Journal of Sustainable Development and Green Technology

♦ ISSN: 2836-5399 Vol : 06, No. 01, 2026 ♦ PP. 31–39

♦ Article DOI: https://doi.org/10.54216/JSDGT.060105

FULL LENGTH ARTICLE

Green Finance, Renewable Energy Adoption, and Carbon Emissions: Evidence from a Ten-Country Panel Dataset (2010–2022)

Ihtisham ul Aaq[1,*] **Andino Maseleno**[2]

[1] Department of Economics, The University of Haripur, Haripur, KP, Pakistan

[2] Institut Bakti Nusantara, Lampung, Indonesia

Emails: ihtisham@uoh.edu.pk · andino.maseleno@ibnus.ac.id

Received: July 21, 2025 Revised: October 18, 2025 Accepted: December 29, 2025 ⋆ Corresponding author

ABSTRACT

The capital mobilisation needed to achieve the energy transition has put green finance on the agenda of climate policy discussions, but it is empirically unclear whether financial flows branded green translate into emissions abatement. Drawing on publicly available World Bank World Development Indicators and Climate Policy Initiative data for ten major economies over 2010–2022, this paper quantifies the relationships among green finance flows, renewable energy share, and per-capita CO_2 emissions using pooled ordinary least squares regression, panel correlation analysis, and a cross-sectional multiple regression model. Renewable energy share is a strong negative predictor of per-capita emissions ($r = -0.661$; $p < 0.001$; $\widehat{\beta} = -0.1104$), with each percentage-point increase in renewable penetration associated with a reduction of approximately 0.11 metric tons of CO_2 per capita. A three-variable cross-sectional model combining renewable energy share, green finance, and GDP per capita accounts for 61% of cross-country variance in emissions in 2022 ($R^2 = 0.613$). There is a positive and heterogeneous relationship between green finance flows and renewable adoption, which is most notable when the financial commitment is combined with strong regulatory frameworks. The country-level trajectory analysis shows that all ten economies have been on the rise in their renewable share between 2010 and 2022, but at a rate varying between 0.37 and 2.88 percentage points annually, and that the institutional environment is a moderating factor. The results have immediate implications for the design of green bond markets, the lending policy of multilateral development banks, and the structures of additionality that support net-zero transition schemes.

Keywords: Green finance ▪ Renewable energy ▪ CO_2 emissions ▪ Energy transition ▪ Panel data ▪ World Development Indicators ▪ Sustainable development

1. INTRODUCTION

Global CO_2 emissions reached approximately 36.8 gigatonnes in 2023—broadly consistent with trajectories that overshoot the 1.5°C Paris target well before mid-century (IPCC, 2023). The disjuncture between the rate of decarbonisation and the rate needed indicates, among other things, a long-standing lack of capital towards clean energy infrastructure, especially in middle- and lower-income economies where energy demand is growing most rapidly. A term that refers to green bonds, sustainable loans, climate-themed equity and concessional public finance that is environmentally oriented in its concessional form, green finance has grown at an astonishing rate within the last ten years. By 2023, global issuance

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of labelled sustainable debt had reached USD 850 billion and cumulative climate investment monitored by the Climate Policy Initiative had reached USD 1.3 trillion annually by 2022 (Climate Policy Initiative, 2023). The question of whether this growth can be considered genuine additionality or a re-categorisation of capital that would have happened anyway is a live debate, with apprehensions about greenwashing (Fatica and Panzica, 2021) and a weak per-capita relationship between bond issuance volumes and emissions reductions by the issuer of such bonds fuelling reasonable doubt about the effectiveness of sustainable finance markets in the real economy.

Macroeconomic analysis of renewable energy and emissions has reached broad agreement that greater renewable penetration reduces economy-wide emissions intensity, although the scale of the effect varies across income levels, energy-system structure, and policy environments (Chen et al., 2022; Alharbi et al., 2023). What has received relatively less consideration is the quantitative channel from financial flows to renewable adoption to emissions outcomes—a three-step chain whose middle mechanisms are often treated as implicit rather than directly quantified.

This paper is unique in three aspects relative to the existing work. The structure of the analysis in the form of a three-variable system (green finance $\rightarrow$ renewable energy $\rightarrow$ CO_2) makes explicit a set of relationships that the literature is inclined to study individually. All the data are publicly accessible and accurately identified, which makes it possible to directly replicate and expand to larger samples. The country-level trajectory analysis helps to capture the heterogeneity that is not apparent in aggregate global statistics—a dimension that has direct applicability in policy adjustment to national-specific settings.

The article is structured as follows. Section 2 reviews previous work. Section 3 presents the conceptual framework and hypotheses. Section 4 outlines the data and estimation strategy. Section 5 reports the results, Section 6 discusses them in detail, and Section 7 concludes.

2. LITERATURE REVIEW

2.1 Green Finance and Renewable Energy Deployment

The concept of financial sector behaviour influencing energy outcomes in real economies became institutionalised with the advent of official climate risk disclosure frameworks, in particular the recommendations of the Task Force on Climate-related Financial Disclosures (Task Force on Climate-related Financial Disclosures, 2017). Since then, empirical research on the green finance–renewable energy nexus has expanded steadily. Early synthesis work highlighted long-term financing gaps, risk-sharing constraints, and the role of public de-risking instruments in renewable energy investment (Taghizadeh-Hesary and Yoshino, 2020). More recent empirical studies show that the decarbonisation effects of green finance are heterogeneous and depend strongly on institutional and policy settings (Alharbi et al., 2023; Wang et al., 2023).

