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Reform, Resilience, and Economic Transformation in MENA

ERF 32nd Annual Conference
June 14-16 | Cairo, Egypt

2026

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ECONOMIC RESEARCH FORUM
منتدى البحوث الاقتصادية

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Carbon Intensity, Regulatory Quality, and Transition Risk

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June 2026

Abstract

Climate transition is reshaping the macro-financial foundations of sustainable growth, especially in carbon-intensive economies. This study examines how carbon intensity and regulatory quality are associated with countries' relative ESG-income positions. We use a sustainability gap measure defined as the percentage deviation between ESG-implied / sustainability-consistent GDP per capita and realized GDP per capita. Positive values indicate that the ESG-implied benchmark is above realized income, whereas negative values indicate that realized income is above the ESG-implied benchmark. Using a panel of 76 countries over 2000-2023 and fixed-effects regressions with lagged explanatory variables, we show that higher production-based CO_2 emissions per unit of output are associated with lower sustainability gaps, indicating less favorable relative ESG-income positions. Stronger regulatory quality is associated with higher gaps and partly attenuates the negative association between carbon intensity and the gap. This moderating role is uneven across country groups and weaker in MENA and resource-rich MENA economies, where structural carbon dependence remains central. System GMM estimates and endogeneity diagnostics indicate that sustainability gaps are highly persistent, reflecting slow-moving structural conditions rather than short-run fluctuations. The findings contribute to the transition-risk literature by interpreting sustainability gaps as macro-financial indicators of carbon-intensive structural vulnerability and institutional transition capacity.

Keywords. Climate transition risk; Carbon intensity; Regulatory quality; Sustainability-adjusted income; Sustainability gap; Macro-finance; Low-carbon transition.
JEL Codes: Q56, Q54, E61, O44, F64

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1 Introduction

Balancing economic growth with environmental sustainability has become one of the central policy and macro-financial challenges of the twenty-first century. Intensifying decarbonization pressures, expanding climate commitments, and the growing financial relevance of climate transition risk have increased scrutiny of national development models across income levels and production structures. Sustainability considerations increasingly shape sovereign risk assessments, international capital allocation, market access, and long-term fiscal resilience (Agarwala et al., 2021; Semieniuk et al., 2021). Yet countries with similar income levels or sustainability ambitions may occupy very different positions relative to the income level implied by their environmental, social, and governance (ESG) fundamentals. Understanding these differences is important for evaluating sovereign transition vulnerabilities and the long-run resilience of development paths.

This paper examines these differences through the concept of a sustainability gap. The gap compares realized GDP per capita with an ESG-implied / sustainability-consistent income benchmark. Positive values indicate that the ESG-implied benchmark is above realized income, while negative values indicate that realized income is above the ESG-implied benchmark. We interpret the gap as a signed measure of countries' relative ESG-income position, not as a standalone ESG score. The construction and interpretation of this measure build on sustainability-adjusted income and sovereign ESG assessment methodologies, including LSEG Sovereign Sustainability Solutions (2025).

The core objective of the paper is to examine how carbon intensity and regulatory quality jointly shape the sustainability gap:

Carbon intensity captures transition-risk exposure embedded in production systems. High CO_2 emissions per unit of output often reflect fossil-fuel dependence, energy-intensive production, technological inefficiency or limited diversification. These features increase exposure to carbon pricing, climate regulation, technological disruption, and shifts in global trade and investment. As a result, higher carbon intensity increases transition-risk exposure and may move countries toward less favorable relative ESG-income positions.

Regulatory quality captures a country's institutional capacity to formulate and implement credible and effective policy frameworks. Stronger regulatory institutions may support more favorable relative ESG-income positions by improving policy predictability, reducing uncertainty, attracting sustainable investment, and facilitating structural adjustment toward lower-carbon production systems. We therefore argue that the association between carbon intensity and the sustainability gap is likely to be conditional on regulatory quality. Stronger regulatory institutions may partially attenuate the negative association between carbon intensity and the gap. However, institutional improvements alone are unlikely to fully offset deep carbon dependence, especially in economies with fossil-fuel-intensive production structures and limited economic diversification. This perspective is consistent with a growing literature linking institutional capacity, structural transformation, and environmental adjustment in low-carbon transitions (e.g., Bowen et al., 2012).

To answer the paper's main research question of how carbon intensity and regulatory quality jointly shape countries' relative ESG-income positions, we use a panel of 76 countries covering the 2000-2023 period. The empirical analysis relates the sustainability gap to lagged production-based CO_2 emissions per unit of GDP, regulatory quality, and their interaction, while controlling for country and year fixed effects. We further examine whether these relationships differ across emerging economies, MENA economies, and resource-rich MENA economies, where transition exposure and institutional capacity may operate under different structural constraints.

Our results show that higher production-based CO_2 emissions per unit of GDP are associated with lower sustainability gaps, indicating less favorable relative ESG-income positions. Regulatory quality is associated with higher gaps and partly attenuates the negative association between carbon intensity and the gap. However, this moderating role varies across country groups. In particular, the regulatory-quality channel appears weaker in MENA and resource-rich MENA economies, where structural carbon dependence remains a central constraint. These findings suggest that institutional capacity matters, but that it does not fully neutralize the transition vulnerabilities associated with carbon-intensive production structures.

We also examine persistence and endogeneity concerns using system GMM estimates and diagnostic specifications. The GMM results show that sustainability gaps are highly persistent, consistent with the view that relative ESG-income positions reflect slow-moving structural conditions rather than short-run fluctuations. Endogeneity diagnostics, including lead-variable, reverse-causality, and lagged-dependent-variable specifications, suggest that the relationships among carbon intensity, regulatory quality, and the sustainability gap are dynamically interconnected. Accordingly, the estimates are interpreted as robust empirical associations consistent with the transition-risk framework, while caution is warranted in drawing strictly causal conclusions.

