeconomic context (GDP, GDP growth rate, and population) and land cover change (including tree-covered areas, shrub-covered areas, grassland, shrubs and/or herbaceous vegetation, aquatic or regularly flooded areas, mangrove areas, areas with

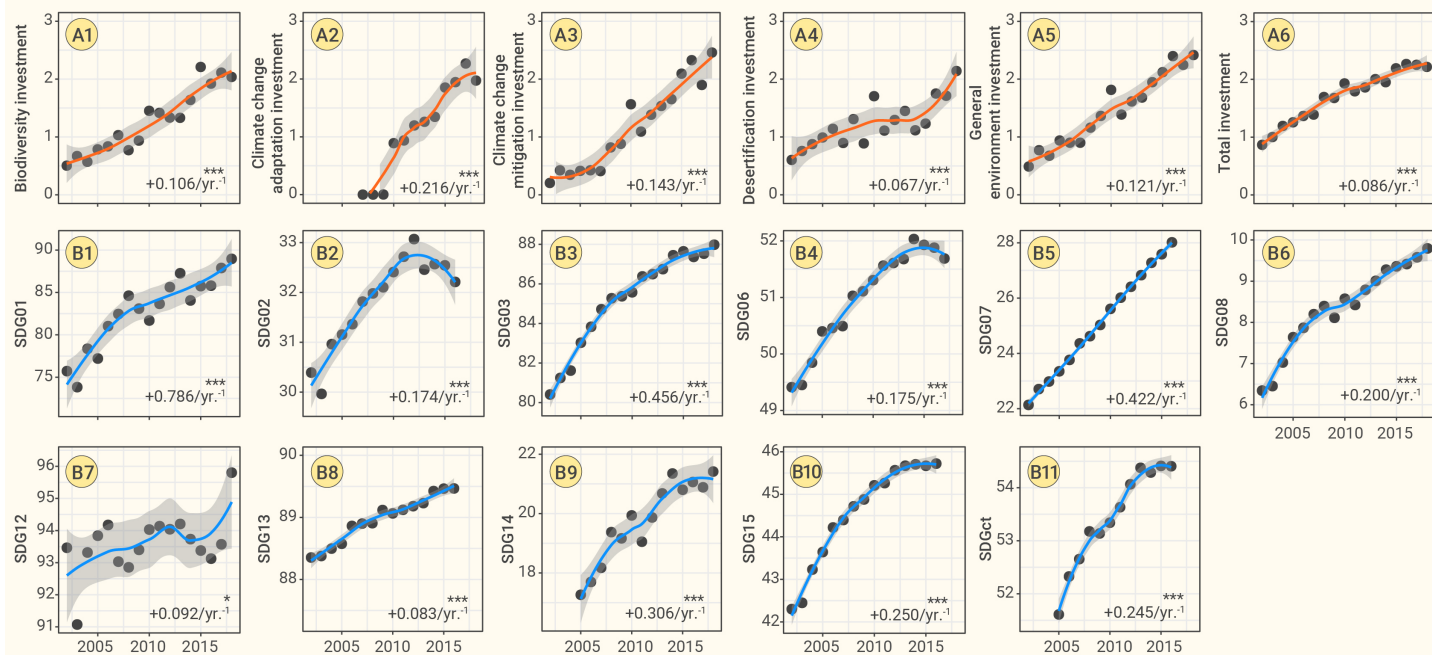


Figure 2. Trends in transnational environmental investment and the sustainable development goals (SDGs) from 2002 to 2018. (A1–A6) Trends of the average transnational environmental investment in biodiversity, climate change adaptation, climate change mitigation, desertification, the general environment, and total transnational environmental investment. (B1–B11) Trends of each individual SDG and the composite SDG (SDGct). The statistical significance levels of trends are as follows: ***: $P \leq 0.005$, **: $0.005 < P \leq 0.01$, and *: $0.01 < P \leq 0.05$.

sparse natural vegetation areas, barren land areas, croplands, and artificial surfaces). By doing so, we aimed to identify the specific strengths and weaknesses associated with the process of transnational environmental investment toward achieving SDGs among different country groups and to link these characteristics to the magnitude of the association of transnational environmental investment in SDGs among different groups.

RESULTS

Overall, both individual SDGs and the composite SDG (SDGct, averaged from 10 SDG scores; see Materials and Methods) showed significant improvements from 2002 to 2018 ($+0.3 \pm 0.2 \text{ yr.}^{-1}$, $P < 0.005$; $+0.3 \text{ yr.}^{-1}$, $P < 0.005$) (Figures 2B1–B11). Notably, both variables were significantly correlated ($P < 0.05$) with the increase in transnational environmental investment ($+0.1 \text{ yr.}^{-1}$, $P < 0.005$) (Figures 2A1–A6), suggesting an overall positive relationship between transnational environmental investment and the promotion of sustainable development globally (Figures 2B1–B11 & S4). See the Supplemental Information for a detailed account of these results and trends.

Transnational environmental investments accounted for 6.4% of the variance in global sustainable development (Figure 3A), with clear variations observed in their associations with both the amount and category of corresponding SDGs across countries (Figures 3A & D1–D6). The SDGs of 56.9% of countries were positively correlated with transnational environmental investments (Figures 3A & D1–D6), with a significant correlation observed for 46.2% of these countries (Figure 3B). The investments in climate change mitigation and combating desertification correspond to the largest and smallest contributions to sustainable development, respectively (6.1% and 2.4% of the variance) (Figure 3A). Specifically, our analysis shows that SDG06, SDG07, and SDG12, which are related to the economic structure and resource utilization, are more correlated with transnational environmental investment than other SDGs, with 3.3%, 6.8%, and 5.7% of the variance explained, respectively. We also found that transnational environmental investment displays the highest correlation with SDG02, SDG07, and SDG13, with significant correlations for more than 60% of the corresponding countries (89.2%, 60.0%, and 72.3% of countries for the respective goals) (see Figures S6, S9, S12B & D1–D6). Conversely, SDG03, SDG08, and SDG15 are the least correlated with transnational environmental investment, with associations in less than 20% of the significantly correlated countries (approximately 19.2%, 10.0%, and 6.9% of countries, respectively) (see Figures S7,

S10, S14B & D1–D6). No significant correlations between total environmental investment or any investment category for all SDGs were found in 10.8% of countries (Figures 3C & S5–S14C); these results were largely due to the counteracting effects among different categories of environmental investment (Figures 4A–F).