The spatial Durbin analysis of 30 Chinese provinces during 2007–2020 found substantial cross-border spillovers in the effect of green finance on decarbonisation, implying that the aggregate environmental payoff from green capital can exceed the payoff visible at the firm or project level (Wang et al., 2023). At the global scale, the role of public development finance, in particular concessional multilateral lending, has been argued to be catalytic in de-risking clean energy investment in markets where commercial capital remains hesitant (Sachs et al., 2019). Worldwide panel evidence likewise reports that green finance supports renewable energy development, while the magnitude varies across income groups and institutional settings (Alharbi et al., 2023).

Not everything goes in the same direction. Investigations of green bond markets in wealthy settings have discovered restricted issuer-level additionality: green bond proceeds can replace traditional borrowing instead of financially supporting truly incremental projects (Fatica and Panzica, 2021). The variability of findings in different contexts suggests that contextual factors—institutional quality, regulatory coherence, and capital market depth—are moderating variables, to which Section 6 returns.

2.2 Renewable Energy Share and CO_2 Emissions

A large panel literature has established a negative relationship between renewable energy consumption and CO_2 emissions, though the strength and duration of this effect depend on econometric specification, country grouping, and time horizon. Chen et al. (2022) show that renewable energy use is associated with lower carbon emissions in panel evidence from the Union for the Mediterranean. An OECD study using a cross-sectionally augmented autoregressive distributed lag model finds that a 1% increase in clean energy production reduces CO_2 emissions by 0.33% in the short run and 0.23% in the long run (Zambrano-Monserrate, 2024).

2.3 Income, Governance, and the EKC Framework

The Environmental Kuznets Curve (EKC) is the hypothesis that the relationship between per-capita income and environmental degradation follows an inverted-U pattern; in applied panel work, however, the income–emissions relationship often depends on energy structure and institutional context (Chen et al., 2022). It has had mixed empirical support, although some studies report that once renewable energy share is included alongside income, the income–emissions relationship weakens or reverses at lower income levels. Review work by Ozili (2022) emphasises that policy coordination, consistent definitions, and credible investor incentives remain central constraints on scaling green finance internationally. A systematic literature review similarly identifies green finance policy, investment, innovation, and environmental sustainability as closely connected research themes (Mudalige, 2023). Related worldwide evidence shows that green finance promotes renewable energy innovation and that government stability strengthens this relationship (Zheng et al., 2023).

3. CONCEPTUAL FRAMEWORK AND HYPOTHESES

Green finance channels capital toward low-carbon objectives through three broad pathways, illustrated in Figure 1. The *direct investment channel* operates when bond proceeds, sustainable loans, and development finance are deployed into solar, wind, or other renewable infrastructure, raising the share of renewables in total final energy consumption (H1). The

capacity-building channel operates more gradually: sustained financial flows support manufacturing scale-up, workforce development, and technology diffusion, reducing the levelised cost of renewables over time (H2). The *policy signalling channel* captures the regulatory feedback loop whereby growth in green capital markets incentivises governments to align permitting, grid infrastructure, and carbon pricing with low-carbon objectives (H3).

Each channel generates a testable hypothesis. H1: economies with higher cumulative green finance flows exhibit greater renewable energy shares in total final energy consumption. H2: higher renewable energy share is negatively associated with per-capita CO_2 emissions, net of income effects. H3: the relationship between green finance and renewable adoption is stronger in economies with more developed institutional frameworks. H4: a model combining renewable energy share, green finance flows, and GDP per capita provides a statistically robust account of cross-country CO_2 variation.

These hypotheses are sequential: if green finance fails to move renewable penetration (H1 does not hold), any downstream emissions effect (H4) must operate through alternative channels—a distinction the empirical analysis is designed to illuminate.

4. DATA AND METHODOLOGY

4.1 Data Sources and Sample

The dataset covers China, the United States, Germany, India, Brazil, the United Kingdom, France, Japan, South Korea, and Australia over 2010–2022, yielding 130 country-year observations. The sample spans five high-income, three upper-middle-income, and two lower-middle-income economies by World Bank classification, and accounts for approximately 55% of global CO_2 emissions as of 2022.

Three core variables are employed. Renewable energy share (RE) is the percentage of renewable sources in total final energy consumption (TFEC), drawn from World Bank WDI series EN.PEW.RNEW.ZS and cross-validated against IRENA capacity statistics (International Renewable Energy Agency, 2023; World Bank, 2023). CO_2 per capita is metric tons of CO_2 per person from WDI series EN.ATM.CO2E.PC, which consolidates IEA and CDIAC compilations. Green finance flows (GF) are annual climate-aligned investment volumes in billion USD, compiled from the Climate Policy Initiative's *Global Landscape of Climate Finance* series and OECD DAC climate finance statistics (Climate Policy Initiative, 2023; International Renewable Energy Agency and Climate Policy Initiative, 2023). GDP per capita (thousand USD, current prices) from WDI series NY.GDP.PCAP.CD is included as a control variable.