This study contributes to the macro-finance and sustainability literature in four ways. First, it extends emerging work on sustainability-adjusted income and sovereign ESG assessment by interpreting the gap between ESG-implied and realized GDP per capita as a signed measure of relative ESG-income position rather than as a standalone ESG score (e.g., LSEG Sovereign Sustainability Solutions, 2025). Second, it contributes to the climate transition-risk literature by linking production-based carbon intensity to macro-financial sustainability gaps, thereby showing how carbon-intensive development paths are reflected in less favorable relative ESG-income positions (Agarwala et al., 2021; Semieniuk et al., 2021). Third, it integrates the institutional dimension of transition risk by examining whether regulatory quality moderates the association between carbon intensity and the sustainability gap, consistent with work emphasizing institutional capacity and structural transformation in environmental adjustment (e.g., Bowen et al., 2012). Finally, it shows that institutional mitigation is structurally bounded: in MENA and resource-rich MENA economies, regulatory quality plays a weaker moderating role, indicating that credible regulation can support transition but cannot substitute for reductions in the carbon intensity of production.

The remainder of the paper is organized as follows. Section 2 presents the background and theoretical context. Section 3 develops the concept and interpretation of the sustainability gap. Section 4 presents the conceptual framework and hypotheses. Section 5 describes the data and variables. Section 6 presents the empirical methodology. Section 7 reports the fixed-effects estimates, system GMM results, endogeneity diagnostics, and regional counterfactual analysis. Section 8 concludes and discusses policy implications for low-carbon transition strategies and macro-financial resilience. Additional robustness checks, including alternative emissions and governance measures and five-year changes in the sustainability gap, are reported in Appendix B.

2 Background and Theoretical Context

Recent developments in macro-financial sustainability analysis increasingly emphasize the limitations of conventional GDP-based indicators for evaluating long-run economic resilience. While GDP captures the scale of economic activity, it does not account for the environmental constraints, transition risks, and institutional conditions that shape countries' future productive capacity. This limitation has become more relevant as climate-transition policies, carbon-pricing mechanisms, technological change, and sustainability-related financial regulations increasingly affect sovereign risk, investment allocation, competitiveness, and fiscal resilience (Agarwala et al., 2021; Semieniuk et al., 2021).

To address these shortcomings, a growing literature has developed sustainability-adjusted measures of economic performance, including green GDP, ecological-efficiency indicators, and ESG-adjusted income frameworks that incorporate environmental and institutional dimensions into macroeconomic assessment (Gratcheva et al., 2020; Necula, 2024). These approaches recognize that observed income levels may overstate sustainable productive capacity when economic activity relies heavily on emissions-intensive production, natural-capital depletion, or weak governance structures. Sustainability therefore represents not only an environmental objective, but also a determinant of long-run economic resilience, competitiveness, and transition preparedness.

The sustainability-gap framework builds on this literature by linking ESG fundamentals to macroeconomic income benchmarks. Rather than treating ESG indicators only as standalone scores, the framework compares realized GDP per capita with an ESG-implied sustainability-consistent income benchmark. This makes it possible to examine whether countries occupy more or less favorable relative ESG-income positions. The next section presents the construction and interpretation of this measure in detail.

Within this framework, production-based CO_2 emissions provide a direct measure of the carbon intensity embedded in national production systems. High emissions per unit of output typically reflect fossil-fuel dependence, energy-intensive industrial structures, technological inefficiencies, and limited diversification away from carbon-intensive sectors. These characteristics increase exposure to transition-related risks associated with tightening climate policies, carbon pricing, technological disruption, and changing patterns of global investment and trade.

A growing body of evidence links carbon-intensive production structures to weaker sustainability outcomes. Mehmood et al. (2024) show that fossil-fuel-dependent production systems and inefficient energy structures reduce carbon productivity and weaken sustainable development performance, while Li et al. (2018) identify carbon intensity and inefficient energy use as major obstacles to long-run sustainability. As global decarbonization policies intensify, carbon-intensive economies may face increasing adjustment costs through declining competitiveness, stranded assets, higher financing costs, and greater sovereign vulnerability (D'Orazio & Popoyan, 2019; Dikau & Volz, 2021). Carbon intensity therefore functions not only as an environmental indicator, but also as a proxy for structural transition exposure embedded in national production systems.

The sustainability implications of carbon-intensive development are unlikely to be determined by production structures alone. Countries differ substantially in their capacity to design, implement, and coordinate policies that facilitate low-carbon transitions. Regulatory quality, commonly measured through the Worldwide Governance Indicators (WGI), captures governments' ability to formulate and implement coherent, credible, and effective policy frameworks. Stronger regulatory institutions can improve policy predictability, reduce transition uncertainty, support technological upgrading, attract sustainable investment, and coordinate structural adjustment toward lower-carbon production systems.

The literature increasingly highlights the importance of institutional capacity for environmental adjustment and sustainable development. Governance indicators are associated with improved environmental outcomes (Vasylieva et al., 2019), while Adrangi and Kerr (2022) argue that economic growth alone is insufficient to achieve sustainability objectives in the absence of effective institutional capacity. Research on climate-related financial regulation similarly emphasizes substantial cross-country differences in climate-policy readiness, green financial regulation, and transition-management capacity (D'Orazio & Popoyan, 2019; Dikau & Volz, 2021; Ramezani et al., 2022). These findings suggest that regulatory quality affects not only environmental outcomes, but also countries' ability to adapt to evolving transition pressures.

The relationship between carbon-intensive development and relative ESG-income position is therefore likely to be conditional on institutional capacity. Stronger regulatory frameworks may partly mitigate the adverse implications of carbon-intensive production by improving policy credibility, facilitating structural adjustment, supporting technological upgrading, and reducing transition uncertainty. At the same time, institutional improvements alone are unlikely to fully offset the constraints associated with deep carbon dependence, particularly in economies characterized by fossil-fuel-intensive production systems and limited diversification.

