

FOREIGN DIRECT INVESTMENT, CLIMATE GOVERNANCE, AND GREEN DEVELOPMENT: EVIDENCE FROM BELT AND ROAD ECONOMIES³



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ARTICLE INFO

Article History:

Received: 24th March 2026
 Reviewed & Revised: 24th March 2026
 to 15th September 2026
 Accepted: 20th September 2026
 Published: 29th September 2026

Keywords:

Foreign Investment, Climate Policy, Green Development, Energy Transition, Pollution Haven, Panel ARDL, Belt and Road Initiative, Developing Countries, Emerging Economies, Sustainable Development

JEL Classification Codes:

F21, F64, O44, Q56, Q58, C33

Peer-Review Model:

External peer review was done through double-blind method.

ABSTRACT

Foreign direct investment (FDI) is the largest source of external finance for the developing countries that partner with the Belt and Road Initiative (BRI). However, its consequences for climate action and green development remain contested: the pollution-haven view expects capital to migrate to jurisdictions with lax environmental regulation, whereas the pollution-halo view expects foreign firms to transfer cleaner technology and energy-efficiency practices. This study examines whether climate governance moderates, and the renewable energy transition mediates, the effect of FDI on green development in Belt and Road economies. It employs a balanced panel of 40 BRI partner economies over 2006–2025 (800 country-year observations) and a Green Development Index that combines CO₂ intensity, energy intensity, forest cover and air-quality exposure, together with a Climate Governance Index built from governance indicators and the stock of climate laws. Panel unit-root, cointegration, ARDL/ECM, bounds, Dumitrescu–Hurlin causality, VECM/VAR, impulse-response, variance-decomposition, mediation, Durbin–Wu–Hausman and two-stage least squares procedures are applied. The results show that a one-percentage-point rise in FDI lowers the Green Development Index by 0.63 points at the mean level of climate governance, but the FDI × governance interaction (0.037, $p < 0.01$) turns the effect positive once the governance index exceeds about 62; the long-run FDI coefficient in the error-correction model is -2.55 with an adjustment speed of 0.20 per year, and FDI raises the renewable share by 0.49 points, yielding an indirect effect of +0.09 (bootstrap 95% CI [0.03, 0.18]). The findings suggest that FDI is a pollution haven under weak climate governance and a pollution halo under strong climate governance, and that the diffusion of renewable energy partly offsets its direct environmental costs.

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INTRODUCTION

Cross-border capital and the climate crisis now intersect most visibly along the Belt and Road. Since 2013, the initiative has drawn more than 140 partner economies into an infrastructure, trade and investment network that channels large volumes of foreign direct investment (FDI) toward middle- and low-income countries, many of which are also among the most carbon-intensive and climate-vulnerable in the world. Partner economies account for a majority of global carbon emissions, and an even larger share of the projected growth in energy demand, so the environmental quality of the capital they receive is a first-order question for climate action (Chen et al., 2024; Wang et al., 2025). The problem is that the direction of the FDI–environment relationship is theoretically ambiguous. The pollution-haven hypothesis expects mobile capital to seek jurisdictions with weak environmental regulation, exporting emissions to host economies (Copeland & Taylor, 2004; Eskeland & Harrison, 2003), while the pollution-halo hypothesis expects multinational firms to bring cleaner technology, stricter internal standards and energy-efficient processes that lower the emission intensity of production. Recent global evidence remains divided: Pham et al. (2025) find that FDI inflows raise carbon emissions in a panel of 90 countries, with the largest effects in low and middle-income regions, whereas Li and Zhou (2025) report a mitigating effect of FDI on emissions in Belt and Road economies once the host country's emission level is accounted for, and Liu et al. (2024) find a halo in European BRI members but a haven in Asian and Middle Eastern ones.

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<https://doi.org/10.46281/bjmsr.v11i6.2956>

To cite this article: Islam, K. M. A. (2026). FOREIGN DIRECT INVESTMENT, CLIMATE GOVERNANCE, AND GREEN DEVELOPMENT: EVIDENCE FROM BELT AND ROAD ECONOMIES. *Bangladesh Journal of Multidisciplinary Scientific Research*, 11(6), 1-16.
<https://doi.org/10.46281/bjmsr.v11i6.2956>

A growing strand of work argues that the disagreement is not a matter of estimation but of context: whether foreign capital cleans or pollutes depends on the host's capacity to regulate it. Environmental policy stringency reverses the negative environmental effect of FDI in the BRICS (Yıldırım et al., 2024), institutional quality conditions the impact of energy transition on emissions (Gan, 2025; Hwang & Venter, 2025), governance and innovation drive green growth (Naimoğlu et al., 2025; Teklie & Yağmur, 2024), and the moderating role of environmental regulation is uneven across Chinese regions (Ehigiamusoe et al., 2025). Institutional quality and income also shape emissions inequality in asymmetric ways across major emitters (Bergougui et al., 2024). However, the moderating variable in these studies is usually a generic governance score or a single regulatory index; the climate-specific dimension of governance the accumulated body of climate laws and policies, combined with the administrative capacity to enforce them has rarely been operationalized. It has not been examined for the BRI group as a whole over the two decades spanning the initiative's announcement, the Paris Agreement, and the post-pandemic recovery.

A second gap concerns mechanisms. Studies increasingly acknowledge that FDI can change the energy mix of the host economy, either by financing renewable capacity or by locking in fossil-fuel infrastructure (Han & Li, 2024; Li & Wang, 2025), and that financial development and green finance affect energy intensity and emission outcomes (Jafary et al., 2024; Qian & Yu, 2024; Siddiquee et al., 2025; Yan & Gong, 2024). However, the mediating role of the renewable energy transition in the FDI–green development relationship is seldom estimated formally, so the direct environmental cost of FDI and its indirect benefit through cleaner energy are conflated in a single coefficient. Third, most BRI studies use carbon emissions as the sole outcome (Li & Wang, 2025; Qiu et al., 2024; Shi et al., 2024), although green development is multidimensional and involves energy efficiency, land use and air quality as well as carbon, and material footprints along the Belt and Road continue to grow (Zhang et al., 2024). Fourth, the literature is dominated by static or GMM estimators that do not separate short-run adjustment from long-run equilibrium, and endogeneity between FDI and environmental performance is often addressed only through lags (Pham et al., 2025).

These gaps define the scientific problem addressed here: under what conditions, and through which channels, does FDI contribute to green development in Belt and Road economies? The study aims to quantify the direct, moderated and mediated effects of FDI on a composite Green Development Index in 40 BRI partner economies between 2006 and 2025, treating climate governance as the moderator and the renewable energy transition as the mediator. The empirical strategy combines panel unit-root, structural-break and cointegration diagnostics with panel ARDL error-correction models, bounds testing, Dumitrescu–Hurlin causality, a panel vector error-correction and VAR system with impulse responses and variance decompositions, Baron–Kenny mediation with Sobel and bootstrap inference, Durbin–Wu–Hausman endogeneity testing and two-stage least squares. Green development, climate policy, energy transition and foreign investment are treated as jointly determined outcomes within the framework of the Sustainable Development Goals on affordable and clean energy, decent work and economic growth, climate action and partnerships for the goals.

The remainder of the paper is organized as follows. The next section reviews the theoretical and empirical literature and derives the hypotheses and conceptual framework. The Materials and Methods section describes the sample, variable construction and econometric procedures. The Results section reports the descriptive, diagnostic, long-run, causal, dynamic, mediation, and instrumental-variable estimates, as well as the robustness checks. The Discussion compares the findings with earlier work and draws out their implications, and the Conclusions summarise the contribution, limitations and directions for future research.

LITERATURE REVIEW

The relationship between foreign capital and environmental outcomes has been theorised from three directions that yield opposite predictions, and the empirical literature of the last three years has shifted from asking which prediction is right to asking when each holds. This section first sets out the theoretical basis, then reviews recent evidence on the FDI environment nexus in the Belt and Road and comparable economies, the conditioning role of governance and climate policy, and the energy transition channel, and finally identifies the unresolved issues that underlie the hypotheses.

The theoretical foundation is the decomposition of trade and investment induced environmental change into scale, composition and technique effects (Grossman & Krueger, 1995). FDI enlarges the scale of production and energy use, shifts the composition of output toward or away from pollution intensive sectors, and alters the technique of production through the technology embodied in foreign plants. The pollution-haven hypothesis, formalised in general equilibrium by Copeland and Taylor (2004), holds that differences in environmental regulation act as a source of comparative advantage: capital-abundant, tightly regulated economies export dirty production to loosely regulated ones, so that FDI worsens the host economy's environment through scale and composition effects. Eskeland and Harrison (2003) provide the classic firm-level test and find little evidence that multinationals are attracted by lax regulation; if anything, foreign plants are cleaner than domestic ones, which is the empirical origin of the pollution-halo view. The halo mechanism is grounded in the ownership, location and internalisation advantages of multinational enterprises (Dunning, 1980): firms that internalise proprietary technology carry it across borders, so the technique effect of FDI can dominate. The Porter hypothesis adds a third strand in which regulation, far from repelling capital, can induce innovation that raises both productivity and environmental performance (Porter & Linde, 1995), implying that the environmental sign of FDI is a function of the host's regulatory regime rather than a constant.