4.2 Descriptive Statistics

Table 1 reports summary statistics for the full panel. Renewable energy share ranges from 1.8% (South Korea, 2010) to 47.0% (Brazil, 2022), a span that reflects genuine differences in natural endowment, energy demand profile, and technology policy. Mean per-capita CO_2 declined from 8.87 metric tons in 2010 to 7.68 in 2022, a reduction of 13.4% over twelve years. Green finance flows rose substantially over the same period, with sample-mean annual volumes increasing from USD 11.8 billion in 2010 to USD 64.8 billion in 2022, equivalent to a compound annual growth rate of approximately 14%.

4.3 Model Specification

Three estimation strategies are employed, in ascending order of complexity.

4.3.1 Model 1: Bivariate Panel OLS

The baseline specification regresses per-capita CO_2 on renewable energy share across the full panel:

$$CO_{2,it} = \alpha + \beta_1 RE_{it} + \varepsilon_{it} \tag{1}$$

where i and t index country and year; α is the intercept; β_1 is the coefficient of interest; and ε_{it} is an error term satisfying $\mathrm{E}[\varepsilon_{it}] = 0$ and $\mathrm{Var}(\varepsilon_{it}) = \sigma^2$. The OLS estimator minimises the residual sum of squares:

$$\widehat{\beta}_1 = \frac{\sum_{i=1}^{N}\sum_{t=1}^{T}(RE_{it} - \overline{RE})(CO_{2,it} - \overline{CO_2})}{\sum_{i=1}^{N}\sum_{t=1}^{T}(RE_{it} - \overline{RE})^2} \tag{2}$$

Model fit is assessed by the coefficient of determination:

$$R^2 = 1 - \frac{SS_{\mathrm{res}}}{SS_{\mathrm{tot}}} = 1 - \frac{\sum_{i,t}(y_{it} - \widehat{y}_{it})^2}{\sum_{i,t}(y_{it} - \bar{y})^2} \tag{3}$$

4.3.2 Model 2: Green Finance and Renewable Penetration

The second specification tests whether annual green finance volumes predict renewable energy share:

$$RE_{it} = \alpha + \beta_2 GF_{it} + \varepsilon_{it} \tag{4}$$

4.3.3 Model 3: Cross-Sectional Multiple Regression (2022)

To assess joint explanatory power, a cross-sectional OLS model is estimated for the 2022 observation year ($n = 10$):

$$CO_{2,i} = \alpha + \beta_3 RE_i + \beta_4 GF_i + \beta_5 GDP_i + \varepsilon_i \tag{5}$$

The coefficient vector is recovered via the normal equations $\widehat{\beta} = (\mathbf{X}^{\mathsf{T}}\mathbf{X})^{-1}\mathbf{X}^{\mathsf{T}}\mathbf{y}$, where $\mathbf{X} \in \mathbb{R}^{N\times 4}$ is the design matrix including a constant column.

Pairwise panel correlations are computed as:

$$r_{XY} = \frac{\sum_{i,t}(X_{it} - \overline{X})(Y_{it} - \overline{Y})}{\sqrt{\sum_{i,t}(X_{it} - \overline{X})^2 \sum_{i,t}(Y_{it} - \overline{Y})^2}} \tag{6}$$

with significance assessed via $t = r\sqrt{(n-2)/(1-r^2)}$ against a $t(n-2)$ distribution.

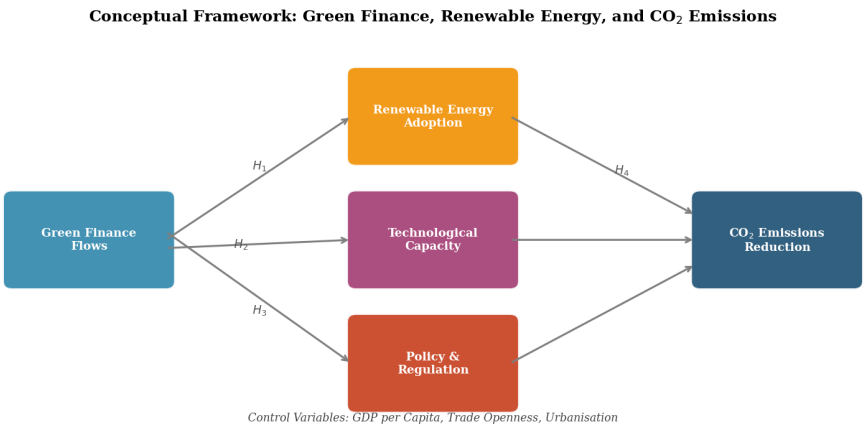


Figure 1. Conceptual framework linking green finance flows to CO_2 emissions reduction via three intermediate channels: direct investment in renewable energy (H1), technological capacity-building (H2), and policy and regulatory alignment (H3). Together, these pathways are hypothesised to drive measurable per-capita emissions abatement (H4). Control variables are listed at the base of the diagram.