Despite growing research on climate transition risk and sustainability governance, three gaps remain. First, existing studies rarely link carbon intensity directly to ESG-implied macroeconomic income benchmarks. Second, carbon intensity and institutional capacity are often examined separately, leaving limited evidence on how regulatory quality conditions the association between carbon-intensive production and relative ESG-income position. Third, relatively little attention has been devoted to how these relationships vary across structurally heterogeneous country groups, including emerging, MENA, and resource-rich MENA economies, where carbon dependence and institutional capacity may interact in distinctive ways.

This study addresses these gaps by integrating structural transition exposure and institutional capacity within a unified sustainability-gap framework. Specifically, it examines how carbon intensity and regulatory quality jointly shape relative ESG-income positions across heterogeneous economies. By interpreting sustainability gaps as macro-financial indicators of transition-related structural vulnerability, the analysis provides a framework for assessing carbon-intensive development paths, institutional resilience, and the structural constraints facing low-carbon transition.

3 The Concept of the Sustainability Gap

This section presents a systematic reconstruction of the methodology developed by LSEG Sovereign Sustainability Solutions (2025), whose sustainability-gap data are used in this paper.[1] We do not reproduce or modify the underlying data. Instead, we formalize the logic of the measure, restate its main steps in standard notation, and clarify how the ESG Score and the sustainability performance gap should be interpreted in the empirical analysis.

The LSEG ESG Factor-In framework is multidimensional by construction. It draws on more than 210 environmental, social, and governance indicators organized into three pillars and 31 themes. These indicators come from both public and proprietary sources, including the World Bank, the United Nations, Enerdata, the International Road Federation, and LSEG Sovereign Sustainability data. The methodology uses these indicators to construct ESG-implied income benchmarks through income-group-specific statistical relationships between ESG indicators and GDP per capita. The sustainability gap used in this paper is therefore not based on a single emissions or governance variable. It is derived from a broad ESG information set that links sustainability fundamentals to income benchmarks.

[1] While the original technical documentation provides a comprehensive overview, it presents the methodology primarily in descriptive rather than formal notation. For clarity and replicability, we restate the main equations, assumptions, and sequence of the approach in standard economic notation. This reconstruction does not modify or reinterpret the original methodology. It presents its logic as a multi-step empirical framework linking ESG indicators to GDP per capita through income-group-specific partial least squares regressions, non-parametric expectations, and global normalization. The purpose is to make the measure transparent for application, comparison, and extension in cross-country sustainability analysis.

Let j denote a country, t a year, i an ESG indicator, $q \in \{E, S, G\}$ a sustainability pillar, and g an income-group classification (low, lower-middle, upper-middle, high non-OECD, high OECD). All variables are expressed in per-capita terms, and income (GDPpc) is measured in PPP-adjusted U.S. dollars.

$$\begin{aligned} Y_{jt} &= \text{actual GDPpc (PPP)}, \\ X_{ijt} &= \text{value of ESG indicator } i \text{ for country } j \text{ in year } t. \end{aligned} \quad (3.1)$$

The methodology constructs, for each country, a sustainability-consistent level of income, denoted $\hat{Y}_{jt,g}^{(q)}$, and two composite outcomes: (1) a normalized ESG score, and (2) a performance gap relative to peers at comparable income levels.

Because the relationship between income and ESG indicators is non-linear, countries are partitioned into income groups g. Within each group, a PLS regression is estimated separately for each pillar q:

$$\mathrm{Y}_{jt,g}^{(q)} = \alpha_{g,q} + \sum_{i \in q} w_{i,g}^{(q)} X_{ijt} + \varepsilon_{jt,g}^{(q)} \quad (3.2)$$

where $w_{i,g}^{(q)}$ are *materiality weights* indicating the contribution of indicator i to explaining cross-country variation in GDPpc within group g. Low-income groups exhibit high weights for infrastructure and health indicators (e.g., access to electricity, infant mortality); middle-income groups for education and digital access; and high-income groups for innovation, energy efficiency, and governance. The PLS stage is predictive rather than causal and identifies which ESG variables co-vary with income among peers.

To benchmark each indicator against income, a *locally weighted regression* (LOESS) of each X_{ijt} on GDPpc Y_{jt} is estimated:

$$\tilde{X}_i^{\text{exp}}(Y_{jt}) = f_i(Y_{jt}), \quad (3.3)$$

where $f_i(\cdot)$ is a non-parametric function describing the expected level of indicator i at income Y_{jt}.

For indicators displaying an inverted-U pattern (e.g., *Voice and Accountability*), the curve is flattened beyond its turning point $Y_{i,\max}^*$ to avoid predicting declines in performance at very high incomes:

$$\tilde{X}_i^{\text{exp}}(Y_{jt}) = \begin{cases} f_i(Y_{jt}), & Y_{jt} \le Y_{i,\max}^*, \\ f_i(Y_{i,\max}^*), & Y_{jt} > Y_{i,\max}^*. \end{cases} \quad (3.4)$$

Monotonic indicators such as energy efficiency retain the unadjusted LOESS function. The indicator-level deviation from expectation is computed as:

$$\text{Perf}_{ijt}^{(i)} = \frac{X_{ijt} - \tilde{X}_i^{\text{exp}}(Y_{jt})}{\tilde{X}_i^{\text{exp}}(Y_{jt})}. \quad (3.5)$$

Positive values denote above-expected performance relative to peers; negative values indicate under-performance.

The income level statistically consistent with a country's ESG profile is reconstructed using the PLS coefficients from (3.1):

$$\hat{Y}_{jt,g}^{(q)} = \alpha_{g,q} + \sum_{i \in q} w_{i,g}^{(q)} X_{ijt}, \tag{3.6}$$

and combined across pillars to obtain the composite ESG value:

$$\hat{Y}_{jt,g}^{(ESG)} = \frac{1}{3}\left(\hat{Y}_{jt,g}^{(E)} + \hat{Y}_{jt,g}^{(S)} + \hat{Y}_{jt,g}^{(G)}\right). \tag{3.7}$$

Both quantities are expressed in PPP-adjusted U.S. dollars per capita, matching the scale of Y_{jt}. Economically, $\hat{Y}_{jt,g}^{(ESG)}$ represents the level of income implied by the country's ESG structure, conditional on the within-group relationship between ESG indicators and income.