It is worth highlighting that 43.1% of countries may not benefit significantly from transnational environmental investments to achieve global sustainable development. In these countries, none of the environmental investment categories displayed a significant correlation with the SDGs. Therefore, there were no counteracting or cumulative associations among investment categories, and the SDGs were not correlated with total investment in general (Figure 3C). Additionally, more than half of the significantly associated countries (~55%) exhibited negative correlations with transnational environmental investments (Figure 3B). General environmental investments account for the largest proportion of negative correlations with the SDGs, a trend observed in 56.8% of countries. Even for biodiversity investment, which displays the smallest negative correlation with the SDGs, the negative correlation is still significant in 43.2% of countries. See the Supplemental Information for details on the associations between transnational environmental investment categories and each SDG.

We divided the evaluated countries into six categories based on their contributions (Figure 3C) to SDGct and the (positive or negative) regression coefficients for transnational environmental investment categories and amounts (Table S2). First, we classified the countries into four categories based on the significance of permutations in total environmental investment and each investment category with respect to SDGct. Then, we further divided the two groups of countries with SDGct values that were significantly correlated with total environmental investment into those with positive and negative correlations based on whether the regression coefficients of total environmental investment were positive or negative, respectively.

These country groups represent distinct approaches to achieving the SDGs with transnational environmental investments, reflecting the unique characteristics of each country and their particular pathways toward meeting the SDGs. In the following paragraphs, we describe the main features of each category, including the total amount and category of transnational environmental investment received and the eco-environmental, resource context, and socioeconomic development characteristics of the countries included (Figures 5–7 & S15–S16).

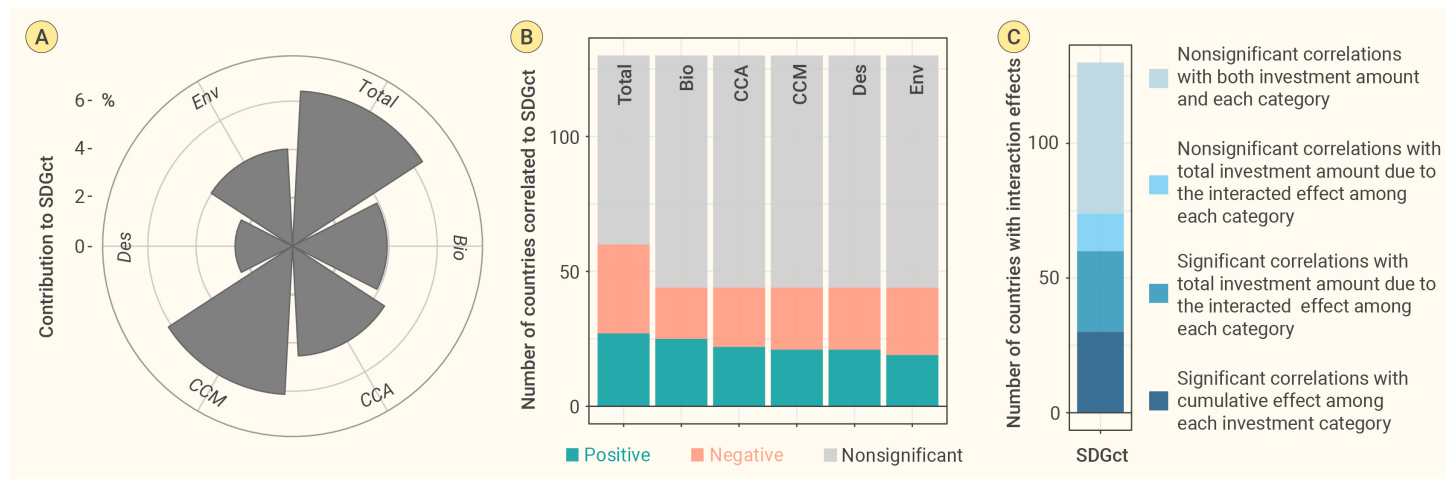


Figure 3. Variations among countries in the contribution of transnational environmental investments to sustainable development goals (SDGs) We examined several factors related to transnational environmental investment and its correlation with the composite SDGs (SDGct), such as (A) the average explanation rates of both the total amount of and each category of transnational investment to SDGct; (B) the ratios of positive and negative correlations of both the total amount of and each category of transnational investment to SDGct; (C) the differences in the interactive correlations between transnational environmental investment categories and SDGct across countries.

Country group I

Transnational environmental investments display a significant and positive correlation with national SDGct due to the cumulative effects of investments across different environmental goals (Figures 5A & 6A). This country group includes nations such as Kazakhstan and Mauritania, which have limited forest and shrub cover, extensive barren land, and sparse natural vegetation (Figure 7). As a result, they have developed alternative industries, mainly related to mining and oil exports.^{28,29}

The total transnational investment in these countries accounts for the largest positive contribution (+15.92%) to the national SDGct among the investments of all country groups. This investment is correlated with progress in SDG01, SDG06, SDG07, SDG13, and SDG15. However, investments in biodiversity and environmental protection have had a low correlation with SDG08, and investments in climate change mitigation have had a low correlation with SDG06. These associations highlight the need for the careful consideration and balancing of priorities when planning and implementing transnational environmental investments to ensure the achievement of the SDGs.