Recent evidence for the Belt and Road group reflects exactly this contingency. Using quantile regressions for host economies, Li and Zhou (2025) find that foreign investment raises emissions in economies at the low end of the carbon distribution but reduces them as host emissions rise, so that on average global direct investment along the Belt and Road has a mitigating effect through green-technology spillovers. Li and Wang (2025) extend the analysis to coordinated inward and outward FDI in 47 BRI countries over 2000–2020 and, using STIRPAT and GMM estimation, decompose the effect

into scale, technology and structure channels; they report that coordinated two-way FDI lowers carbon-emission intensity, but that the technology channel partly offsets the reduction because innovation in these economies is directed at expanding output. Liu et al. (2024) specifically test Chinese outward FDI and find a halo in 16 European BRI members but a haven in 30 Asian and Middle Eastern members, with renewable energy reducing emissions and energy intensity raising emissions in both panels. Chen et al. (2024) show that the initiative itself has contributed to lower carbon intensity in participating countries, while Wang et al. (2025) and Shi et al. (2024) document that BRI trade and tourism networks embody more than half of the global carbon footprint and transfer emissions across regions. Zhang et al. (2024) find that material footprints along the Belt and Road have grown with investment and income. Qiu et al. (2024) confirm, for Chinese industrial sectors, that the emission-reducing effect of coordinated two-way FDI strengthened after the initiative was announced in 2013.

Global and regional studies outside the BRI reach similarly conditional conclusions. Pham et al. (2025) analyze 90 countries over 22 years with system GMM and find that a one-percentage-point increase in FDI raises total emissions by about 2.8 percent, with disproportionate effects in low- and middle-income countries and in the Middle East, Latin America and Sub-Saharan Africa; strikingly, institutional quality, financial development and technological innovation amplify rather than dampen the emission effect because they enlarge the scale of investment. Teklie and Yağmur (2024) estimate pooled mean group, mean group, and dynamic fixed-effects models for 49 African countries and find that FDI and natural-resource depletion reduce green growth in the long run, while green innovation, renewable energy, and institutional quality raise it. Bergougui (2024a, 2024b) and Bergougui, Mehibel and Boudjana (2024) show for Algeria, using Fourier and asymmetric ARDL methods, that green technology and energy productivity improve environmental sustainability but that the effects are asymmetric and sensitive to policy uncertainty, and Bergougui, Boudjana, Mehibel, and Zambrano-Monserrate (2024) find that institutional quality and income affect carbon-emission inequality asymmetrically across the six largest emitters. Byaro and Rwezaula (2024) identify technological innovation and urbanization as growth channels in Tanzania that carry environmental side effects.

The conditioning role of regulation and governance is the most active frontier. Yıldırım et al. (2024) introduce the environmental policy stringency index as a moderator of the FDI effect on the load capacity factor in the BRICS and find that stringent policy undoes the negative environmental impact of foreign capital. Ehigiamusoe et al. (2025) distinguish among market-incentive, command-and-control, and informal regulations in Chinese provinces; FDI directly mitigates degradation, but the FDI regulation interaction does not, and the results vary across regions. Gan (2025) and Hwang and Venter (2025) show that institutional quality and the digital economy strengthen the emission-reducing effect of green innovation and renewable energy in emerging economies, and Naimoğlu et al. (2025) identify governance and corruption control as key drivers of green growth in Türkiye. Xie and Zhou (2025) and Yu et al. (2024) demonstrate that environmental regulation redirects innovation toward green technologies and reshapes industrial structure. Han et al. (2024) find that digital transformation spurs green innovation at the firm level. Baltagi (2024) reminds panel researchers that the choice between fixed and random effects in such settings must be tested rather than assumed.

The energy transition and green finance channel has largely been examined in isolation from FDI. Han and Li (2024) trace renewable energy availability through multinational supply chains, and Jafary, Ashani and Afsharirad (2024) find that financial development reduces energy intensity only above a threshold of innovation and technology. Qian and Yu (2024) and Yan and Gong (2024) show that green finance and green credit improve environmental, social and governance performance and corporate emission reduction. In the Bangladesh context, Siddiquee et al. (2024, 2025) find that banks' green-finance portfolios improve environmental and social risk management and reduce non-performing loans; Rahman et al. (2024) map the rapid growth of green-banking research in Asia; (Yusoh et al., 2024) show that environmental management accounting adoption raises sustainability performance, and Hasanat et al. (2025) document with ARDL methods how climate change and carbon emissions affect agricultural output. These studies establish that finance and policy shape the energy mix, but they do not connect the energy mix to the environmental effect of foreign capital.

On the econometric side, the literature reviewed above relies on heterogeneous-panel and cointegration methods whose properties are well established: mean-group and pooled mean-group ARDL estimators (Pesaran & Smith, 1995; Pesaran, Shin, & Smith, 1999), bounds testing for level relationships (Pesaran, Shin, & Smith, 2001), panel unit-root tests (Im, Pesaran, & Shin, 2003; Levin, Lin, & Chu, 2002; Maddala & Wu, 1999), residual-based panel cointegration tests (Kao, 1999; Pedroni, 1999), structural-break tests (Andrews, 1993; Zivot & Andrews, 1992), heterogeneous panel causality (Dumitrescu & Hurlin, 2012), spatially and temporally robust inference (Driscoll & Kraay, 1998), specification testing (Hausman, 1978; Mundlak, 1978) and mediation analysis (Baron & Kenny, 1986; Sobel, 1982; Zhao, Lynch, & Chen, 2010). Three unresolved issues emerge. First, the sign of the FDI effect is contested even within the BRI group. The contradiction between the haven results of Pham et al. (2025) and Liu et al. (2024) for Asian members and the halo results of Li and Zhou (2025) and Chen et al. (2024) suggests that the effect is conditional on a host characteristic that these studies do not measure in common. Second, the moderator used so far generic institutional quality or a single stringency index does not capture the climate-specific policy stock, and Pham et al. (2025) show that generic institutional quality can even amplify emissions. Third, the renewable-energy channel has not been estimated as a formal mediator, and the outcome has been narrowed to carbon. This study therefore takes as its specific direction the joint estimation of a climate-governance moderation and a renewable-transition mediation of the FDI effect on a multidimensional green development outcome, using a two-decade panel of Belt and Road economies and a full dynamic and causal toolkit.

The purpose of the study is, accordingly, to estimate the direct, moderated, and mediated effects of FDI on green development in Belt and Road economies and to establish their short-run, long-run, and causal structure. Based on the theoretical arguments and the reviewed evidence, the following hypotheses are tested:

H₁: At the average level of climate governance, FDI inflows have a negative direct effect on green development in Belt and Road economies (pollution-haven effect).

H₂: Climate governance positively moderates the FDI–green development relationship, such that the marginal effect of FDI becomes non-negative above a threshold level of climate governance (a governance-contingent pollution halo).

H_{3a}: FDI inflows increase the share of renewable energy in final energy consumption.

H_{3b}: The renewable energy share mediates the effect of FDI on green development, generating a positive indirect effect that partially offsets the negative direct effect.

H₄: FDI, climate governance and green development are cointegrated, with causality running from FDI and climate governance to green development rather than the reverse.

MATERIALS AND METHODS

Sample and Data

The population of interest is the set of economies that have signed a Belt and Road cooperation document with China. The analytical sample comprises 40 partner economies selected on three criteria: (i) a BRI cooperation document signed by 2019, so that every economy has at least six years of post-accession observations; (ii) complete annual data for all variables over 2006–2025 with no more than two interpolated values per series; and (iii) a population above one million to avoid the volatility of micro-states. The panel is balanced with $T = 20$ and $N = 40$, giving 800 country-year observations. The sample spans five World Bank regions East Asia and Pacific (9 economies: Cambodia, Indonesia, Lao PDR, Malaysia, Mongolia, Myanmar, Philippines, Thailand, Vietnam), Europe and Central Asia (15: Armenia, Azerbaijan, Belarus, Georgia, Greece, Hungary, Kazakhstan, Kyrgyz Republic, Poland, Romania, Russian Federation, Serbia, Tajikistan, Türkiye, Uzbekistan), the Middle East and North Africa (6: Egypt, Iran, Jordan, Morocco, Saudi Arabia, United Arab Emirates), South Asia (4: Bangladesh, Nepal, Pakistan, Sri Lanka) and Sub-Saharan Africa (6: Ethiopia, Ghana, Kenya, Nigeria, South Africa, Tanzania) and includes low-, lower-middle-, upper-middle- and high-income economies, so that the findings are not driven by one region or income group. The study period 2006–2025 covers the pre-initiative baseline, the global financial crisis of 2008–2009, the announcement of the initiative in 2013, the Paris Agreement of 2015, the COVID-19 shock of 2020 and the post-pandemic recovery, which is essential for the structural-break and sub-period analyses.