An optional performance accentuation allows stronger weighting of relative over- or under-performance. Let ρ denote the exogenous exponent ($\rho = 0$ yields no amplification, $\rho = 1$ proportional adjustment, and $\rho > 1$ accentuates deviations), distinct from the income-group index g:

$$\hat{Y}_{jt,q}^{\text{adj}} = \hat{Y}_{jt,g}^{(q)} \left(1 + \text{Perf}_{jt}^{(q)}\right)^{\rho}. \tag{3.8}$$

For each pillar q, adjusted sustainable incomes are globally normalized on a 0–100 scale:

$$\text{Score}_{j,q} = \frac{\log\left(\hat{Y}_{j,q}^{\text{adj}}\right) - \min_{p}\left[\log\left(\hat{Y}_{p,q}^{\text{adj}}\right)\right]}{\max_{p}\left[\log\left(\hat{Y}_{p,q}^{\text{adj}}\right)\right] - \min_{p}\left[\log\left(\hat{Y}_{p,q}^{\text{adj}}\right)\right]} \times 100. \tag{3.9}$$

The minimum and maximum are taken across all countries p, ensuring that the highest adjusted GDPpc corresponds to 100 and the lowest to 0 for each pillar. The logarithmic transformation reduces skewness and compresses extreme income differences. While normalization is global, each $\hat{Y}_{j,q}^{\text{adj}}$ originates from a group-specific regression (3.1) - (3.6). Scores are therefore comparable numerically across countries, but their underlying indicator weights differ by income group.

The performance gap measures the percentage difference between sustainable and actual income:

$$\text{Perf}_{jt}^{(ESG)} = \frac{\hat{Y}_{jt}^{(ESG)} - Y_{jt}}{Y_{jt}}. \tag{3.10}$$

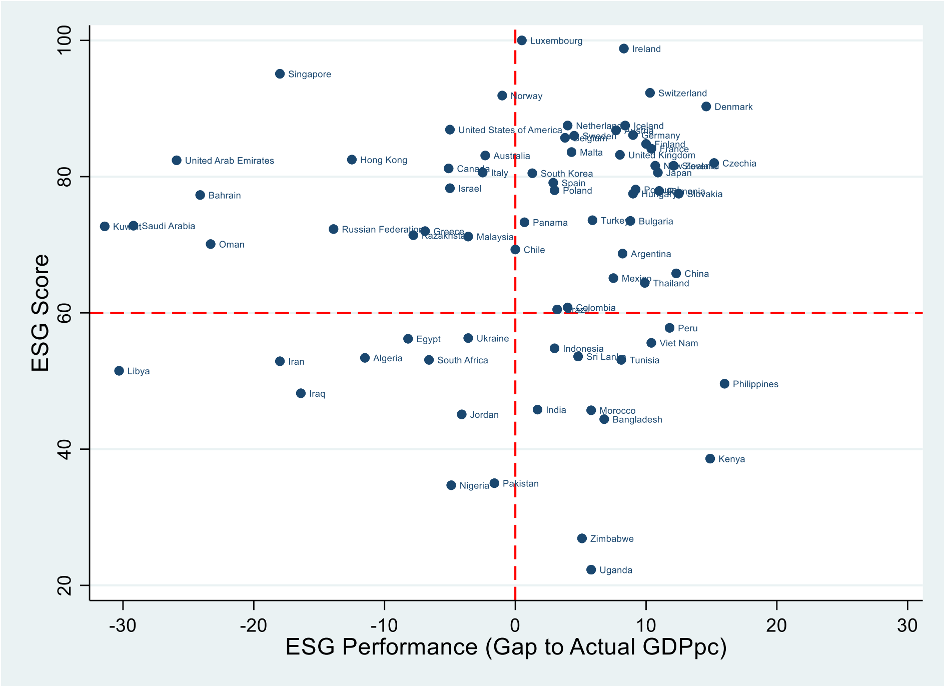
The distinction between the ESG Score and the performance gap is central to the interpretation of the measure. The ESG Score captures the absolute sustainability level generated by the methodology. The performance gap captures a relative ESG-income position. It shows whether realized GDP per capita is below or above the income level implied by the country's ESG structure.

The performance gap is therefore a signed relative measure. A value of zero means that realized GDP per capita equals the ESG-implied benchmark. A positive gap means that the ESG-implied benchmark is above realized GDP per capita. A negative gap means that realized GDP per capita is above the ESG-implied benchmark. The sign of the gap indicates the direction of the deviation. It should not be read as an absolute distance from zero.

Figure 1 summarizes this two-dimensional interpretation by plotting the ESG Score against the performance gaps. Countries in the upper-right quadrant combine high ESG Scores with positive gaps. They therefore have both strong absolute ESG levels and favorable relative ESG-income positions.

Countries in the upper-left quadrant also have high ESG Scores, but their realized income is high relative to the ESG-implied benchmark. These countries combine strong absolute ESG levels with less favorable relative gap positions. Countries in the lower-right quadrant have lower ESG Scores but positive gaps. Their absolute ESG levels remain more limited, yet the ESG-implied benchmark is above realized income. These countries may be interpreted as catch-up performers. Countries in the lower-left quadrant combine lower ESG Scores with negative gaps. They therefore have both weaker absolute ESG levels and less favorable relative ESG-income positions.