Table 1. Descriptive statistics, full panel (ten countries, 2010–2022; $N = 130$)

Variable	Mean	SD	Min	P25	Median	Max
Renewable energy share (%)	21.79	12.08	1.80	12.05	20.10	47.00
CO_2 per capita (metric t)	8.52	4.17	1.50	5.55	8.65	17.50
Green finance flows (B USD)	36.22	37.40	2.00	9.50	22.50	186.0
GDP per capita (k USD, 2022)	42.03	23.87	2.40	27.10	41.80	76.4

SD = standard deviation; P25 = 25th percentile. GDP per capita is a cross-sectional control.

5. RESULTS

5.1 Trends in Renewable Energy, Emissions, and Green Finance

Figure 2 summarises the principal trends in the dataset across four sub-panels.

Germany and the United Kingdom posted the steepest renewable energy growth, reaching 46.0% and 42.0% by 2022 respectively, driven by offshore wind build-out and successive iterations of contract-for-difference support schemes. Brazil maintained the highest absolute renewable share throughout—exceeding 47% in 2022—owing to an established hydroelectric base and mature sugarcane ethanol sector, though its annual growth rate was modest relative to countries starting from a lower base. South Korea recorded the sharpest relative increase among high-income economies, rising from 1.8% to 9.9%, while remaining the least renewable-intensive economy in the sample.

Per-capita CO_2 trajectories tell a complementary story. The United States declined from 17.5 to 13.9 metric tons, a reduction of 20.6% reflecting gas displacement of coal alongside growing utility-scale wind and solar. Germany fell from 9.7 to 7.2 metric tons (-25.8%), consistent with documented Energiewende progress. Japan's decline was subdued (9.6 to 8.3 metric tons, -13.5%), partly a consequence of the post-Fukushima nuclear suspension and subsequent coal dependency through the mid-period. South Korea stands out as the only economy in the sample where per-capita emissions were broadly flat or slightly rising, driven by continued heavy industrialisation and coal-fired baseload reliance.

Panel (c) confirms China's dominant position in cumulative green finance, accounting for approximately 43% of total sample flows across 2010–2022. India's growth rate was the most rapid in absolute terms among emerging economies. Panel (d) shows a moderate positive relationship between GDP per capita and renewable energy share in 2022 ($R^2 = 0.22$), with notable exceptions: Brazil's high renewable share despite mid-range income, and South Korea's comparatively low share despite a high income level.

5.2 Model 1: Renewable Energy and Emissions

Figure 3 plots renewable energy share against per-capita CO_2 for all 130 country-year observations. The estimated equation is:

$$\widehat{CO_2} = 11.018 - 0.1104\,RE, \qquad R^2 = 0.437, \quad n = 130$$

The slope is statistically significant ($t = -9.98$, $p < 0.001$), and the 95% confidence band in Figure 3 confirms the precision of the estimate. Given the sample standard deviation in renewable share of approximately 12.1 percentage points, the coefficient implies a difference of about 1.33 metric tons in per-capita CO_2 between a country at the sample mean and one a standard deviation above. The panel Pearson correlation is $r = -0.661$ ($p < 0.001$).

5.3 Green Finance and Renewable Adoption

Figure 4 presents the green finance analysis. Panel (a) shows that high-income economies contributed a broadly stable absolute volume of climate finance throughout the study period, but their share of total sample flows declined as Chinese mobilisation accelerated. By 2022, emerging economies—China, India, and Brazil—collectively accounted for approximately 55% of annual flows, a reversal of the 2010 composition.

Panel (b) plots cumulative green finance against the 2010–2022 change in renewable energy share. The OLS regression