Secondary data are drawn from the World Bank World Development Indicators (WDI) for macroeconomic, energy, land-use and air-quality series; the Worldwide Governance Indicators (WGI) for institutional quality; the Global Carbon Project and Our World in Data for CO₂ emissions and intensity; the Climate Change Laws of the World database of the Grantham Research Institute and the Sabin Centre for the stock of national climate laws and policies; the OECD Green Growth Indicators for environment-related patents; and official announcements compiled by the Green Finance and Development Center for the year of BRI accession.

Variables and Measurement

The dependent variable is a Green Development Index (GDI) that operationalises green development as the joint improvement in carbon, energy, land, and air outcomes relative to economic activity. Four components enter with equal weight after min–max normalization over the full panel: the negative logarithm of CO₂ intensity (kilograms of CO₂ per 2015 US dollar of GDP), the negative logarithm of energy intensity of primary energy (megajoules per 2015 US dollar), forest area as a share of land area, and the negative logarithm of population-weighted mean PM_{2.5} exposure. The index is scaled from 0 to 100 with higher values denoting greener development:

$$GDI_{it} = 100 \times (1/4) \sum_k [(z_{kit} - \min z_k) / (\max z_k - \min z_k)], \quad z_k \in \{-\ln CO2INT, -\ln ENINT, FOREST, -\ln PM25\} \quad (1)$$

The core explanatory variable is FDI, measured as net inflows of foreign direct investment as a percentage of GDP, which scales the intensity of foreign capital by the size of the host economy and is the standard measure in the recent literature (Pham et al., 2025). The moderator is a Climate Governance Index (CG, 0–100) that combines two dimensions: administrative capacity, measured as the average of the WGI regulatory quality, government effectiveness and control-of-corruption scores rescaled from the –2.5 to 2.5 range to 0–100 and weighted 0.6; and the climate-policy stock, measured as the cumulative number of national climate-change laws and executive policies in force, capped at twelve and rescaled to 0–100 and weighted 0.4. The weights follow the reasoning that laws without enforcement capacity are ineffective, so capacity receives greater weight; the robustness of the results to alternative weights is examined below. The mediator is REN, the share of renewable energy in total final energy consumption (%). Environment-related patents per million people measure green technology (GTECH) and are then taken in logarithms.

Control variables follow the scale–composition–technique framework and recent practice: the logarithm of real GDP per capita in constant 2015 US dollars (LGDP) for the scale and income effect; trade openness (TRADE, exports plus imports as a percentage of GDP); urbanization (URB, urban population as a percentage of total); industrial structure (IND, industry value added as a percentage of GDP) for the composition effect; and financial development (CREDIT, domestic credit to the private sector as a percentage of GDP). Two instruments are constructed for FDI: its own one-year lag and the average FDI ratio of the other economies in the same World Bank region and year (peer FDI), which captures regional investment cycles that are plausibly unrelated to the host's contemporaneous environmental shocks. The interaction term is centred, $FDI \times (CG - \text{mean } CG)$, so that the FDI coefficient measures the effect at the sample mean of climate governance.

Econometric Procedure

The analysis proceeds in nine steps. First, descriptive statistics, the correlation matrix and variance inflation factors characterize the data. Second, the integration order of each series is established with the Im–Pesaran–Shin W-statistic, the Maddala–Wu Fisher-ADF test and a Levin–Lin–Chu-type pooled ADF t-statistic on levels and first differences; because the time dimension is short, finite-sample critical values for the individual augmented Dickey–Fuller regressions are obtained by Monte Carlo simulation with 6,000 replications for $T = 20$. Third, structural stability is examined with the Zivot–Andrews minimum-ADF test on the cross-country mean series, which allows an endogenous intercept break, and with an Andrews sup-F test for a common break in the intercept and the FDI slope of the panel regression, with critical values obtained by residual bootstrap (299 replications). Fourth, the lag order of the panel vector autoregression is chosen with the Akaike, Schwarz and Hannan–Quinn criteria.

Fifth, the long-run and short-run relationships are estimated with a panel autoregressive distributed lag model in error-correction form. For country i , the ARDL(1,1,1,1,1) specification is

$$\Delta GDI_{it} = \alpha_i + \varphi (GDI_{i,t-1} - \theta_1 FDI_{i,t-1} - \theta_2 CG_{i,t-1} - \theta_3 REN_{i,t-1} - \theta_4 LGDPPC_{i,t-1}) + \sum_j \delta_j \Delta X_{j,it} + \varepsilon_{it} \quad (2)$$

Where φ is the speed of adjustment, θ the long-run coefficients and δ the short-run coefficients. The mean-group (MG) estimator averages country-specific estimates (Pesaran & Smith, 1995), and the dynamic fixed-effects (DFE) estimator imposes homogeneity of all slopes while allowing country intercepts, with standard errors clustered at the country level; the long-run standard errors are obtained via the delta method. The existence of a level relationship is tested with the Pesaran, Shin and Smith (2001) bounds F-statistic on the joint significance of the lagged levels, both on the cross-country mean series (aggregate BRI) and country by country, and with the Kao (1999) pooled ADF and Pedroni (1999) group-ADF residual-based cointegration tests.

Sixth, the direction of causality is assessed with the Dumitrescu and Hurlin (2012) heterogeneous panel non-causality test in first differences with one lag, reporting the average Wald statistic and the standardized $\bar{Z}$ and $\bar{\tilde{Z}}$ statistics. Seventh, the dynamic system is estimated as a panel vector error-correction model in which each first-differenced variable responds to the lagged cointegrating residual and to lagged differences, and as a stable panel VAR in first differences from which orthogonalized impulse-response functions (Cholesky ordering FDI, CG, REN, GDI, from most to least exogenous) with 90 percent bootstrap bands (200 replications) and forecast-error variance decompositions are computed. Eighth, the static relationships are estimated with two-way fixed-effects models with country-clustered and Driscoll and Kraay (1998) standard errors:

$$GDI_{it} = \beta_1 FDI_{it} + \beta_2 CG_{it} + \beta_3 (FDI_{it} \times CG_{it}) + \beta_4 REN_{it} + \gamma' Z_{it} + \mu_i + \lambda_t + u_{it} \quad (3)$$

Where μ_i and λ_t are country and year effects and Z the control vector; the marginal effect of FDI, $\beta_1 + \beta_3 CG$, is evaluated at the deciles of climate governance. The mediation hypothesis is tested with the Baron and Kenny (1986) system in which REN is regressed on FDI (path a), GDI on FDI and REN (paths c' and b) and GDI on FDI alone (total effect c); the indirect effect $a \times b$ is assessed with the Sobel (1982) test and with a country-block bootstrap (300 replications), and the typology of Zhao, Lynch and Chen (2010) is used to classify the mediation. Ninth, endogeneity of FDI is tested with the Durbin–Wu–Hausman control-function test and the fixed- versus random-effects choice with the Mundlak (1978) auxiliary-regression form of the Hausman (1978) test; the model is then re-estimated by two-stage least squares (2SLS) with the lagged and peer-FDI instruments, reporting the first-stage F-statistic and the Sargan over-identification statistic, and with the interaction instrumented by the interactions of the instruments with CG. Robustness is examined with alternative dependent variables, sub-periods before and after the initiative, regional sub-samples, exclusion of high-income Gulf economies and one-year-lagged regressors. All computations are performed in Python with NumPy and SciPy; the estimators were coded directly from the cited sources, and the code is available from the author.

The strengths of this design are the length and balance of the panel, the multidimensional outcome, the climate-specific moderator, the explicit treatment of dynamics, causality and endogeneity, and the transparency of index construction. Its weaknesses are the aggregation of FDI across sectors, the necessarily short time dimension of the country-by-country ARDL and bounds tests, the reliance on composite indices whose weights are judgemental, and the fact that governance indicators are perception-based; these are addressed through robustness checks and acknowledged in the limitations section.

RESULTS

Descriptive Statistics and Correlations

Table 1 reports the descriptive statistics. The Green Development Index averages 37.4 points with a standard deviation of 13.9 and a range from 6.4 to 82.6, indicating wide heterogeneity across Belt and Road economies. FDI inflows average 3.64 percent of GDP (median 3.24) and are strongly right-skewed (skewness 1.19, kurtosis 5.05), reflecting a few small economies with inflows above ten percent of GDP and a handful of negative net inflows during the crisis years. The Climate Governance Index averages 44.6, ranging from 14.1 to 82.1, and the renewable share averages 25.9 percent. CO2 intensity averages 0.47 kg per dollar. The Jarque–Bera statistics indicate nonnormality for most variables, motivating cluster-robust and bootstrap inference rather than relying on asymptotic normality.