Figure 1. ESG Score and the Sustainability Gap: Absolute Sustainability Levels and Relative ESG-Income Positions



Note: The figure plots the ESG Score against the sustainability performance gap. The ESG Score captures the absolute sustainability level generated by the methodology. The performance gap captures the relative ESG-income position, defined as the percentage difference between ESG-implied GDP per capita and realized GDP per capita. Positive gaps indicate that the ESG-implied benchmark is above realized income. Negative gaps indicate that realized income is above the ESG-implied benchmark.

This structure is useful because the score and the gap answer different questions. The ESG Score indicates how strong a country's sustainability fundamentals are in absolute terms. The performance gap indicates how realized income compares with the income benchmark implied by those fundamentals. In the empirical analysis, coefficients are interpreted as movements along the horizontal axis. A positive coefficient is associated with a higher performance gap, meaning a shift toward a more favorable relative ESG-income position. A negative coefficient is associated with a lower performance gap, meaning a shift toward a less favorable relative ESG-income position.

4 Conceptual Framework and Hypotheses

This section develops the hypotheses linking carbon intensity, regulatory quality, and the sustainability gap. Section 3 used the term performance gap when reconstructing the LSEG methodology, consistent with the terminology in the original documentation. In the empirical analysis that follows, we refer to the same variable as the sustainability gap. This terminology better reflects the paper's focus on the distance between realized GDP per capita and the ESG-implied sustainability-consistent income benchmark. Building on the interpretation developed in Section 3, the sustainability gap is treated as a signed measure of relative ESG-income position. Higher values of the gap indicate a more favorable position relative to the ESG-implied income benchmark. Lower values indicate a less favorable position.

Production-based carbon intensity captures transition-risk exposure embedded in national production systems. Economies with high CO_2 emissions per unit of output are more exposed to carbon pricing, climate regulation, technological disruption, and changes in global trade and investment patterns. High carbon intensity often reflects fossil-fuel dependence, energy-intensive production, technological inefficiency, or limited diversification. These features can make realized income less consistent with the income level implied by ESG fundamentals. This leads to the first hypothesis:

H1: *Higher production-based CO_2 emissions per unit of output are associated with lower sustainability gaps.*

The expected negative association reflects the role of carbon intensity as a structural transition-risk indicator. A lower sustainability gap means that a country moves toward a less favorable relative ESG-income position. In empirical terms, H1 predicts a negative coefficient on production-based CO_2 emissions per unit of output.

Regulatory quality captures institutional capacity to formulate, implement, and enforce credible and effective policy frameworks. Stronger regulatory institutions can support transition management by improving policy predictability, reducing uncertainty, attracting sustainable investment, and facilitating structural adjustment toward lower-carbon production systems. These mechanisms may improve the relative position of realized income with respect to the ESG-implied benchmark. This leads to the second hypothesis:

H2: *Stronger regulatory quality is associated with higher sustainability gaps.*

The expected positive association reflects the role of regulatory quality as an institutional transition-capacity indicator. A higher sustainability gap means that a country moves toward a more favorable relative ESG-income position. In empirical terms, H2 predicts a positive coefficient on regulatory quality.

The central mechanism in the paper is the interaction between carbon intensity and regulatory quality. The association between carbon-intensive production and the sustainability gap is unlikely to be uniform across countries. Countries differ in their capacity to manage transition-related adjustment pressures. Stronger regulatory institutions may reduce the adverse association between carbon intensity and the sustainability gap by improving policy credibility, facilitating adaptation, and coordinating low-carbon transition strategies.

At the same time, the moderating role of regulatory quality is expected to be partial. Regulatory institutions can support transition management, but they may not fully offset the constraints associated with entrenched fossil-fuel dependence, energy-intensive production, and limited diversification. In economies where carbon dependence is deeply embedded in production structures, fiscal systems, energy pricing, and export specialization, institutional capacity may be less effective in changing the relative ESG-income position. This leads to the third hypothesis:

H3: *Regulatory quality attenuates the negative association between carbon intensity and the sustainability gap.*

In empirical terms, H3 predicts a positive coefficient on the interaction between carbon intensity and regulatory quality. Such a result would indicate that the negative association between carbon intensity and the sustainability gap becomes weaker when regulatory quality is higher.

The analysis also examines whether these relationships differ across structurally heterogeneous country groups. Emerging economies, MENA economies, and resource-rich MENA economies face different combinations of development constraints, fossil-fuel dependence, industrial composition, export concentration, and institutional capacity. These differences may affect both the direct association between carbon intensity and the sustainability gap and the degree to which regulatory quality moderates that association.

Resource-rich and carbon-intensive economies are especially relevant for this framework. In these economies, transition exposure is often embedded in the structure of production and public finance. Improvements in regulatory quality may strengthen transition-management capacity, but their moderating effect may remain limited when carbon dependence is structurally entrenched. The empirical analysis therefore examines whether the carbon-intensity association and the regulatory-quality moderation differ across emerging, MENA, and resource-rich MENA economies.

Overall, the conceptual framework generates three empirical expectations. Carbon intensity is expected to be associated with lower sustainability gaps. Regulatory quality is expected to be associated with higher sustainability gaps. Regulatory quality is expected to weaken the negative association between carbon intensity and the gap. The strength of this moderating role may vary across country groups, especially where carbon dependence is structurally embedded.

5 Data and Variables

We assemble an annual country panel for $j = 1, \dots, 76$ and $t = 2000, \dots, 2023$. The dependent variable is taken from LSEG Sovereign Sustainability Solutions, ESG Factor-In, 2025. Explanatory variables come primarily from EDGAR and the WGI. Countries are classified into advanced, emerging, MENA, and resource-rich MENA groups. Variable definitions, data sources, pairwise correlations, and country lists are reported in Appendix A. The data are harmonized at the country-year level. Income variables are measured in PPP-adjusted U.S. dollars where relevant. The baseline specifications use the available panel after matching the LSEG, EDGAR, and WGI series.