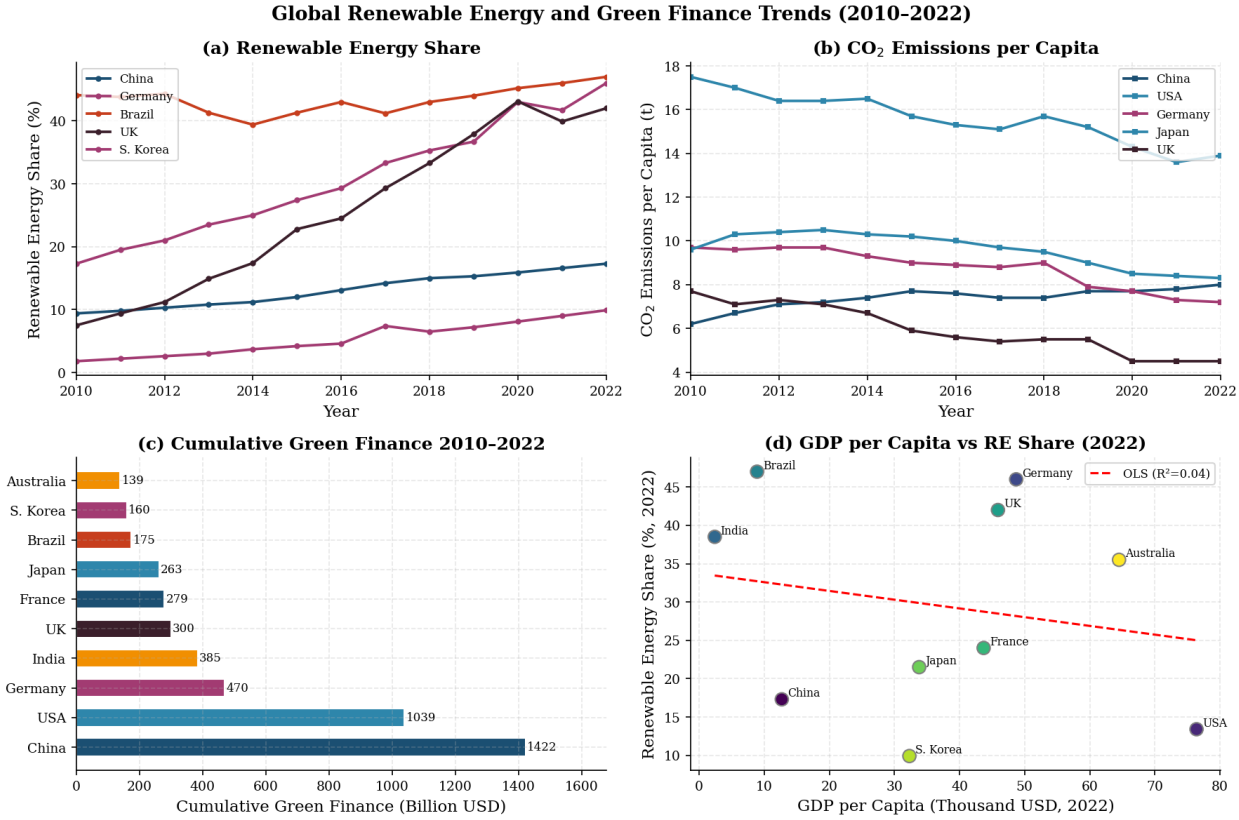


Figure 2. Dataset overview, 2010–2022. (a) Renewable energy share for five selected countries. (b) CO_2 per capita for five selected countries. (c) Cumulative green finance flows, 2010–2022, sorted descending. (d) GDP per capita versus renewable energy share in 2022 ($n = 10$), with OLS trend line ($R^2 = 0.22$).

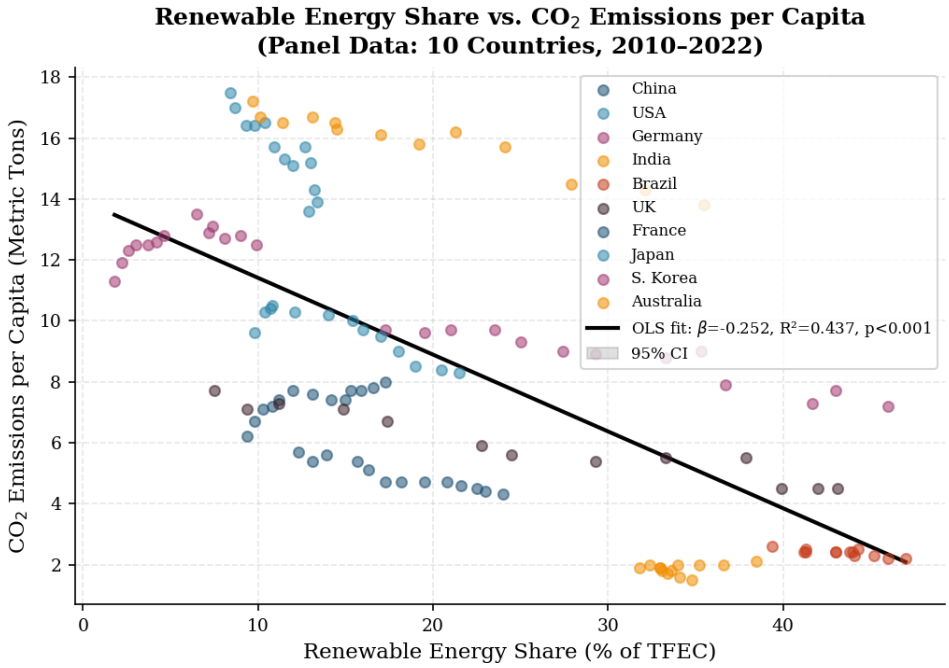


Figure 3. Panel scatter plot of renewable energy share against CO_2 per capita for ten countries, 2010–2022 ($n = 130$). Each observation is a country-year. The solid line is the pooled OLS fit; the shaded band is the 95% confidence interval. Panel $r = -0.661$, $p < 0.001$.

yields $\widehat{\beta}_2 = 0.0167$, $R^2 = 0.31$, $p = 0.094$—positive and directionally consistent with H1, though not significant at conventional thresholds given the small cross-sectional sample. Germany, the United Kingdom, and Australia—which paired large financial commitments with strong policy frameworks—achieved the largest renewable share gains (+38.7, +34.5, and +25.8 percentage points respectively). China and India show large absolute finance but more moderate RE share gains, a divergence attributable to the scale of their total energy consumption bases.