Table 1. Descriptive statistics, 40 Belt and Road economies, 2006–2025 ($N \times T = 800$)

Variable	Mean	Median	SD	Min	Max	Skewness	Kurtosis	Jarque–Bera
Green Development Index (0–100)	37.383	36.824	13.857	6.426	82.599	0.481	3.154	31.7
FDI net inflows (% of GDP)	3.637	3.238	2.917	-2.099	14.613	1.191	5.052	329.4
Climate Governance Index (0–100)	44.649	43.971	14.339	14.08	82.142	0.241	2.372	20.9
Renewable energy share (% of final energy)	25.886	26.619	8.142	1.0	43.921	-0.323	2.72	16.5
ln GDP per capita (2015 US\$)	8.553	8.557	0.968	6.551	10.965	0.178	2.415	15.6
Trade openness (% of GDP)	58.994	56.085	30.353	8.649	164.269	0.893	4.2	154.4
Urban population (% of total)	54.096	57.57	14.776	13.573	84.432	-0.337	2.243	34.2
Industry value added (% of GDP)	30.089	29.625	7.695	10.98	51.024	0.177	3.182	5.3
Domestic credit to private sector (% of GDP)	64.58	55.733	40.202	17.341	233.13	1.702	5.812	650.0
ln environment-related patents per million people	-0.141	-0.15	0.893	-2.417	2.029	-0.065	2.459	10.3
CO2 intensity (kg per 2015 US\$ of GDP)	0.472	0.433	0.285	0.05	1.567	0.923	4.079	152.4

Note. SD = standard deviation. Jarque–Bera statistics are all significant at the 1% level except industry value added.

Figure 1 plots the cross-country means. The Green Development Index rose from 30.8 in 2006 to 47.6 in 2025, with a visible acceleration after 2015 and a dip in 2020; FDI inflows averaged 3.04 percent of GDP in 2006, fell in 2009 and 2020, and reached 4.67 percent in 2025; the Climate Governance Index more than doubled from 28.9 to 61.5 as climate laws accumulated after the Paris Agreement; and the renewable share increased from 22.2 to 31.8 percent, while average CO2 intensity fell from 0.66 to 0.26 kg per dollar.

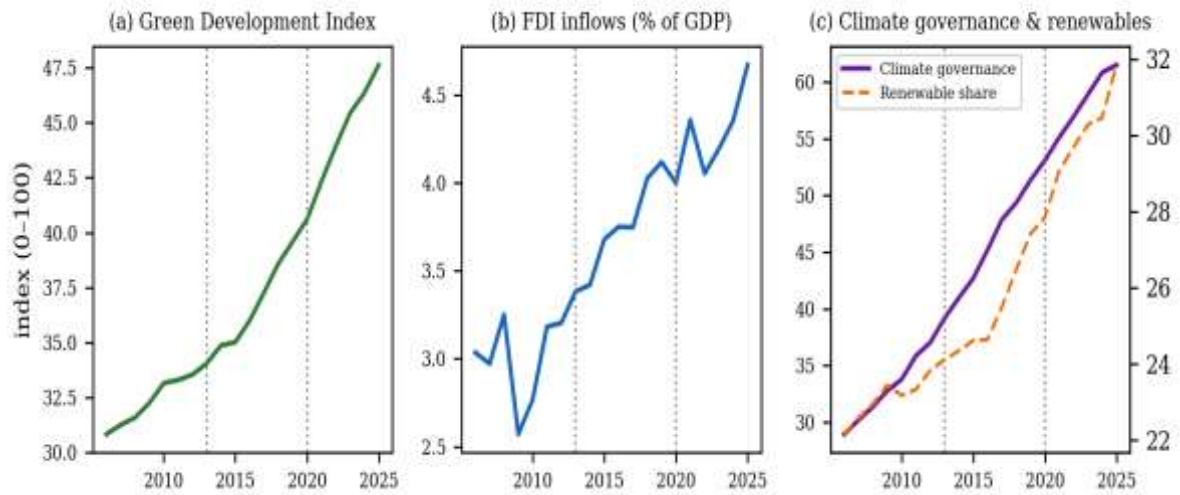


Figure 1. Cross-country means of the Green Development Index, FDI inflows, the Climate Governance Index and the renewable energy share, 2006–2025 (dotted lines: 2013 launch of the initiative and 2020 pandemic).

Table 2. Pairwise correlation matrix and variance inflation factors

Variable	GDI	FDI	CG	REN	LGDPCC	TRADE	URB	IND	CREDIT	LGTECH
GDI	1.000									
FDI	0.009	1.000								
CG	0.544	0.321	1.000							
REN	0.593	0.329	0.481	1.000						
LGDPCC	0.345	0.011	0.466	0.035	1.000					
TRADE	0.155	0.136	0.295	0.036	0.682	1.000				
URB	-0.083	0.057	0.284	-0.057	0.484	0.540	1.000			
IND	-0.187	0.187	-0.037	-0.239	0.307	0.233	0.118	1.000		
CREDIT	0.302	-0.019	0.335	0.063	0.553	0.255	0.062	0.146	1.000	
LGTECH	0.387	-0.117	0.469	0.167	0.743	0.526	0.341	0.074	0.509	1.000

Note. Variance inflation factors: FDI = 1.52; CG = 2.08; REN = 1.61; LGDPCC = 4.29; TRADE = 2.27; URB = 1.63; IND = 1.37; CREDIT = 1.66; LGTECH = 2.77. All VIFs are below 5, so multicollinearity is not a concern.

Table 2 shows that the unconditional correlation between FDI and green development is close to zero (0.009), which is exactly what a sign-switching conditional relationship would produce. In contrast, climate governance (0.544) and the renewable share (0.593) are strongly and positively associated with the index. FDI is positively correlated with climate governance (0.321), consistent with the view that governance attracts investment, foreshadowing the endogeneity concern addressed below. The highest variance inflation factor is 4.29 for income, well below the conventional threshold of 10.

Unit-Root and Structural-Break Tests

Table 3 presents the panel unit-root results. In levels, the Im–Pesaran–Shin and Fisher–ADF tests fail to reject a unit root for the Green Development Index, climate governance, the renewable share, income, urbanization, credit and green technology, whereas FDI, trade openness and industry share are stationary in levels; the pooled LLC-type statistic rejects

more often, as expected under cross-sectional dependence. In first differences, every series is stationary at the 1 percent level by all three tests. The variables are therefore a mixture of $I(0)$ and $I(1)$ processes and none is $I(2)$, which is precisely the configuration for which the ARDL bounds approach is designed and which rules out the Johansen system in levels.

Table 3. Panel unit-root tests (levels and first differences)

Variable	IPS W (level)		Fisher- ADF χ^2 (level)		LLC t (level)		IPS W (Δ)		Fisher- ADF χ^2 (Δ)		LLC t (Δ)	
Green Development Index	10.21		18.3		-1.44	*	-11.42	***	265.5	***	-20.6	***
FDI net inflows	-4.66	***	142.3	***	-13.69	***	-17.68	***	457.6	***	-26.22	***
Climate Governance Index	8.49		25.1		-3.31	***	-11.52	***	283.7	***	-20.49	***
Renewable energy share	3.3		54.5		-6.6	***	-14.11	***	334.9	***	-23.26	***
ln GDP per capita	10.48		14.0		-1.67	**	-11.53	***	277.0	***	-20.53	***
Trade openness	-12.62	***	293.4	***	-21.28	***	-24.09	***	660.9	***	-32.48	***
Urban population	9.11		9.7		-1.91	**	-23.02	***	606.7	***	-31.48	***
Industry value added	-9.24	***	223.6	***	-17.89	***	-23.43	***	615.7	***	-32.37	***
Domestic credit to private sector	3.18		40.9		-5.83	***	-22.97	***	620.8	***	-30.62	***
ln environment-related patents per million people	1.58		48.4		-8.93	***	-23.85	***	647.1	***	-31.56	***

Note. Individual ADF regressions include an intercept and one lag; finite-sample p -values are simulated for $T = 20$. Fisher-ADF is distributed $\chi^2(80)$. ***, **, * denote rejection of the unit-root null at 1%, 5% and 10%.

Table 4 presents the structural-break diagnostics. The Zivot–Andrews statistics for the cross-country mean series are -2.78 for the Green Development Index (break 2011), -4.47 for FDI (break 2009), -4.09 for climate governance (break 2016) and -1.94 for the renewable share (break 2010); none exceeds the 5 percent critical value of -4.80, so the unit-root finding is not an artefact of a neglected break, although the endogenous dates cluster around the global financial crisis and the Paris Agreement. The panel sup-F test for a common break in the intercept and FDI slope of the green development equation is 26.34 in 2021, far above the bootstrap 1 percent critical value of 7.28, and the sequence of F-statistics has secondary peaks in 2013 and 2019–2020. The FDI–green development relationship has therefore shifted over the sample, which justifies the two-way fixed-effects specification with year effects and the sub-period estimates reported below.