Dependent variables

The primary dependent variable is the sustainability gap introduced in Section 3. Let Y_{jt} denote realized GDP per capita for country j in year t, measured in PPP-adjusted U.S. dollars. Let $\hat{Y}_{jt}^{(ESG)}$ denote the ESG-implied / sustainability-consistent income benchmark constructed by LSEG. The sustainability gap is defined as:

$$G_{jt} \equiv \text{Perf}_{jt}^{(ESG)} \equiv \frac{\hat{Y}_{jt}^{(ESG)} - Y_{jt}}{Y_{jt}}.$$

The variable is expressed as a percentage deviation. Positive values indicate that the ESG-implied benchmark is above realized GDP per capita. Negative values indicate that realized GDP per capita is above the ESG-implied benchmark. Following Section 3, G_{jt} is interpreted as a signed measure of relative ESG-income position.

As a supplementary outcome, we use the five-year change in the sustainability gap:

$$\Delta^5 G_{jt} \equiv G_{jt} - G_{j,t-5}$$

This variable measures movement in the sustainability gap over the preceding five years. A positive value indicates an upward movement in the gap. A negative value indicates a downward movement. Since $\Delta^5 G_{jt}$ is constructed as a difference in percentage gaps, it is measured in percentage points.

Independent variables

The baseline carbon-intensity variable is production-based fossil CO_2 emissions per unit of output, derived from the EDGAR 2024 fossil CO_2 database. The original EDGAR series reports fossil CO_2 emissions per thousand U.S. dollars of GDP. For interpretability, we rescale the variable by a factor of 10:

$$C_{j,t} \equiv \text{CO2/GDP}_{j,t}^{(10k)}$$

The resulting variable is measured in tons of CO_2 per USD 10,000 of GDP. Higher values indicate greater production-based carbon intensity, meaning more emissions per unit of economic output.

As an alternative emissions measure, we use production-based fossil CO_2 emissions per capita:

$$C_{j,t} \equiv \text{CO2 per capita}_{j,t},$$

This variable is measured in tons of CO_2 per person per year. It scales production-based fossil CO_2 emissions by population and captures the average emissions intensity associated with a country's production system at the individual level. Using both variables allows us to assess whether sustainability gaps are more closely associated with emissions per unit of economic output or with emissions per person.

The main institutional variable is Regulatory Quality from the WGI. It is expressed as a percentile rank ranging from 0 to 100. The indicator captures perceptions of the ability of governments to formulate and implement sound policies and regulations that permit and promote private-sector development. We denote this variable as:

$$I_{j,t} \equiv \text{Regulatory Quality}_{j,t}$$

In robustness checks, we replace Regulatory Quality with Control of Corruption, also from the WGI. This alternative indicator captures perceptions of the extent to which public power is exercised for private gain. It provides a complementary measure of institutional credibility and enforcement capacity.

To examine structural heterogeneity, we use three group indicators. Each is included in a separate specification:

$$D_j \in \{\text{EMR, MENA, RR MENA}\},$$

where each definition is applied in a separate model: $EMR_j = 1$ if country j is an *emerging or developing* economy, and 0 otherwise. $MENA_j = 1$ if country j belongs to the Middle East and North Africa region, and 0 otherwise. $RR\ MENA_j = 1$ if country j is a *resource-rich* MENA economy, and 0 otherwise. Country lists for each category are provided in Appendix A. These indicators enter the regressions via interaction and triple-interaction terms such as:

$$C_{j,t-1} \times D_j, \qquad I_{j,t-1} \times D_j, \qquad C_{j,t-1} \times I_{j,t-1} \times D_j,$$

This structure allows us to examine three forms of heterogeneity. First, it tests whether the association between carbon intensity and the sustainability gap differs across country groups. Second, it tests whether the association between regulatory quality and the gap differs across groups. Third, it tests whether the moderating role of regulatory quality differs in emerging, MENA, and resource-rich MENA economies.

In accordance with the identification strategy detailed in Section 6, all right-hand-side variables enter with a one-year lag: $C_{j,t-1}$, $I_{j,t-1}$, and their interactions. This timing separates predetermined carbon-intensity and institutional conditions from contemporaneous movements in the sustainability gap. Country fixed effects absorb time-invariant country characteristics, including geography, persistent development patterns, long-run institutional features, and baseline regional characteristics. Year fixed effects absorb common global shocks, such as energy-price cycles, global climate-policy developments, and changes in the international macro-financial environment.

Basic descriptives

Table 1 reports summary statistics for the main variables. The sustainability gap, G_{jt}, has a mean close to zero, at -1.01 percent, but displays substantial cross-country dispersion. The standard deviation is 12.71 percentage points, and the 1st and 99th percentiles range from -31.75 to 17.98 percent. This indicates that countries differ considerably in their relative ESG-income positions. The five-year change in the gap, $\Delta^5 G_{jt}$, is much less dispersed. Its standard deviation is 2.99 percentage points, suggesting that movements in the sustainability gap are gradual relative to the cross-sectional differences observed in levels.