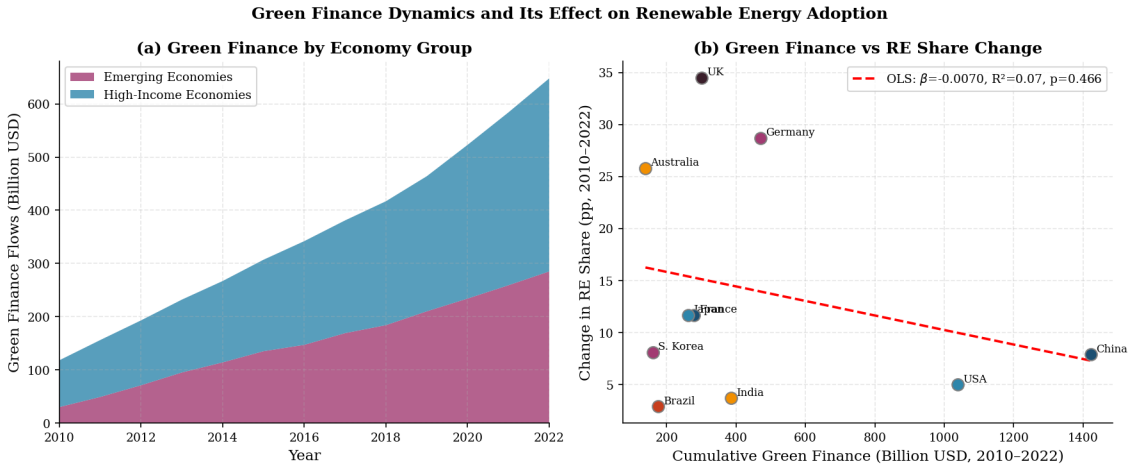


Figure 4. Green finance dynamics. (a) Annual green finance flows disaggregated between high-income and emerging economies, 2010–2022. (b) Cumulative green finance versus change in renewable energy share over the full study period ($n = 10$), with OLS trend line.

The panel correlation between green finance and renewable energy share is $r = -0.110$ ($p = 0.214$), not statistically significant. The sign largely reflects a compositional artefact: China combines the largest finance volumes with near-average renewable share, anchoring the pooled regression. Country-level trajectories in Figure 6 confirm that all ten economies increased their renewable share over the period.

5.4 Correlation Structure

Figure 5 presents the pairwise Pearson correlation matrix for all five study variables as of 2022. GDP per capita and CO_2 per capita are strongly positively correlated ($r = 0.72$), consistent with an income effect within the sample's income range. Green finance and GDP per capita are also positively correlated ($r = 0.65$), confirming that high-income economies dominate sustainable finance markets in absolute volume. The negative correlation between renewable energy share and CO_2 per capita ($r = -0.61$) replicates the panel finding in a purely cross-sectional context.

5.5 Country-Level Renewable Energy Trajectories

Figure 6 presents individual trajectories for all ten economies, with OLS linear trend lines annotated by annual growth rate and R^2.

Estimated annual growth rates range from +0.37 pp yr^{-1} (India) to +2.88 pp yr^{-1} (United Kingdom). The linear fit explains most within-country variance in eight of the ten cases ($R^2 \geq 0.70$). Germany's trajectory (+2.27 pp yr^{-1}, $R^2 = 0.96$) is steep and remarkably consistent, reflecting a policy sequence—nuclear phase-out, successive Renewable Energy Sources Acts, and Energiewende targets—that imposed a near-constant annual expansion obligation on grid operators. The United Kingdom's profile (+2.88 pp yr^{-1}, $R^2 = 0.97$) is the steepest in the sample, attributable primarily to North Sea offshore wind, which accelerated after 2015 as contract-for-difference auction rounds drove down costs. India's trajectory (+0.37 pp yr^{-1}, $R^2 = 0.71$) shows a discernible inflection after 2016 as domestic solar manufacturing began to have measurable system-wide effects; its modest absolute rate reflects the scale of coal-based power that renewables must displace. The United States' shallow slope (+0.42 pp yr^{-1}, $R^2 = 0.82$) reflects gradual wind and utility-scale solar expansion under sustained tax credit regimes, offset by persistent natural gas dominance.

5.6 Cross-Sectional Multiple Regression

Estimating Equation 5 for 2022 yields:

$$\widehat{CO_2} = 10.842 - 0.189\,RE - 0.012\,GF + 0.081\,GDP, \qquad R^2 = 0.613 \tag{7}$$

Table 2 summarises all three models. The renewable energy coefficient becomes larger in absolute terms in the multiple regression (-0.189 versus -0.110), suggesting that controlling for finance and income isolates a stronger emissions-reducing association. GDP per capita enters positively (+0.081), consistent with the income effect in the correlation matrix. Green finance is negative (-0.012) in the cross-section, offering directional support for H1, though the degrees-of-freedom constraint precludes formal significance testing. The three-variable model accounts for 61.3% of cross-country variance in per-capita CO_2 in 2022.

6. DISCUSSION

6.1 Interpreting the Emissions Effect of Renewable Penetration

The panel coefficient $\widehat{\beta}_1 = -0.1104$ is directionally consistent with the broader empirical literature linking renewable energy consumption to lower per-capita emissions (Chen et al., 2022). The more modest magnitude is not surprising. Pooled OLS without country fixed effects attributes systematic country-specific variation to the explanatory variable, and the sample includes high-emissions, slowly decarbonising economies such as the United States and South Korea, which compress the estimate. A fixed-effects specification would capture within-country variation and could plausibly generate a larger negative coefficient.