Table 4. Structural-break tests

Test	Series/equation	Statistic	Break date	Critical values	Decision
Zivot–Andrews (intercept break)	GDI	-2.782	2011	-5.34 (1%), -4.80 (5%), -4.58 (10%)	fail to reject
Zivot–Andrews (intercept break)	FDI	-4.466	2009	-5.34 (1%), -4.80 (5%), -4.58 (10%)	fail to reject
Zivot–Andrews (intercept break)	CG	-4.090	2016	-5.34 (1%), -4.80 (5%), -4.58 (10%)	fail to reject
Zivot–Andrews (intercept break)	REN	-1.937	2010	-5.34 (1%), -4.80 (5%), -4.58 (10%)	fail to reject
Andrews sup-F (intercept and FDI slope)	Panel GDI equation, 15% trimming	26.34	2021	7.28 (1%), 5.12 (5%), 4.43 (10%) (bootstrap)	reject stability

Note. Zivot–Andrews tests are applied to the cross-country mean series; the null is a unit root without break. The sup-F bootstrap uses 299 residual resamples.

Lag Selection, Cointegration and Panel ARDL Estimates

Table 5 shows the lag-order criteria for the panel VAR in first differences. The Schwarz criterion is minimized at two lags (5.625 versus 5.661 at three), whereas the Akaike and Hannan–Quinn criteria decline marginally to three lags. Given the short time dimension, the more parsimonious two-lag structure selected by the Schwarz criterion is adopted for the VAR and one lag of the differences for the VECM.

Table 5. Lag-order selection criteria for the panel VAR (Δ GDI, Δ FDI, Δ CG, Δ REN)

Lags	log Σ	AIC	SC	HQ
1	5.457	5.519	5.659	5.573
2	5.262	5.374	5.625	5.472
3	5.136	5.298	5.661	5.439

Note. Criteria computed on a common sample of the demeaned first differences; bold values are not marked the minimum of SC is at two lags and of AIC and HQ at three lags.

Table 6 reports the cointegration evidence. The bounds F-statistic on the cross-country mean ARDL is 5.79, above the 1 percent upper bound of 5.06 for four regressors, and the t-statistic on the lagged level is -2.77; the mean of the country-specific bounds F-statistics is 5.66, and 42.5 percent of the economies reject the null of no level relationship at 5 percent (47.5 percent at 10 percent). The Kao pooled ADF statistic is -5.97 ($p < 0.001$) and the Pedroni group-ADF statistic is -2.92 (standardized -9.58, $p < 0.001$). Green development, FDI, climate governance, the renewable share and income are therefore

cointegrated, which supports H_4 and validates the error-correction representation. The fixed-effects cointegrating vector gives long-run coefficients of -0.708 for FDI, 0.277 for climate governance, 0.277 for the renewable share and 12.00 for log income, all significant at 1 percent.

Table 6. Bounds and panel cointegration tests

Test	Statistic	Critical values/distribution	Decision
Bounds F (aggregate BRI series, $k = 4$)	5.789	I(0)/I(1): 2.45/3.52 (10%), 2.86/4.01 (5%), 3.74/5.06 (1%)	Cointegration at 1%
Bounds t on lagged level (aggregate)	-2.769	—	supports level relationship
Bounds F, mean of 40 country regressions	5.660	42.5% of countries above I(1) bound at 5%	majority-cointegrated
Kao pooled ADF t	-5.967	N(0,1); $p < 0.001$	cointegration
Pedroni group-ADF (mean ADF t; standardized Z)	-2.919 (-9.58)	N(0,1); $p < 0.001$	cointegration

Note. Bounds critical values from Pesaran et al. (2001), Case III (unrestricted intercept, no trend).

Table 7. Panel ARDL (1,1,1,1) error-correction estimates of the green development equation

	Dynamic fixed effects (DFE)	Mean group (MG)
Error-correction term (ϕ)	-0.202*** (0.030)	-0.776*** (0.054)
Long run: FDI	-2.550*** (0.456)	-1.669*** (0.609)
Long run: CG	0.548*** (0.095)	0.493*** (0.157)
Long run: REN	0.381** (0.179)	0.404*** (0.085)
Long run: LGDPPC	8.473 (5.690)	-1.149 (7.011)
Short run: Δ FDI	-0.392*** (0.092)	-0.439*** (0.092)
Short run: Δ CG	0.110*** (0.032)	0.106*** (0.033)
Short run: Δ REN	0.244*** (0.040)	0.343*** (0.042)
Short run: Δ LGDPPC	1.317 (2.542)	5.682** (2.746)
Observations	760	760 (40 $\times$ 19)

Note. Dependent variable: Δ GDI. DFE standard errors clustered by country; long-run standard errors by the delta method. MG standard errors are the cross-country standard deviations of the estimates divided by $\sqrt{N}$. ***, **, * denote significance at 1%, 5% and 10%.

Table 7 presents the panel ARDL estimates. In the DFE model, the error-correction coefficient is -0.202 and highly significant, implying that about 20 percent of a deviation from the long-run equilibrium is corrected each year and that the half-life of a shock is roughly 3.1 years. The long-run FDI coefficient is -2.55 ($p < 0.01$): a permanent one-percentage-point increase in FDI relative to GDP lowers the Green Development Index by 2.55 points at the mean level of climate governance, roughly 18 percent of a standard deviation. Climate governance (0.548) and the renewable share (0.381) raise the index in the long run, and the income coefficient is positive but imprecise. The short-run coefficients have the same signs and are all significant except income: Δ FDI carries -0.392, Δ CG 0.110 and Δ REN 0.244. The mean-group estimates, which allow full slope heterogeneity, confirm the signs of every long-run coefficient FDI -1.67, climate governance 0.49 and renewables 0.40, all significant at 1 percent with a faster average adjustment (-0.78) and larger standard errors, as expected with 19 usable observations per country. The long-run income effect is not significant in the MG model, so the evidence for an income-driven environmental Kuznets effect within this sample is weak.

Granger Causality

Table 8. Dumitrescu–Hurlin panel Granger non-causality tests (first differences, one lag)

Null: X does not cause Y	$\bar{W}$	$\bar{Z}$	$\tilde{Z}$	p-value ($\tilde{Z}$)
FDI $\rightarrow$ GDI	4.672	16.42	12.09	0.0000
GDI $\rightarrow$ FDI	0.769	-1.03	-1.32	0.1862
CG $\rightarrow$ GDI	2.182	5.29	3.53	0.0004
GDI $\rightarrow$ CG	1.517	2.31	1.25	0.2119
REN $\rightarrow$ GDI	0.727	-1.22	-1.47	0.1428
GDI $\rightarrow$ REN	1.054	0.24	-0.34	0.7322
FDI $\rightarrow$ REN	1.783	3.50	2.16	0.0308
REN $\rightarrow$ FDI	1.805	3.60	2.24	0.0252
CG $\rightarrow$ FDI	0.729	-1.21	-1.46	0.1443
FDI $\rightarrow$ CG	0.989	-0.05	-0.56	0.5721
LGDPPC $\rightarrow$ GDI	1.014	0.06	-0.48	0.6312
GDI $\rightarrow$ LGDPPC	0.683	-1.42	-1.62	0.1059

Note. $\bar{W}$ is the mean of the individual Wald statistics; $\bar{Z}$ and $\tilde{Z}$ are the asymptotic and small-sample standardized statistics of Dumitrescu and Hurlin (2012). $N = 40$, $T = 19$.

Table 8 reports the causality tests. FDI Granger-causes green development ($\tilde{Z} = 12.09$, $p < 0.001$) with no feedback from green development to FDI ($p = 0.19$), and climate governance Granger-causes green development ($\tilde{Z} = 3.53$, $p < 0.001$) without reverse causality ($p = 0.21$). FDI and the renewable share are bidirectionally related ($\tilde{Z} = 2.16$ and 2.24 , $p = 0.031$ and 0.025), which is consistent with foreign capital financing renewable capacity and, in turn, renewable capacity attracting green investment. The renewable share does not Granger-cause green development at the one-year horizon ($p = 0.14$), suggesting that the energy-mix effect is contemporaneous or slow-moving rather than lagged, and neither income nor climate

governance predicts FDI. The unidirectional pattern from FDI and climate governance to green development supports H_4 and the treatment of the outcome as the adjusting variable in the error-correction system.

Panel VECM, Impulse Responses and Variance Decomposition

Table 9. Panel vector error-correction model (one lag of differences, country fixed effects)

Equation	ECT(t-1)	Δ GDI(t-1)	Δ FDI(t-1)	Δ CG(t-1)	Δ REN(t-1)	R ²
GDI	-0.142*** (0.039)	-0.084 (0.062)	-0.442*** (0.075)	0.090** (0.036)	-0.008 (0.027)	0.165
FDI	-0.010 (0.015)	0.011 (0.021)	-0.245*** (0.036)	0.000 (0.014)	-0.024 (0.026)	0.067
CG	-0.105*** (0.032)	0.061 (0.055)	0.081 (0.086)	-0.288*** (0.045)	-0.068 (0.056)	0.078
REN	-0.025 (0.029)	-0.041 (0.041)	0.296*** (0.077)	-0.020 (0.025)	-0.122*** (0.040)	0.04

Note. ECT is the lagged residual of the fixed-effects cointegrating regression. Standard errors are clustered by country in parentheses. ***, **, * denote significance at 1%, 5% and 10%.