It is worth noting that SDG02, which includes agricultural and livestock production, is also affected by ecological protection targets, which could restrict the livelihoods of some populations. However, reasonable ecological compensation policies, environmental protection, and the creation of additional job opportunities through industrial development may effectively aid in achieving SDG01.³⁰

Country group II

The national SDGct is significantly and negatively correlated with the cumulative effect of transnational environmental investment under different environmental goals (Figures 5B & 6B). This group includes countries such as the Philippines and Samoa, which rely heavily on natural capital. They have large areas of forests, shrublands, and wetlands and small areas of barren land, areas with sparse natural vegetation, and artificial surfaces (Figure 7). Total transnational investment in these countries has made the largest negative contribution (-16.9%) to the national SDGct among all categories.

Transnational environmental investment in these countries has aided in the development of secondary and tertiary industries, as an alternative to reliance on local natural resources for livelihoods.^{31,32} This approach has significantly improved the production patterns and lifestyles of local people, correlating with an improvement in SDG12 and the level of economic development, which supports SDG08. However, transnational environmental investment displays a range of negative correlations with national development due to an accumulation of side effects from multiple environmental objectives. For example, biodiversity conservation projects and climate policies that limit the development and expansion of traditional agriculture (contributing to SDG02) may increase the number of poor people in some countries, thus negatively

correlating to SDG01. The rapid development of secondary and tertiary industries has also had a negative impact on multiple SDGs, such as SDG06, SDG07, SDG13, SDG14, and SDG15.

For this country group, the indirect negative correlation between SDGs and these environmental investments is much greater than the direct positive correlation between SDGs and environmental protection policies.

Country group III

Countries in this category display significant positive correlations between SDGct and investments due to the cumulative and counteracting effects of transnational environmental investments across various environmental goals (Figures 5C & 6C). Examples of such countries are Kenya and Argentina, which have the highest GDP and population among the studied countries, as well as the largest areas of barren land, cultivated land, and artificial surfaces (Figure 7). Economic development in these countries is primarily driven by the primary sector. With a considerable amount of transnational environmental investment (7,467.13 million \$) (Figure S16), these investments display broad positive correlations with ecological protection, agricultural growth and livestock development, leading to increased yields (contributing to SDG02). Promoting the development of national secondary and tertiary industries (such as mining³³ and foreign trade³⁴) has also reduced dependence on domestic natural capital for development, correlating with SDG08 and SDG12. Transnational environmental investments are positively correlated with several SDGs, such as SDG07, SDG13, SDG14, and SDG03. However, the large population and socioeconomic underdevelopment of these countries pose challenges to the sustainable conservation of natural resources. Transnational environmental investments display negative correlations with SDGs such as SDG01, SDG06, and SDG15, indicating that ecological conservation policies have exacerbated poverty and resource scarcity in these countries.

Country group IV

The SDGct of this category is significantly and negatively correlated with the cumulative and counteracting effects of transnational environmental investments under different environmental goals (Figures 5D & 6D). This group mostly includes island and coastal countries, such as the Republic of the Congo and Bahrain. These countries have the largest mangrove and sparse vegetation areas among all countries studied, with the highest scores for SDG14 and SDG15 (Figures 7 & S15). Compared to those for countries in group III, the secondary and tertiary sectors for these countries play a greater role in economic development. Despite the range of positive actions triggered by environmental investments, the negative correlations far outweigh the positive correlations.

Transnational environmental investments are positively correlated with SDG15, partially due to the establishment of localized cropping schemes, and