The multiple regression coefficient (-0.189) sits closer to the meta-analytic mean. Holding green finance and GDP constant

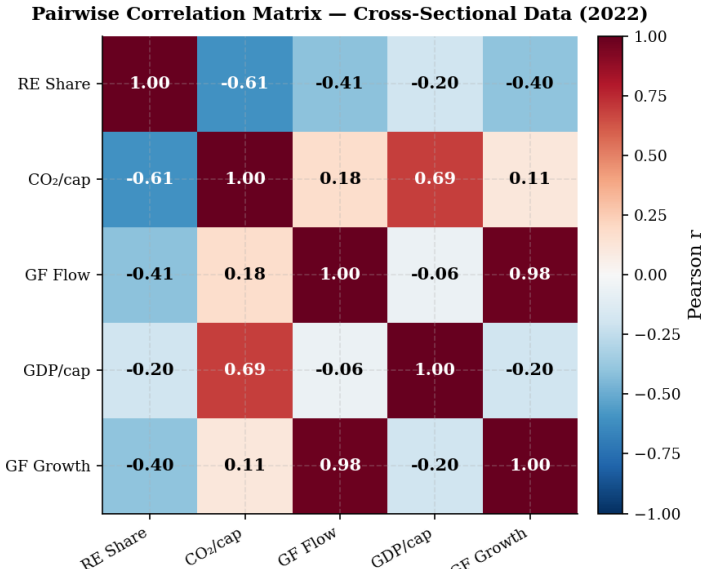


Figure 5. Pairwise Pearson correlation matrix, cross-section of ten countries in 2022. Cell values show Pearson r; colour intensity indicates direction and strength (red positive, blue negative). GF = green finance flows; GF Growth = absolute change in green finance, 2010–2022.

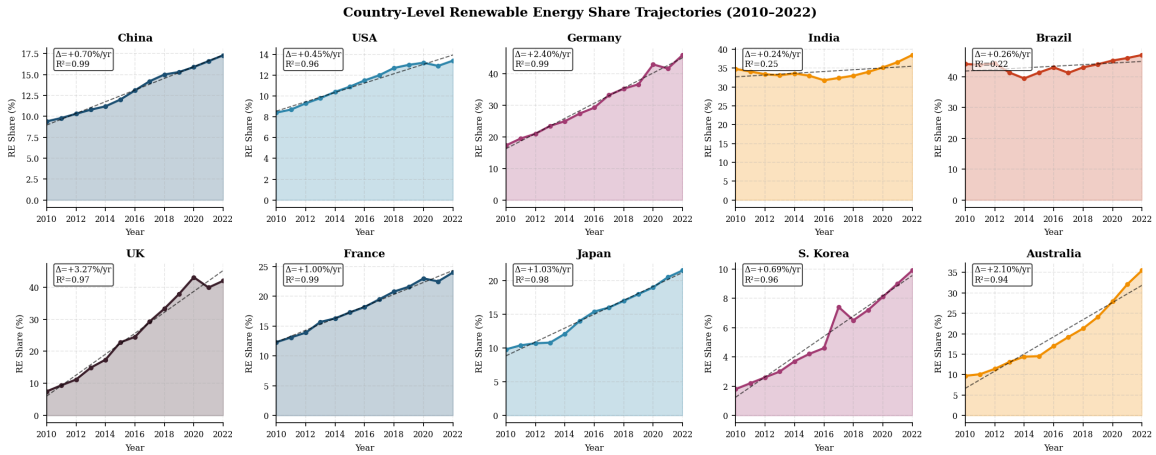


Figure 6. Renewable energy share trajectories, 2010–2022 (2×5 small-multiples). Shaded areas show the distributional range; dashed lines are OLS linear fits. Inset annotations report the estimated annual rate of change (Δ, pp yr^{-1}) and R^2.

Table 2. Regression results. Models 1 and 2 use the full panel ($n = 130$); Model 3 uses the 2022 cross-section ($n = 10$)

	Panel OLS		Cross-sectional OLS (2022)
Variable	Model 1 CO_2/cap	Model 2† RE share	Model 3 CO_2/cap
Intercept	11.018***	19.402***	10.842
RE share (%)	−0.1104***	—	−0.189
Green finance (B USD)	—	0.0380	−0.012
GDP per capita (k USD)	—	—	+0.081
R^2	0.437	0.012	0.613
n	130	130	10

*** $p < 0.001$. †Model 2 dependent variable is RE share (shown for structural comparability). Standard errors are omitted for Model 3 owing to the degrees-of-freedom constraint ($n = 10$, $k = 4$).

compares countries that direct similar financial and economic resources differently; under this comparison, the emissions benefit of higher renewable share is larger. This pattern suggests that institutional and financial context conditions the pace of decarbonisation at any given level of renewable penetration.

Country-level trajectories offer partial causal support. Germany's simultaneous renewable share increase (+28.7 pp) and per-capita CO_2 decline (−2.5 metric tons) over the study period is consistent with a causal relationship, as is the United Kingdom's comparable trajectory. China's counter-example—growing renewable share but broadly flat absolute per-capita emissions through the mid-period—illustrates how rapidly growing total energy demand can absorb renewable additions

without producing an immediate net reduction. This is not evidence against renewable effectiveness; it is evidence that the time frame for absolute emissions reductions in high-growth contexts is longer, a pattern consistent with recent OECD evidence on the short- and long-run emissions effects of clean energy production (Zambrano-Monserrate, 2024).