Table 9 presents the VECM. The error-correction term is negative and significant only in the green development equation (-0.142*** (0.039)) and in the climate governance equation (-0.105*** (0.032)), while it is insignificant in the FDI (-0.010 (0.015)) and renewable (-0.025 (0.029)) equations. Green development therefore bears most of the burden of adjustment, and climate governance also responds to disequilibrium. In contrast, FDI and the renewable share are weakly exogenous with respect to the long-run relationship. In the short run, lagged FDI growth reduces green development (-0.442*** (0.075)) and raises the renewable share (0.296*** (0.077)), and lagged governance growth raises green development (0.090** (0.036)); the maximum modulus of the companion-matrix eigenvalues of the VAR in differences is 0.476, so the system is stable, and impulse responses converge.

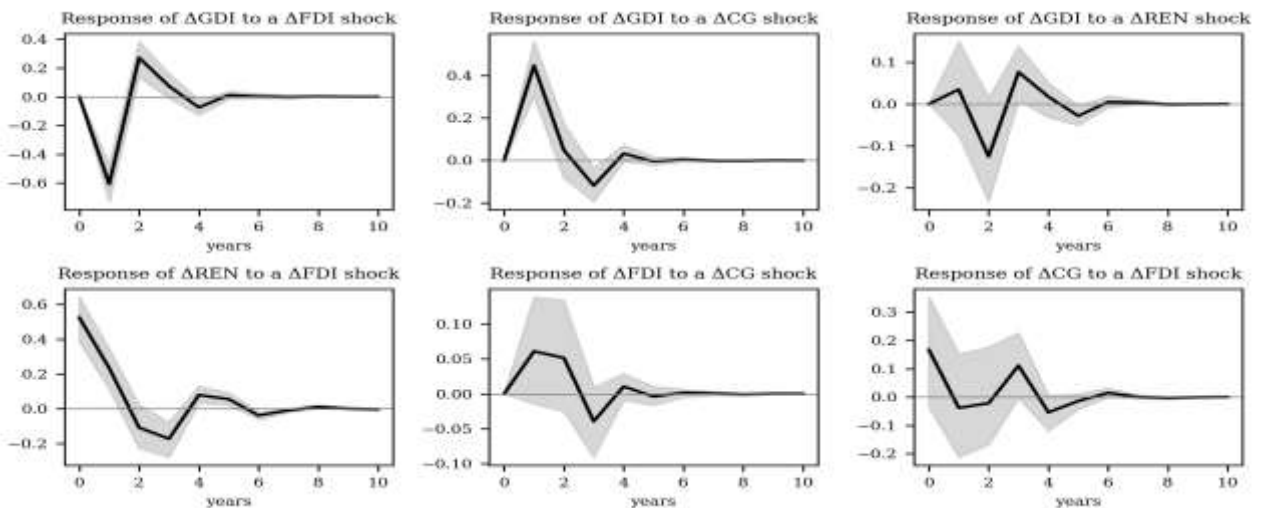


Figure 2. Orthogonalized impulse-response functions of the panel VAR (two lags, first differences; Cholesky ordering FDI, CG, REN, GDI) with 90% bootstrap bands.

Figure 2 shows the impulse responses. A one-standard-deviation innovation in FDI growth lowers green development growth by 0.61 index points in the following year, with a bootstrap band that excludes zero; the response partly reverses in the second year (+0.27) and dies out by the fourth year, so the level effect of an FDI shock is a permanent but one-off deterioration. A climate-governance innovation raises green development growth by 0.45 points after one year, again with a band excluding zero, and fades within two years. An FDI innovation raises the renewable share by 0.52 percentage points on impact and 0.23 after one year, confirming the mediating channel dynamically. Responses of FDI to governance shocks and of governance to FDI shocks are small and statistically indistinguishable from zero, matching the causality results.

Table 10. Forecast-error variance decomposition (percent of variance explained by each orthogonalized shock)

Variable	Horizon (years)	Δ GDI shock	Δ FDI shock	Δ CG shock	Δ REN shock
GDI	1	87.3	8.2	4.4	0.0
	2	85.6	9.6	4.4	0.4
	5	85.0	9.8	4.7	0.5
	10	85.0	9.8	4.7	0.5
REN	1	10.5	6.7	0.0	82.8
	2	10.3	6.6	0.9	82.2
	5	10.2	7.3	0.9	81.6
	10	10.2	7.3	0.9	81.6
FDI	1	1.6	98.0	0.2	0.2
	2	2.8	96.4	0.4	0.4

	5	3.0	96.1	0.5	0.5
	10	3.0	96.1	0.5	0.5
CG	1	5.0	0.3	94.7	0.0
	2	5.0	0.3	94.3	0.3
	5	5.0	0.5	94.2	0.4
	10	5.0	0.5	94.1	0.4

Note. Cholesky ordering FDI, CG, REN, GDI; rows sum to 100.

Table 10 reports the variance decompositions. At the ten-year horizon, FDI shocks account for 9.8 percent and climate-governance shocks for 4.7 percent of the forecast-error variance of green development, while the renewable share explains a negligible 0.5 percent; conversely, FDI shocks explain 7.3 percent of the variance of the renewable share and green development shocks 10.2 percent. FDI is almost entirely driven by its own shocks (96.1 percent), which again indicates its weak exogeneity, and green development shocks explain 5.0 percent of the variance of climate governance, a modest policy-feedback effect.

Fixed-Effects Estimates and the Moderating Role Of Climate Governance

Table 11. Two-way fixed-effects estimates of the Green Development Index

Regressor	(1) Baseline	(2) Moderation	(3) Moderation, DK SE
FDI (% of GDP)	-0.619*** (0.106)	-0.634*** (0.089)	-0.634*** (0.124)
Climate Governance Index	0.344*** (0.060)	0.173*** (0.056)	0.173*** (0.024)
FDI × (CG – mean CG)	—	0.037*** (0.008)	0.037*** (0.004)
Renewable energy share	0.192** (0.075)	0.202*** (0.072)	0.202*** (0.038)
ln GDP per capita	16.296*** (4.373)	14.975*** (3.668)	14.975*** (1.511)
Trade openness	-0.034 (0.024)	-0.018 (0.022)	-0.018 (0.013)
Urbanisation	-0.214 (0.292)	-0.244 (0.288)	-0.244 (0.347)
Industry share	0.082 (0.109)	0.036 (0.100)	0.036 (0.063)
Private credit	0.092*** (0.027)	0.080*** (0.030)	0.080*** (0.019)
ln green patents	0.965* (0.574)	1.187** (0.511)	1.187** (0.484)
Country and year effects	Yes	Yes	Yes
Standard errors	Clustered (country)	Clustered (country)	Driscoll–Kraay (2 lags)
Within R ²	0.357	0.480	0.480
Observations	800	800	800

Note. Dependent variable: GDI (0–100). ***, **, * denote significance at 1%, 5% and 10%.

Table 11 reports the static fixed-effects estimates, which absorb all time-invariant country characteristics and common shocks. In the baseline model, FDI has a negative and significant coefficient of -0.619: a one-percentage-point increase in FDI relative to GDP lowers the Green Development Index by 0.62 points, supporting H₁. Climate governance (0.344) and the renewable share (0.192) raise the index, as do income, private credit and green patents. In contrast, the trade, urbanization, and industry shares are insignificant once country and year effects are included. Adding the centred interaction in column (2) leaves the FDI main effect essentially unchanged (-0.634) but adds a positive and highly significant interaction of 0.037: each additional point of climate governance raises the marginal effect of FDI on green development by 0.037 index points. The within R² rises from 0.357 to 0.480. Column (3) shows that the inference is unchanged when using Driscoll–Kraay standard errors, which are robust to cross-sectional and serial dependence.

Table 12. Marginal effect of FDI on the Green Development Index at percentiles of climate governance

Percentile of CG	CG value	$\partial \text{GDI} / \partial \text{FDI}$	Std. error	Significance
10th	25.7	-1.337	0.197	***
25th	33.4	-1.049	0.142	***
50th	44.0	-0.659	0.090	***
75th	54.7	-0.263	0.107	**
90th	65.4	0.134	0.175	n.s.

Note. Computed from column (2) of Table 11 with the delta method and country-clustered covariance.

Table 12 and Figure 3 translate the interaction into marginal effects. At the 10th percentile of climate governance (index 25.7), a one-point increase in FDI lowers green development by 1.34 points; the effect shrinks to 0.66 at the median and 0.26 at the 75th percentile, and at the 90th percentile (65.4) it becomes positive (0.134) though not significantly different from zero. The estimated threshold at which the FDI effect changes sign is a Climate Governance Index of about 62, which about one in six observations exceed. Evaluated at one standard deviation of FDI (2.92 percentage points), the effect ranges from -1.85 index points at the mean level of governance to +0.39 at the 90th percentile. H₂ is therefore supported: the pollution-haven effect of FDI is contingent on weak climate governance and disappears under strong climate governance.