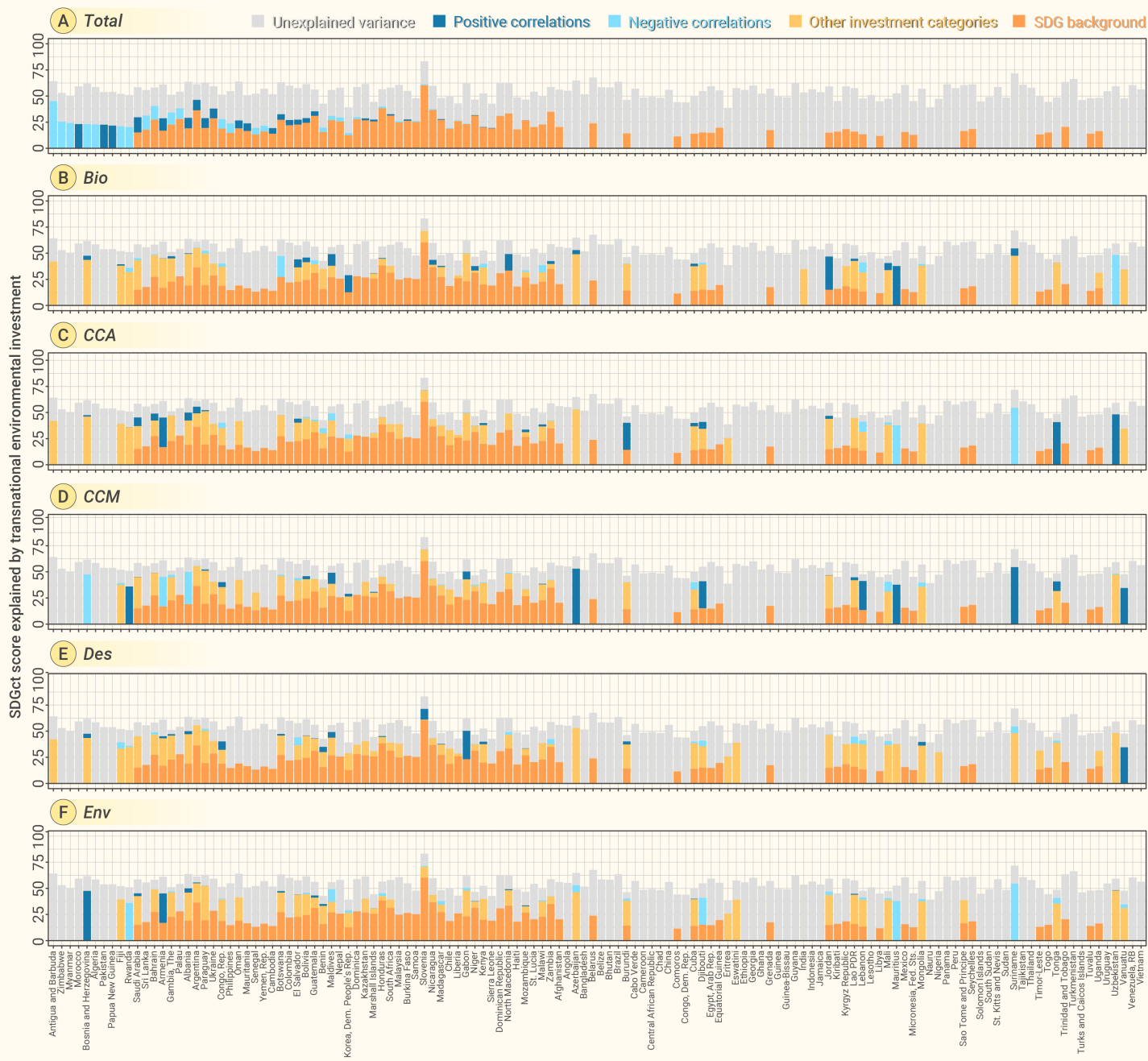


Figure 4. SDGct explained by transnational environmental investments in each country (A–F) The contributions of the total amount of transnational environmental investment (Total) and investments in biodiversity (Bio), climate change adaptation (CCA), climate change mitigation (CCM), desertification (Des), and the general environment (Env) to SDGct. Countries are ranked based on the contribution of the total investment to SDGct. In cases in which the correlation between transnational environmental investment and SDGct is not significant for a given country, the default order is alphabetical according to the name of the country.

SDG02, mainly due to the increased use of ecoagricultural technologies (e.g., crop diversification).³⁵ However, the management of agricultural production and the limitations of primitive industries are negatively correlated with SDG01. Although transnational environmental investment has reduced the negative environmental impacts of socioeconomic and production trends in these countries, as demonstrated by the positive correlations with SDG07 and SDG13, the economies in these countries are still highly dependent on natural capital for development.

At the same time, the rapid development of the secondary and tertiary sectors has increased regional constraints on achieving SDG06 and SDG14. For instance, increased urbanization and industrialization have led to a rise in pollution levels and depletion of natural resources, negatively correlating with SDG06. Additionally, transnational investments in extractive industries have contributed to resource exploitation and damage to ecosystems, negatively

correlating with SDG14. Overall, the negative correlation of environmental investments with the SDGs in this category highlights the need for sustainable economic development strategies that balance the needs of the economy and the environment.

Country group V

The correlations between transnational environmental investment and SDGs under different environmental goals appear to cancel each other out for countries in this group, resulting in no statistically significant correlation with SDGct (Figures 5E & 6E). This group includes countries such as the Lao People's Democratic Republic (PDR) and Lebanon, which are characterized by poor ecological and natural resource conditions, a predominantly nonagricultural economic structure, and heavy reliance on foreign aid (Figure 7). These countries receive the lowest amount of transnational environmental