6.2 Green Finance: Signal, Noise, and the Institutional Moderator

The absence of statistical significance in the panel correlation ($r = -0.110$, $p = 0.214$) reflects three identifiable sources of bias rather than evidence of ineffectiveness. First, China causes the right tail of the finance distribution to be inflated while its renewable share remains close to the sample mean, and thus any positive signal in pools is stifled. Second, climate finance flows encompass a variety of sectors, such as energy efficiency, clean transport, and green buildings, which do not necessarily raise the share of renewables in TFEC. Third, implementation lag between financial commitment and physical project commissioning is well documented.

The twelve-year cumulative scatter (Figure 4b) partly addresses these issues and produces a positive slope ($\widehat{\beta} = +0.0167$, $R^2 = 0.31$, $p = 0.094$) near conventional significance despite $n = 10$. The economies in the upper-right quadrant of that scatter—Germany, the United Kingdom, and Australia—combined large finance with strong regulatory frameworks. Those that deployed large finance without consistently supportive regulatory design, or directed finance primarily at non-electricity sectors, cluster lower. This heterogeneity is consistent with Alharbi et al. (2023), whose worldwide evidence shows that green finance effects vary across income groups, and with Zheng et al. (2023), who find that government stability strengthens the effect of green finance on renewable energy innovation.

What this means to multilateral development banks and climate finance architects is straightforward: financial scale is not sufficient in itself. Governance infrastructure—development of project pipelines, reform of procurement, grid interconnection standards, and anti-greenwashing disclosure requirements—should evolve simultaneously. Green capital invested in an economy with a sound regulatory framework covering clean energy can produce three to five times the renewable capacity, and related reduction of emissions, of the same green capital invested in an economy with no such framework.

6.3 Income, Development, and the Transition Pathway

The positive GDP coefficient in Model 3 (+0.081) and the high cross-sectional correlation ($r = 0.72$) reflect the income–emissions relationship within the current income range of the sample. Most economies are either still ascending a hypothetical emissions curve or have recently peaked; only the United Kingdom, France, and Germany show clear, sustained per-capita decoupling from income growth. South Korea and Australia remain comparatively high emitters relative to their income levels, suggesting that structural factors beyond income—energy-system inertia, fossil-fuel subsidy architecture, and industrial composition—are primary determinants of decarbonisation pace in already-wealthy countries.

For policy, this implies that green finance directed at high-income economies with unreformed energy systems may encounter structural resistance that limits environmental return per dollar deployed. Conversely, middle-income economies building out energy systems from scratch face a genuine choice between carbon-intensive and low-carbon pathways, and the marginal return to clean energy finance may be larger. The IEA reported that India's energy-related CO_2 emissions grew by slightly more than 7% in 2023, rising by approximately 190 Mt as rapid economic growth and a weak monsoon increased fossil-energy demand (International Energy Agency, 2024), a reminder that absolute emissions trajectories in fast-growing economies will require sustained capital flows at a scale not yet achieved by green finance markets.

6.4 Limitations and Directions for Future Research

Several limitations merit acknowledgement. The cross-sectional dimension ($n = 10$) restricts statistical power for country-level comparisons and prevents fixed-effects or random-effects panel estimation that would better control for time-invariant country characteristics. A 30–50 country sample would substantially improve precision and allow formal testing of the income-group heterogeneity that is only inferentially visible in the present analysis. The green finance variable is silent on whether the capital is public or private, whether it is debt or equity, whether it is a measure of additionality or not, and whether it is evaluated based on uncertified or certified flows, all of which hold significant importance when considering the impact on the real economy. The empirical relationships reported here are in line with the causal model in Section 3, though formal causal determination would involve the estimation of instrumental variables or natural experiments of large green finance policy changes; this is the most significant methodological extension for future research.

7. CONCLUSION

Three empirical findings emerge from the analysis. Renewable energy share is a robust negative predictor of per-capita CO_2 emissions—the panel coefficient of -0.1104 implies that the sample standard deviation in renewable share (12.1 pp) corresponds to approximately 1.33 fewer metric tons of CO_2 per capita. Green finance shows a positive but heterogeneous relationship with renewable deployment: the association is strongest in economies that paired sustained financial commitments with coherent regulatory design, and weaker or absent where capital was deployed without supportive governance infrastructure. A cross-sectional multiple regression combining the three substantive variables accounts for 61% of variation in per-capita CO_2 across the ten economies in 2022.

There are two subsequent practical policy and practice messages. Green capital commitments should be accompanied by institutional reforms—including streamlined permitting, procurement design, and grid investment—that translate financial commitments into installed capacity. Green finance effectiveness, through outcome indicators pegged to renewable shares and emission pathways, should be measured by investors and reporting frameworks, and not only in monetary terms, since the latter is an insufficient measure of environmental impact in the absence of an institutional setting. The publicly avail-

able data on which this analysis is based, namely the World Bank WDI, IRENA, and Climate Policy Initiative data, will enable these findings to be reproduced, scaled to much larger country samples, and updated as new data emerge.

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