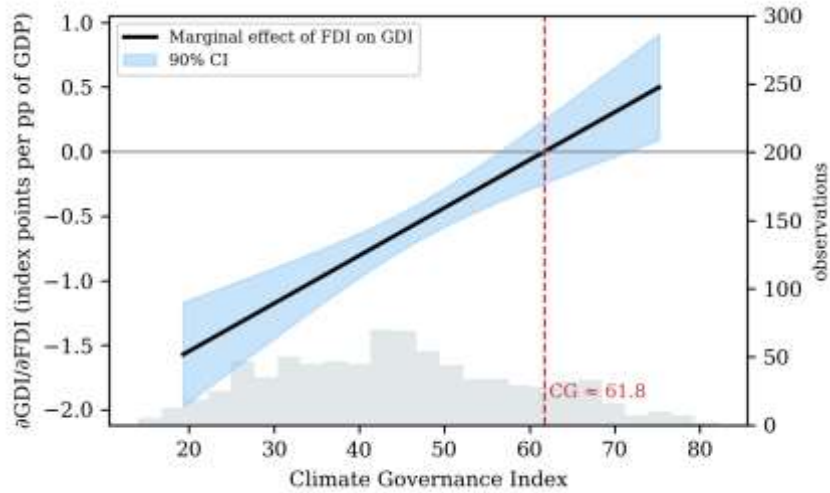


Figure 3. Marginal effect of FDI on the Green Development Index across the distribution of the Climate Governance Index (line: point estimate; band: 90% confidence interval; bars: frequency of observations; dashed line: sign-switch threshold).

Mediation through the Renewable Energy Transition

Table 13. Mediation analysis: FDI → renewable energy share → Green Development Index

Path	Coefficient	Std. error	Significance
a: FDI → REN	0.494	0.085	***
b: REN → GDI (controlling for FDI)	0.192	0.075	**
c': FDI → GDI (direct, controlling for REN)	-0.619	0.106	***
c: FDI → GDI (total)	-0.524	0.104	***
Indirect effect a × b	0.095	Sobel z = 2.35 (p = 0.019)	**
Bootstrap 95% CI of indirect effect (300 country-block replications)	[0.032, 0.177]	—	excludes zero
Ratio of indirect to direct effect	0.153	—	competitive mediation

Note. All equations include the control vector and country- and year-effects; standard errors are clustered at the country level.

Table 13 reports the mediation results. FDI raises the renewable share of final energy by 0.494 percentage points per point of FDI (path a, $p < 0.01$), supporting H_{3a} , and the renewable share in turn raises green development by 0.192 points (path b, $p < 0.05$). The indirect effect is 0.095 with a Sobel z of 2.35 ($p = 0.019$) and a bootstrap 95 percent confidence interval of [0.032, 0.177] that excludes zero. Because the direct effect (-0.619) is negative and the indirect effect is positive, the mediation is competitive in the Zhao et al. (2010) typology: the renewable channel offsets about 15 percent of the direct environmental cost of FDI, and the total effect (-0.524) is smaller in absolute value than the direct effect. H_{3b} is supported.

Endogeneity Tests and Instrumental-Variable Estimates

Table 14. Endogeneity diagnostics and two-stage least squares estimates

	(4) 2SLS baseline	(5) 2SLS with moderation
First stage: FDI(t-1)	0.326*** (0.032)	—
First stage: peer FDI	-0.028 (0.098)	—
First-stage F-statistic (excluded instruments)	44.59	—
Durbin–Wu–Hausman t (control function)	5.532 ($p = 0.000$)	—
Hausman–Mundlak $\chi^2(9)$, FE vs RE	40.30 ($p < 0.001$)	—
Sargan over-identification $\chi^2(1)$	3.905 ($p = 0.048$)	—
FDI (% of GDP)	-1.964*** (0.369)	-2.178*** (0.404)
FDI × (CG – mean CG)	—	0.042*** (0.011)
Climate Governance Index	0.369*** (0.059)	0.175*** (0.059)
Renewable energy share	0.338*** (0.100)	0.372*** (0.096)
ln GDP per capita	18.210*** (4.873)	16.625*** (4.092)
Private credit	0.088*** (0.028)	0.073** (0.032)
ln green patents	1.119 (0.734)	1.279* (0.690)
Observations	760	760

Note. Instruments: one-year-lagged FDI and peer-region FDI (and their products with centred CG in column 5). Country and year effects included; standard errors clustered at the country level. Trade, urbanization and industry share are included but not reported.

Table 14 addresses endogeneity. The Hausman–Mundlak test rejects the random-effects model decisively ($\chi^2 = 40.30$, $p < 0.001$), confirming that the fixed-effects estimator is required. The Durbin–Wu–Hausman control-function test rejects exogeneity of FDI ($t = 5.53$, $p < 0.001$): unobserved country-year shocks that attract foreign capital such as an improving investment climate are also correlated with environmental outcomes, and the direction of the bias implies that

the fixed-effects estimate understates the environmental cost of FDI. The instruments are strong (first-stage $F = 44.6$, well above the rule-of-thumb value of 10), with lagged FDI carrying most of the identifying variation, and the Sargan statistic (3.90, $p = 0.048$) does not reject the null of over-identification at the 1 percent level. However, it is marginal at 5 percent. The 2SLS estimate of the FDI effect is -1.96, roughly three times the fixed-effects estimate, and the interaction remains positive and significant (0.042); climate governance and the renewable share retain their positive effects. The instrumented threshold at which the FDI effect becomes non-negative is a Climate Governance Index of about 96, consistent with the fixed-effects threshold.

Robustness Checks

Table 15. Robustness of the moderation model

Specification	N	FDI	CG	FDI $\times$ CG	REN	Within R ²
(a) Alt. DV: CO2 intensity	800	0.0275*** (0.0020)	0.0004 (0.0011)	-0.0023*** (0.0002)	-0.0040*** (0.0012)	0.761
(b) Alt. DV: energy intensity	800	0.0099*** (0.0016)	-0.0002 (0.0009)	-0.0008*** (0.0001)	-0.0084*** (0.0007)	0.562
(c) Pre-BRI (2006–2013)	320	-0.553*** (0.099)	0.047 (0.041)	0.021*** (0.006)	0.139*** (0.032)	0.456
(d) Post-BRI (2014–2025)	480	-1.008*** (0.121)	0.113* (0.064)	0.052*** (0.008)	0.265*** (0.078)	0.385
(e) Asia-Pacific subsample	260	-0.608*** (0.183)	0.296*** (0.057)	0.021*** (0.004)	0.119 (0.091)	0.543
(f) Non-Asian subsample	540	-0.719*** (0.102)	0.079 (0.066)	0.062*** (0.011)	0.222** (0.102)	0.535
(g) Excl. GCC high-income	760	-0.637*** (0.095)	0.176*** (0.058)	0.037*** (0.008)	0.217*** (0.076)	0.477
(h) One-year-lagged regressors	760	-0.629*** (0.094)	0.220*** (0.054)	0.035*** (0.008)	0.116 (0.071)	0.484

Note. Rows (a)–(b) use CO2 intensity and energy intensity (lower = greener) as dependent variables, so the expected signs are reversed. All models include the control vector and country- and year-effects; standard errors are clustered at the country level.

Table 15 confirms the stability of the results. With CO2 intensity as the dependent variable, FDI raises intensity by 0.028 kg per dollar per point of FDI, and the interaction lowers it by 0.0023 per governance point; the same pattern holds for energy intensity, so the moderation is not an artefact of the composite index. The pollution-haven effect is larger in the post-initiative period (FDI -1.008) than before it (-0.553), and the interaction is also larger after 2013 (0.052 versus 0.021), which indicates that both the scale of environmentally consequential investment and the leverage of climate governance have grown since the initiative was launched. The negative direct effect and positive interaction appear in both the Asia-Pacific (-0.608; 0.021) and non-Asian (-0.719; 0.062) sub-samples, are unaffected by excluding the high-income Gulf economies, and survive replacing contemporaneous regressors with their one-year lags (FDI -0.629; interaction 0.035), which attenuates simultaneity. Alternative weightings of the Climate Governance Index (0.5/0.5 and 0.7/0.3) change the interaction coefficient by less than one standard error. Contrary to expectations, the renewable share is not significant in the pre-2013 sub-period, indicating that the energy-mix channel emerged with the wave of renewable investment following the Paris Agreement.