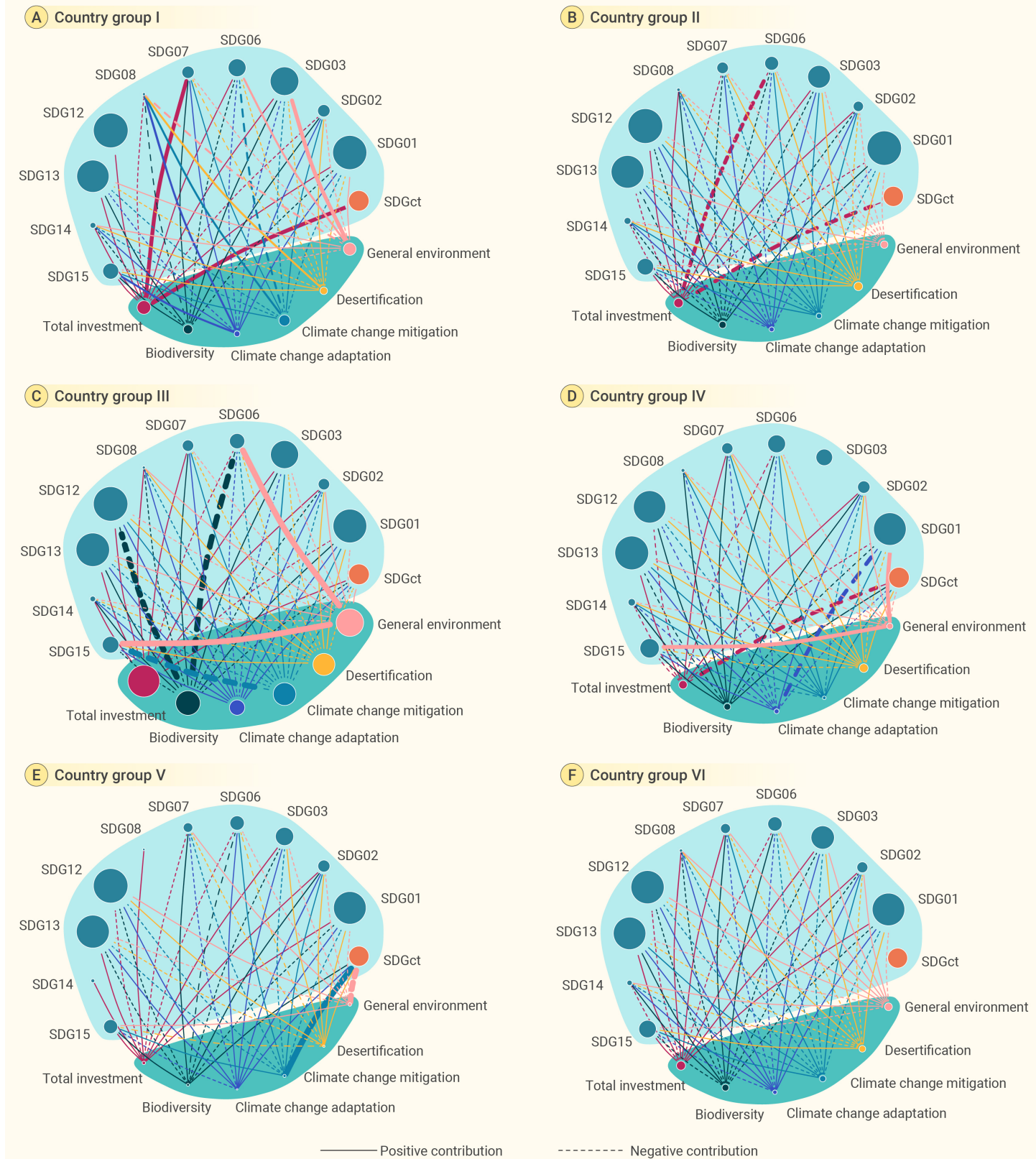


Figure 5. The correlation between sustainable development goals (SDGs) and transnational environmental investment within each country group These network graphs illustrate significant correlations and the directions of total environmental investment and the investment in each category to achieve SDGs. Additionally, SDGct is shown for each country group. The specific SDGs that are positively or negatively correlated with transnational environmental investments can be identified. In each graph, the circles represent the amount of transnational environmental investment and the magnitude of the SDG score, and the purple and brown shapes encompassing the circles represent the overall level of transnational environmental investment and the overall SDG score, respectively. The lines pointing from transnational environmental investment to the SDGs represent significant correlations, with the color and thickness of each line indicating the category or total amount of transnational environmental investment and the contribution of the transnational environmental investment to each SDG, respectively. A solid line indicates a positive correlation between transnational environmental investment and a given SDG, and a dashed line represents a negative correlation (see Materials and Methods for details).