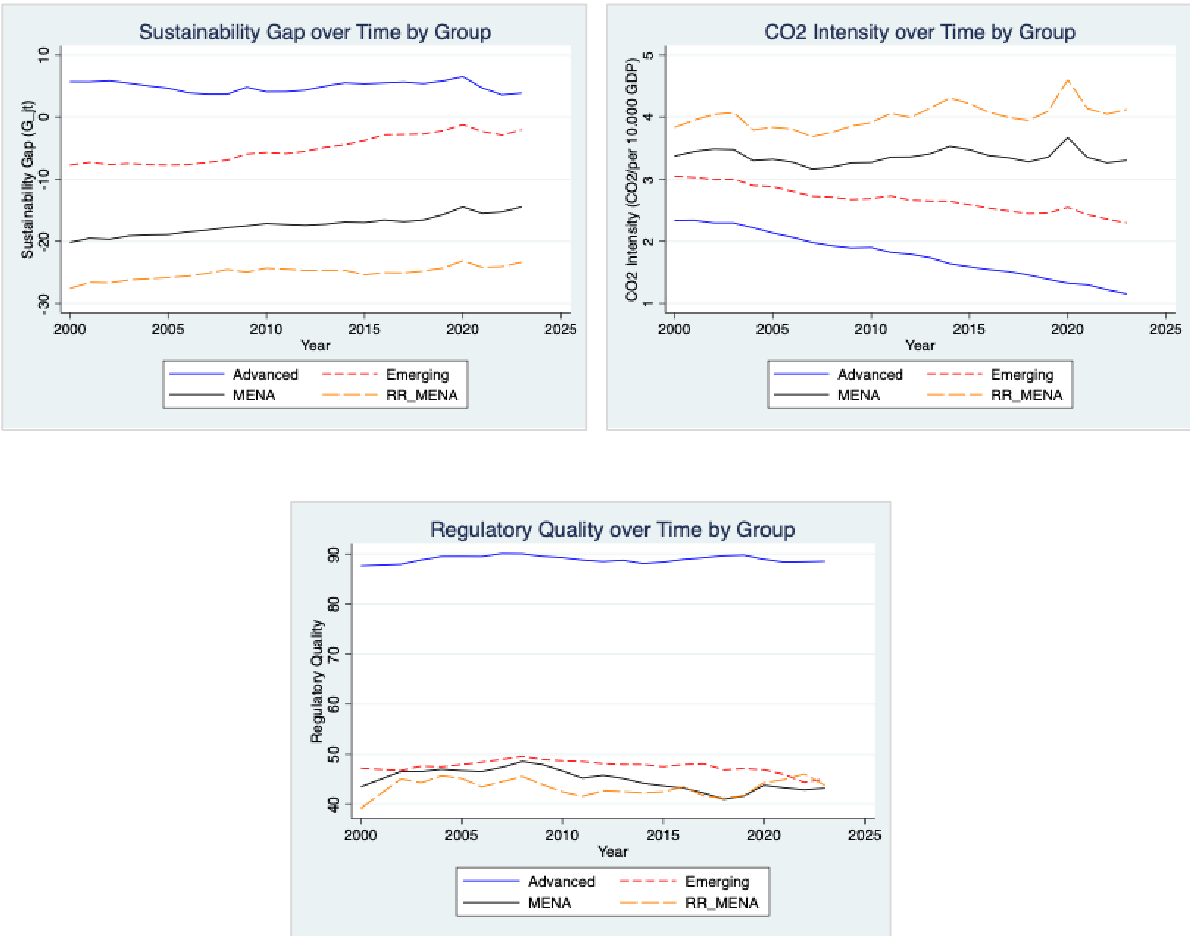
The carbon variables also show substantial heterogeneity. Production-based CO_2 intensity has a mean of 2.32 tons per USD 10,000 of GDP, with a standard deviation of 1.35. The upper tail is considerably higher, with the 99th percentile reaching 6.64. CO_2 emissions per capita are even more dispersed, with a mean of 7.78 tons per person and a standard deviation of 7.30. The 99th percentile reaches 42.37 tons per person, reflecting the presence of highly carbon-intensive economies in the sample. Institutional capacity also varies widely. Regulatory Quality has a mean of 64.47 on the 0 to 100 scale, but its standard deviation is 26.91, indicating large differences in institutional capacity across countries. Control of Corruption displays a similar pattern.

Table 1. Summary Statistics

Variable	N	mean	sd	min	max	p1	p99
G_{jt} (%)	1,822	-1.01	12.71	-35.50	21.90	-31.75	17.98
$\Delta^5 G_{jt}$ (%)	1,442	0.75	2.99	-9.90	10.40	-6.20	7.66
CO2/GDP$^{(10k)}_{j,t}$	1,822	2.32	1.35	0.38	9.49	0.53	6.64
CO2 per capita$_{j,t}$	1,822	7.78	7.30	0.06	56.07	0.14	42.37
Regulatory Quality$_{j,t}$ (0-100)	1,746	64.47	26.91	0.48	100.00	1.93	100.00
Control of Corruption$_{j,t}$ (0-100)	1,746	59.80	29.15	0.00	100.00	2.86	100.00

Figure 2 presents the evolution of the main variables by country group. The upper-left panel shows persistent differences in the sustainability gap. Advanced economies remain in positive territory throughout the sample period. Emerging economies occupy an intermediate position and move gradually upward over time. MENA economies remain below emerging economies, while resource-rich MENA economies display the lowest average sustainability gaps throughout the period. These patterns indicate that relative ESG-income positions differ systematically across development levels and carbon-dependent regions.

Figure 2. Main Variables over Time by Country Groups



The upper-right panel shows similarly persistent differences in Regulatory Quality. Advanced economies maintain substantially higher regulatory quality than all other groups, with values close to the upper end of the scale. Emerging economies remain well below advanced economies but generally above MENA and resource-rich MENA economies. MENA and resource-rich MENA countries display lower and more volatile regulatory quality, especially after the mid-2010s. This pattern supports the view that institutional capacity differs sharply across the country groups used in the empirical analysis.

The lower panels highlight important differences in carbon intensity. Advanced economies exhibit the lowest and most steadily declining CO_2 intensity per unit of GDP. Emerging economies also show a downward trend, although from a higher initial level. MENA and resource-rich MENA economies remain substantially more carbon-intensive. Resource-rich MENA economies display the highest CO_2 intensity throughout most of the period, with a visible increase around 2020.

Briefly, Table 1 and Figure 2 show that sustainability gaps, carbon intensity, and regulatory quality are not randomly distributed across countries. Advanced economies combine relatively favorable sustainability-gap positions with stronger regulatory quality and declining production-based carbon intensity. MENA and resource-rich MENA economies combine lower sustainability gaps, weaker regulatory quality, and higher carbon intensity. These descriptive patterns motivate the empirical analysis below, which examines whether carbon intensity and regulatory quality are systematically associated with the sustainability gap and whether these associations differ across country groups.