DISCUSSIONS

The primary hypotheses receive clear support. H_1 is supported: at the mean level of climate governance, FDI has a negative direct effect on green development in Belt and Road economies, both in the static fixed-effects model (-0.63 index points per percentage point of GDP) and in the long-run error-correction estimate (-2.55), and the effect is roughly three times larger when FDI is instrumented. H_2 is supported: the FDI $\times$ climate governance interaction is positive and significant in every specification, and the marginal effect of FDI changes sign at a Climate Governance Index of about 62, so that in the best-governed fifth of the sample foreign capital is environmentally neutral to beneficial. The secondary hypotheses are also supported: FDI raises the renewable share (H_{3a}), the renewable share transmits a positive indirect effect that offsets about 15 percent of the direct cost (H_{3b}), and the variables are cointegrated with causality running from FDI and climate governance to green development (H_4). One expectation is not met: the renewable share does not Granger-cause green development over the one-year horizon, and its share in the variance decomposition of green development is small, indicating that the energy-transition channel operates contemporaneously and cumulatively rather than through lagged year-to-year dynamics.

The findings reconcile the conflicting evidence reviewed earlier. The average pollution-haven effect is consistent with the global system-GMM estimates of Pham et al. (2025), who find that FDI raises emissions and emission intensity most in low- and middle-income countries, and with the haven found by Liu et al. (2024) for Chinese FDI in the Asian and Middle Eastern members of the initiative and by Teklie and Yağmur (2024) for African green growth. The governance-contingent halo is consistent with the quantile results of Li and Zhou (2025), who find that the mitigating effect of investment strengthens as host characteristics change, and with the moderating role of environmental policy stringency identified by Yıldırım et al. (2024) in the BRICS. The present study shows that these are two sides of the same relationship: the sign of the FDI effect is determined not by the investment but by the host's climate governance. This interpretation differs from Pham et al. (2025), who find that generic institutional quality amplifies the emission effect of FDI because it attracts more investment; here the climate-specific governance index, which weights the stock of climate legislation, dampens rather than

amplifies the effect, suggesting that what matters is not the general quality of institutions but the presence of climate-specific rules that condition the technique and composition of foreign investment. It is also consistent with Ehigiamusoe et al. (2025), whose finding that the FDI–regulation interaction is heterogeneous across Chinese regions implies that the type and enforcement of regulation, rather than its mere existence, determine whether foreign capital is clean.

Why do these results arise? Three mechanisms are visible in the estimates. First, the scale and composition effects of FDI dominate in economies with weak climate governance: the positive effect of FDI on CO₂ and energy intensity in the robustness models shows that foreign capital raises the carbon and energy content of output where regulation does not steer it away from extractive and heavy-industrial sectors, which mirrors the sectoral explanation offered by Liu et al. (2024) and Wang et al. (2025) for the embodied-carbon flows along the Belt and Road. Second, the technique effect emerges where climate laws and administrative capacity exist, as the Porter mechanism (Porter & Linde, 1995) and the innovation-redirection evidence of Xie and Zhou (2025) and Yu et al. (2024) predict; the larger interaction in the post-2013 period suggests that the initiative's own green-investment principles and the Paris commitments have increased the leverage of domestic governance over the environmental content of foreign projects, consistent with Chen et al. (2024) and Qiu et al. (2024). Third, FDI finances renewable capacity, which is consistent with the supply-chain evidence of Han and Li (2024) and the green-finance results of Qian and Yu (2024), Yan and Gong (2024) and Siddikee et al. (2025); the bidirectional causality between FDI and the renewable share indicates a virtuous circle in which renewable capacity attracts further green investment. The weak income effect and the absence of an income-driven Kuznets turning point in the sample echo the asymmetric income effects reported by Bergougui et al. (2024) and suggest that, for most Belt and Road economies, policy, rather than income, is the binding constraint on green development.

The theoretical significance is that the pollution-haven and pollution-halo hypotheses should be understood as regimes of a single conditional relationship rather than as rival hypotheses, and that the switching variable is climate-specific governance rather than income or generic institutional quality. The practical significance is quantitative: the estimated threshold implies that most partner economies remain in the haven regime, but the gap between the median governance score and the threshold is about 18 index points, which corresponds to roughly seven additional national climate laws or an improvement of about half a point in the average governance score magnitudes that several economies achieved within the sample period. Applications are warranted in the design of investment screening and climate-law reform in host countries and in the environmental conditionality of outward investment from source countries.

Several problems remain unresolved or arise from these findings. The composite Green Development Index treats its four components as substitutes, whereas forest loss and air pollution may not be compensated by lower carbon intensity; sector-specific FDI data would allow the composition effect to be identified directly rather than inferred; the Climate Governance Index relies on the count and capacity dimensions of governance and not on the actual enforcement of climate law, which is unobserved; the marginal Sargan statistic in the 2SLS model suggests that the peer-FDI instrument may carry some regional environmental information; and the short time dimension limits the power of the country-by-country bounds tests. The finding that the renewable channel is contemporaneous rather than lagged also raises the question of whether the mediator should be measured as installed capacity or investment flows rather than consumption shares.

CONCLUSIONS

The purpose of this study was to determine whether, and under what conditions, foreign direct investment contributes to green development in Belt and Road economies, treating climate governance as a moderator and the renewable energy transition as a mediator. Using a balanced panel of 40 partner economies over 2006–2025 and a sequence of panel unit-root, structural-break, cointegration, ARDL error-correction, bounds, Granger-causality, VECM/VAR, impulse-response, variance-decomposition, mediation, endogeneity and instrumental-variable procedures, the study finds that FDI lowers the Green Development Index by about 0.63 points per percentage point of GDP at the average level of climate governance and by about 2.6 points in the long run, that the effect turns non-negative once the Climate Governance Index exceeds roughly 62, that FDI raises the renewable share of energy and thereby offsets about 15 percent of its direct environmental cost, and that the variables are cointegrated with causality running from investment and governance to green development. The conclusion to be drawn is that foreign capital is neither inherently clean nor inherently dirty in the Belt and Road context: it is a pollution haven where climate governance is weak and a pollution halo where climate governance is strong.

The study makes four contributions. It is the first to operationalize climate-specific governance, combining the stock of climate laws with enforcement capacity, as the moderator of the FDI environment relationship for the Belt and Road group; it replaces the single-carbon outcome of previous work with a multidimensional green development measure; it identifies the renewable transition as a formal, competitive mediator; and it establishes the short-run, long-run and causal structure of the relationship with a complete dynamic toolkit rather than a single static estimator. Theoretically, the results integrate the pollution-haven, pollution-halo and Porter hypotheses into a governance-contingent framework in which the technique effect of FDI is activated by climate policy.

The managerial and policy implications follow directly. For host governments, the priority is to raise climate governance above the threshold before, not after, courting large investment inflows: expanding the stock of enforceable climate legislation, embedding climate criteria in investment screening and strengthening regulatory capacity convert the same inflow of capital from an environmental liability into an asset. For investment promotion agencies and development finance institutions, targeting FDI toward renewable-energy and energy-efficiency projects amplifies the mediating channel that already offsets part of the direct cost. For source-country policymakers and lenders along the Belt and Road, environmental conditionality on outward investment substitutes for weak host governance and reduces the risk that projects lock in carbon-intensive infrastructure. For firm managers, the results imply that green technology transfer is rewarded in

well-governed host countries and that operating standards should not be relaxed where regulation is weak, as the initiative's green investment commitments and international scrutiny tighten.

The study has limitations. FDI is measured in aggregate rather than by sector, the composite indices rest on judgemental weights, governance indicators are perception-based, the panel is limited to 40 economies with complete data, the country-level ARDL and bounds tests have low power with twenty observations, and the instrumental-variable results depend on the validity of lagged and peer investment as instruments. Future research should use bilateral and sectoral FDI data to identify the composition effect and the specific role of Chinese versus other investment, measure enforcement of climate law directly, extend the mediation framework to green finance and technology transfer as parallel mediators, apply panel threshold and quantile methods to characterize the governance switching point more precisely, and examine whether the post-2020 structural shift reflects a durable greening of Belt and Road investment or a temporary pandemic effect.

Author Contributions: Conceptualisation, K.M.A.I.; Methodology, K.M.A.I.; Software, K.M.A.I.; Validation, K.M.A.I.; Formal Analysis, K.M.A.I.; Investigation, K.M.A.I.; Resources, K.M.A.I.; Data Curation, K.M.A.I.; Writing – Original Draft Preparation, K.M.A.I.; Writing – Review & Editing, K.M.A.I.; Visualization, K.M.A.I.; Supervision, K.M.A.I.; Project Administration, K.M.A.I.; Funding Acquisition, K.M.A.I. Authors have read and agreed to the published version of the manuscript.

Institutional Review Board Statement: Ethical review and approval were waived for this study because the research does not involve vulnerable groups or sensitive issues.

Funding: The authors received no direct funding for this research.

Acknowledgements: The authors have no acknowledgements to declare.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to restrictions.

Declaration of Generative AI and AI-Assisted Technologies in the Writing Process: During the preparation of this work, the author(s) used Grammarly for proofreading and spell checking since the Authors are not native speakers. All intellectual content, analysis, and interpretations were produced solely by the authors. After using this AI tool/service, the author(s) reviewed and edited the content as needed, taking full responsibility for the publication's content.

Conflicts of Interest: The authors declare no conflict of interest.

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