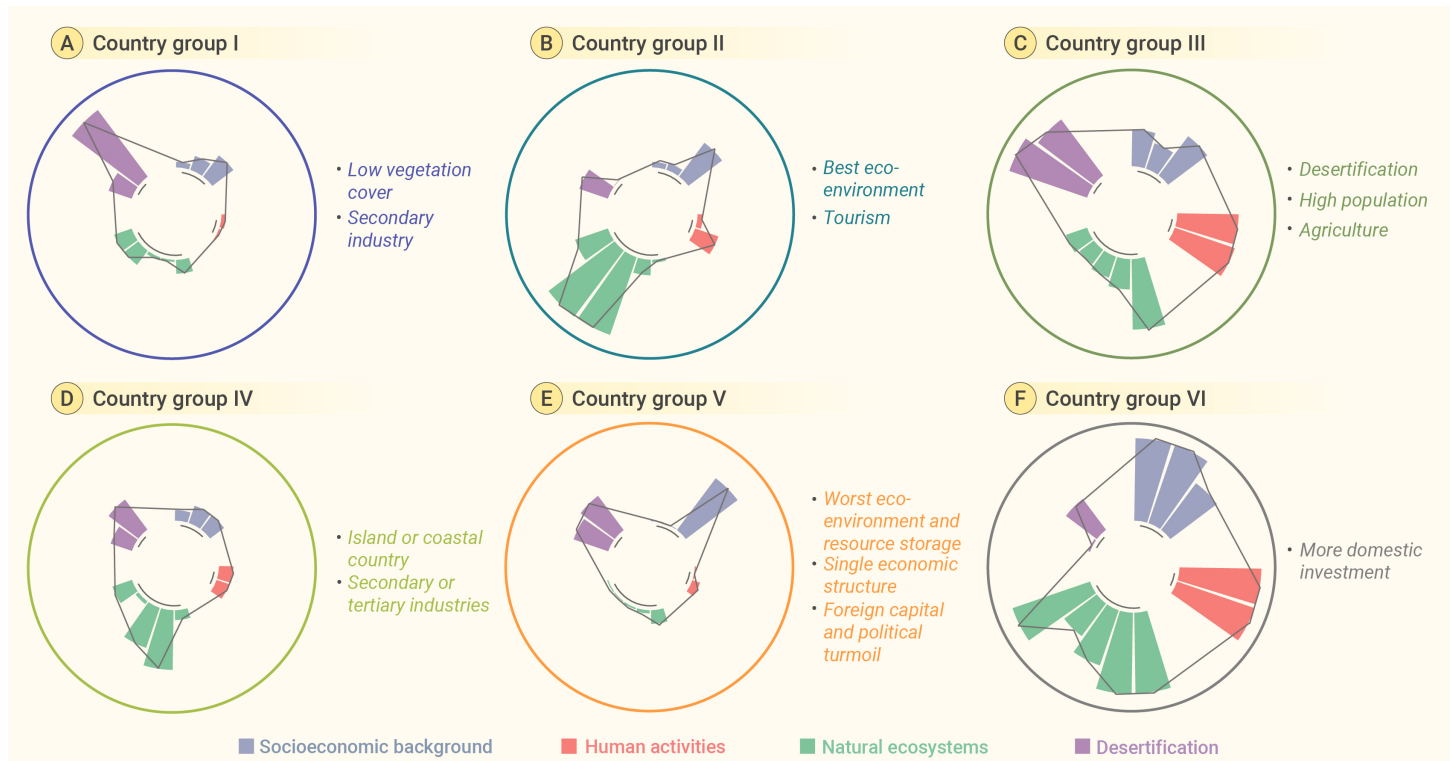


Figure 6. Environmental conditions, resource context, and socioeconomic development level for each country group The circular bar plot provides an overview of the average level of socioeconomic development and the typical land cover for the countries in each category. The blue segments (clockwise) represent the country's socioeconomic background including population, GDP, and GDP growth rate. The red segments (clockwise) correspond to land cover types directly related to human activities including artificial surfaces (urban and associated areas) and crops (herbaceous crops and woody crops). The green segments (clockwise) represent land cover types related to natural ecosystems including grassland, mangroves, shrub-covered areas, shrubs and/or herbaceous vegetation, aquatic or regularly flooded areas, and tree-covered areas. The purple segments (clockwise) correspond to land cover types related to desertification including sparse natural vegetated areas and terrestrial barren land. On the right side of each subfigure, we illustrate the main characteristics of the physical and socioeconomic backgrounds of the countries in each category.

investment (678.35 million \$) (Figure S16). Additionally, the positive correlations between this investment and SDG02, SDG13, and SDG15 may be counteracted by increasing population pressure and the rapid development of natural capital-based industries such as mining and agroprocessing. These industries create environmental challenges that may constrain progress toward achieving SDG06 and SDG07. Additionally, strong economic control associated with the provision of foreign capital and political instability have impeded the successful implementation of environmental policies and sustainable development initiatives in these countries.³⁶

Country group VI

The correlation between each transnational investment category, as well as the total transnational investment, with the SDGct is not statistically significant for countries in this group (Figures 5F & 6F). This group is represented by countries such as China, Brazil, and India. One possible reason for this finding is that these countries receive smaller amounts of transnational environmental investment than do those in other groups (Figure S16). Additionally, some of these countries have made significant investments in environmental actions themselves, which may outweigh the correlations between transnational investments and SDGs. For example, China's transnational environmental investments have decreased since 2003 (-101.9 million \$ yr.⁻¹, $P < 0.001$), and in 2018, they accounted for only 0.27% of the country's total ecological investments.

DISCUSSION

By using a unique and comprehensive approach accounting for national development contexts and the impact of interactions among SDGs, our results confirm the broad potential of transnational environmental investment to achieve sustainable development. The findings provide novel insights into the differences in the differential correlations of transnational environmental investment across countries. We identified significant differences among country groups, which differ in the total environmental investment

amount, the distribution of these investments, and the trade-offs among the different types of investments for different SDGs.

The amount of transnational environmental investment was significantly correlated with the SDGs. Countries for which transnational environmental investment displayed a significant correlation with the SDGs received 2.5 times the amount of funds than did countries without significant (or negative) correlations to the SDGs (Figure S16). These findings indicate that there is a pressing need for an increase in total environmental investment assistance in developing countries worldwide. During the recovery period from the COVID-19 pandemic, countries invested heavily in restoring damaged economic and social structures, resulting in a significant decrease in the share of environmental investments.³⁷ Although more than half of global GDP is derived from natural resources, governments are currently spending only 0.34% of their financial support on natural capital measures.³⁷ The IPCC 6th Assessment Report declared a global climate emergency that requires immediate action by countries worldwide, such as by improving energy and material efficiency, accelerating the deployment of sustainable and scalable carbon dioxide removal technologies, and increasing the cost effectiveness and share of renewable energy.³⁸ These solutions and technological breakthroughs will require financial support far beyond what is available today. Additionally, regional-scale environmental investment projects rely on effective long-term investments. One example of a major environmental initiative that faces significant challenges is the African Great Green Wall. Despite the ambitious goal of restoring 100 million hectares of degraded land by 2030, as of now, only 4% of this target has been achieved. To meet the restoration goals, the initiative requires substantial funding, with estimates suggesting costs of between US\$3.6 and 4.3 billion per year, assuming an accelerated recovery rate of five times the 2020 level.³⁹ Similar land-based management projects often require additional follow-up investment to achieve continuity, long-term sustainability, and profitability. Indeed, investments in environmental goals should triple by 2030 and increase fourfold by 2050 if attempts to address the ongoing planetary emergency are to succeed.⁴¹

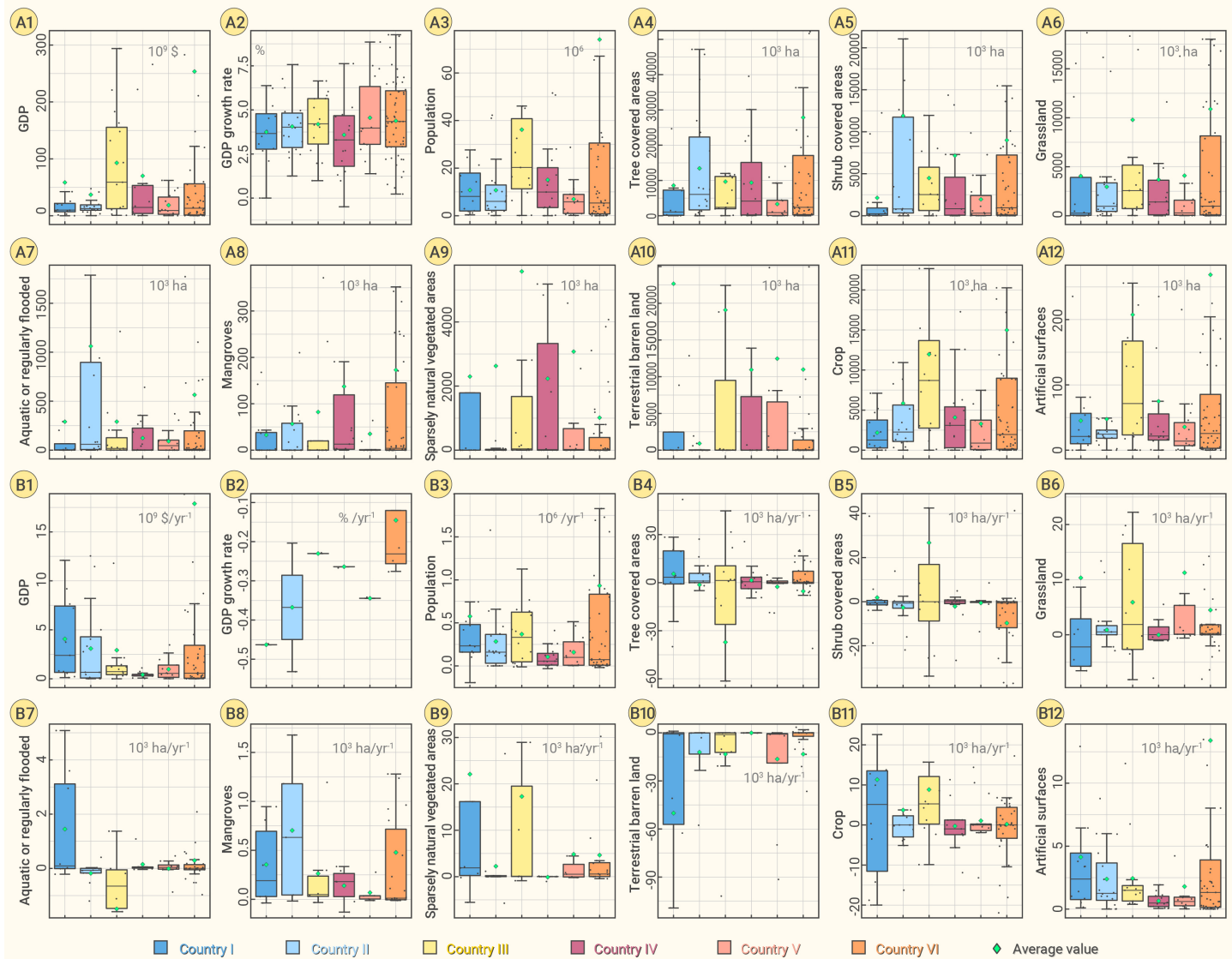


Figure 7. Average level and trend of economic development across the six identified country groups (A) Average level and trend of economic development and land cover for each country group. (B) Trends of economic development and land cover in each country group. (1–3) Average level and trend of GDP, GDP growth rate, and population in each country group. (4–12) Average level and trend of various land cover categories in each country group: tree-covered areas, shrub-covered areas, grassland, shrubs and/or herbaceous vegetation, aquatic or regularly flooded areas, mangroves, sparsely naturally vegetated areas, terrestrial barren land, crops (including herbaceous crops and woody crops), and artificial surfaces (including urban and associated areas).

Our analyses suggest that a fair and rational international redistribution of transnational environmental investment could help reduce disparities across countries and lead to an overall improvement in the achievement of the SDGs globally. Transnational environmental investments have played a more significant role in promoting sustainable development in countries with limited national investment in the environment, such as those in category III, than in countries with higher environmental investment, such as those in category VI. This is because external aid funds complement the limited investment in environmental strategies by these countries' governments. For instance, Niger, the top country in terms of total investment in the African Great Green Wall project, received 870 times more external investment than internal investment, and Mauritania received 15 times more external investment than internal investment.³⁹ Reducing external investments could create a serious imbalance between socioeconomic development and environmental protection in underdeveloped countries facing population pressure and climate change. Therefore, a unified investment framework with multichannel parallel financing (public or private investment) could be often useful.⁴⁰ Additionally, national capacity building, especially the development of policies that integrate science into decision-making, can help underdeveloped countries attract investors.⁴¹ For example, the African Centre for Technology Studies in Kenya and the Sustainable Development Policy Institute in Pakistan

have attracted strong interest from foreign investors.⁴¹

Our findings also highlight the need to search for possible synergies among ecological conservation, rational resource use, and socioeconomic development to overcome associated conflicts. We found that investments considering biodiversity targets generally provide a greater proportion of positive correlations with achieving the SDGs, while investments in general environmental goals must be made considering the accompanying negative correlations with other SDGs (e.g., SDG01, SDG07, and SDG08) within these investment categories. This is likely because biodiversity conservation projects are now commonly combined with livelihood improvements and industrial transformation.^{42,43} However, achieving environmental goals often relies on sound planning and technological advances, which can easily lead to cost overruns, damage to related industrial development, and even the expansion of alternative industries.^{7,44} Livelihood assistance in countries in categories II, IV, and V is particularly important for those countries most affected by changes in industrial structure or adjustments to production methods.⁴⁵ In developing countries, industrial restructuring in response to biodiversity conservation or climate objectives often faces demographic and developmental pressures, and the synergy among these objectives often requires stakeholder facilitation and leadership, such as the participation of youth groups and indigenous peoples.⁴⁵ Furthermore, intentional policy

promotion of synergies can promote a shared understanding of how environmental investments can be used at the national level and increase coherence across sectors in achieving multiple SDGs. This can be achieved by relying on inclusive and centralized decision-making by the fund management sector and other relevant sectors, such as forestry and agriculture.⁴⁰

It is also necessary to integrate the benefits of particular actions at specific locations to promote global biodiversity, adaptable national socioeconomic development and environmental investments through additional development opportunities that consider site-specific factors and the distribution of corresponding investment types.⁴⁶ Achieving policy coherence requires synergistic strategies that rely on relevant scientific and technological advances. For countries in category V, developing national specialties can enrich the industrial structure and avoid the negative effects of political conflicts. For example, tourism is being developed in Lebanon and Lao PDR.^{47,48} In the case of already highly developed industries, such as the oil/gas and manufacturing industries, in countries from categories II and IV, the adoption of more environmentally friendly technologies in production processes can contribute to positive synergies between national development and natural resource conservation.⁴⁹ Furthermore, investment in nature-based solutions can help to synergize the achievement of multiple environmental goals and SDGs.⁴⁵

Our study has limitations that must be acknowledged. We specifically focused on the 10 SDGs that have corresponding measurable indicators and available data and are directly linked to environmental investments. Our SDG scores were calculated using indicators selected by the Interagency and Expert Group on SDG Indicators, which included 20 corresponding targets and 37 indicators with available data from the UN indicator system. The indicator selection prioritized the shared characteristics of developing countries in the interplay between transnational environmental investments and SDGs—specifically, the indicators' environmental relevance and data availability—over country-specific contexts such as war. In addition, some indicators were not included due to a lack of data or the potential covariance with other indicators. For instance, SDG 17 (Partnerships for the Goals), which embodies the strengthening of global partnerships and forms a crucial foundation for implementing the Rio Convention and associated transnational environmental investment, was excluded from our analysis because of data constraints.⁵⁰ Moreover, the absence of socioeconomic spatial connectivity indicators represents a significant limitation of the current global SDG framework.⁵⁰ The indicator selection under these data limitations may have potential implications for our studies. Our results were derived from an analysis of statistical panel data, and we did not analyze the specific mechanisms behind the correlations between transnational environmental investment and SDGs. Future research should incorporate a more complete system of SDG indicators and contextual data, such as socioeconomic development and climate change data, to better understand the correlations between environmental investments and sustainable development.⁵¹ As more data become available in the future, our methodology can be easily applied to updated environmental investment data, SDG targets, and corresponding indicators to provide a more comprehensive and detailed global analysis.

While our approach was used to successfully distinguish six country groups based on the relationship between transnational environmental investments and national SDG achievements at the country level, it has limitations related to explaining the underlying reasons for the clustering of these groups based on the unique characteristics of associated countries. Although we have attempted to explain the causes of these variations and generalize the distinctions based on corresponding country backgrounds, we recognize that some country groups may have unique characteristics that are beyond our generalization. These characteristics may still lead to the same relationship between environmental investments and national SDGs, necessitating further analysis of countries with these characteristics—such as by introducing corresponding indicators. Additionally, the process of transnational environmental investment associated with sustainable development achievement is complex and difficult to explain with the currently available data. To further explore these differences and identify key processes and factors that contribute to variations in this relationship, systematic modeling, such as coupled human-land models, may aid in providing useful, context-specific and concrete environmental policy

recommendations for countries to reach the 2030 SDGs. For example, the optimization of water management in the Indus Basin using hydrological models could be an effective way to address specific challenges in that region.⁵²

Our analysis provides the first comprehensive assessment of the associations between multiple environmental investment categories and SDGs across developing nations. Although our findings suggest an overall positive correlation between such investments and SDGs, they also indicate that this correlation falls short of the optimistic estimates and the expectations of previous studies.^{53–56} The wide variations in the associations of these investments observed across countries contribute to this result. Therefore, our findings call for an increase in the amount of transnational environmental investments and for optimizing their allocation across countries. We also emphasize the need for enhanced coordination among sectors within countries to address their most critical environmental goals and shortcomings. Our approach enables researchers, policymakers, and stakeholders to link financial capital to environmental investment with national development characteristics, thus providing a direct reference for the full integration of transnational environmental investment in global macropolicies. This represents a key step forward in advancing the effective use of this investment to facilitate more sustainable development across developing countries worldwide.

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FUNDING AND ACKNOWLEDGMENTS

This work was supported by the National Natural Science Foundation of China (W2412141), Science-based Advisory Program of the Academic Divisions of the Chinese Academy of Sciences, European Research Council [BIODESERT] (647038), Generalitat Valenciana (CIDEGENT/2018/041), and Spanish Ministry of Science and Innovation (EUR2022-134048). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

AUTHOR CONTRIBUTIONS

F.X.M. designed the study. Z.C.W. and F.X.M. conducted the data analysis and interpretation. Z.C.W. and F.Y. drafted the manuscript, with significant contributions to the writing by F.X.M., M.F., L.Y.H., and F.B.J. All authors contributed to the manuscript and approved the final version.

DECLARATION OF INTERESTS

The authors declare no competing interests.

DATA AND CODE AVAILABILITY

Transnational environmental investment assistance data can be obtained from the DAC CRS database (<https://stats.oecd.org/Index.aspx?DataSetCode=crs1>). The SDG data are available from public databases of the World Bank (<https://datacatalog.worldbank.org/dataset/sustainable-development-goals>; <https://datacatalog.worldbank.org/dataset/world-development-indicators>) and FAO (<http://www.fao.org/sustainable-development-goals/en/>). The socioeconomic data are available from the World Development Indicators of the World Bank (<http://wdi.worldbank.org/tables>). The land cover data can be obtained from FAO (<https://www.fao.org/statistics/data-collection/en/>). All computer code used in conducting the analyses summarized in this paper is available from the corresponding author upon reasonable request.

SUPPLEMENTAL INFORMATION

It can be found online at <https://doi.org/10.59717/j.xinn-geo.2025.100138>

LEAD CONTACT WEBSITE

https://rcees.cas.cn/yj/zqj/202401/t20240125_6970421.html