6 Empirical Methodology

The empirical analysis examines whether carbon intensity and regulatory quality are systematically associated with the sustainability gap, (G_{jt}). As described in Section 3, the LSEG ESG Factor-In framework draws on a broad information set of more than 210 indicators organized across environmental, social, and governance pillars and 31 themes. The dependent variable is therefore not constructed from any single emissions or governance indicator. It reflects an ESG-implied income benchmark derived from a multidimensional sustainability framework.

Nevertheless, some emissions, energy-efficiency, and governance-related indicators are part of the wider information set used to construct the ESG-implied benchmark. We therefore adopt a conservative empirical design to reduce the possibility that estimated associations reflect contemporaneous measurement overlap. First, all explanatory variables enter with a one-year lag. This timing separates predetermined carbon-intensity and institutional conditions from contemporaneous movements in the sustainability gap. Second, all baseline models include country and year fixed effects. Country fixed effects absorb time-invariant country characteristics, including geography, persistent development patterns, long-run institutional features, and structural characteristics embedded in country trajectories. Year fixed effects absorb common global shocks, including energy-price cycles, global climate-policy developments, and macro-financial conditions affecting all countries in a given year.

This strategy does not eliminate all endogeneity concerns. It is designed to support a disciplined interpretation of the estimates as conditional empirical associations. We therefore complement the baseline fixed-effects estimates with system GMM specifications, endogeneity diagnostics, and regional counterfactual exercises.

Baseline specification

The baseline model relates the sustainability gap G_{jt} defined in Section 3 to lagged production-based carbon intensity, lagged regulatory quality, and their interaction:

$$G_{jt} = \beta_0 + \beta_1 C_{j,t-1} + \beta_2 I_{j,t-1} + \beta_3 \left(C_{j,t-1} \times I_{j,t-1} \right) + \mu_j + \tau_t + \varepsilon_{jt} \qquad (6.1)$$

Here, $C_{j,t-1}$ denotes production-based fossil CO_2 emissions per USD 10,000 of GDP and $I_{j,t-1}$ denotes Regulatory Quality. The terms μ_j and τ_t denote country and year fixed effects.

Because the model includes an interaction term, the coefficient on carbon intensity alone is not the main substantive effect. The relevant quantity is the marginal effect of carbon intensity evaluated at observed values of regulatory quality:

$$\beta_1 + \beta_3 I_{j,t-1}$$

A negative marginal effect indicates that higher carbon intensity is associated with a lower sustainability gap, meaning a movement toward a less favorable relative ESG-income position. A positive marginal effect indicates that higher carbon intensity is associated with a higher sustainability gap, meaning a movement toward a more favorable relative ESG-income position. The interaction coefficient β_3 indicates whether regulatory quality changes the strength or direction of the carbon-intensity association. A positive β_3 implies that the negative association between carbon intensity and the sustainability gap becomes weaker as regulatory quality increases.

To examine whether these associations differ across structurally heterogeneous country groups, we estimate an extended specification with group interactions:

$$G_{jt} = \beta_0 + \beta_1 C_{j,t-1} + \beta_2 I_{j,t-1} + \beta_3\left(C_{j,t-1} \times I_{j,t-1}\right) + \beta_4\left(C_{j,t-1} \times D_j\right) + \beta_5\left(I_{j,t-1} \times D_j\right) + \beta_6\left(C_{j,t-1} \times I_{j,t-1} \times D_j\right) + \mu_j + \tau_t + \varepsilon_{jt} \quad (6.2)$$

Equation (6.2) extends the baseline specification by allowing the carbon-intensity and regulatory-quality associations to differ across country groups. D_j denotes a group indicator, defined separately for emerging economies, MENA economies, and resource-rich MENA economies. Since D_j is time-invariant, its standalone effect is absorbed by the country fixed effects, μ_j, and is therefore not included separately.

For countries outside the group identified by D_j, the marginal effect of carbon intensity is:

$$\beta_1 + \beta_3 I_{j,t-1}.$$

For countries inside the group, the marginal effect is:

$$(\beta_1 + \beta_4) + (\beta_3 + \beta_6) I_{j,t-1}$$

The coefficient β_4 captures whether the carbon-intensity association differs for the group. The coefficient β_5 captures whether the regulatory-quality association differs for the group. The coefficient β_6 captures whether the moderating role of regulatory quality differs for the group. A positive β_6 means that regulatory quality weakens the negative carbon-intensity association more strongly within the group. A negative β_6 means that this moderating role is weaker within the group.

Robustness and endogeneity diagnostics

The fixed-effects specifications are complemented with dynamic panel estimates and additional endogeneity diagnostics. These exercises address three related issues: persistence in the sustainability gap, possible reverse-causality concerns, and anticipatory dynamics.

First, we estimate dynamic panel specifications using two-step system GMM. These models include the lagged dependent variable to account for persistence in the sustainability gap. This is important because relative ESG-income positions are likely to adjust slowly over time. Production structures, energy systems, institutional capacity, and ESG-implied income benchmarks are all persistent. The system GMM specifications therefore assess whether carbon intensity and regulatory quality retain additional explanatory power once this persistence is explicitly modeled. The models include year dummies, use collapsed instruments, and restrict lag depth to limit instrument proliferation. Instrument validity and serial correlation are evaluated using the Hansen test and the Arellano-Bond AR (1) and AR (2) tests.

Second, we implement lead-variable diagnostics. These specifications include future values of carbon intensity and regulatory quality to examine whether the baseline associations may reflect anticipatory dynamics. We also estimate models that include both lagged and future explanatory variables. These specifications assess whether the lagged relationships remain meaningful after controlling for lead effects.

Third, we estimate reverse-causality specifications. These tests examine whether the sustainability gap predicts subsequent carbon intensity or regulatory quality. This helps evaluate whether the baseline relationships are likely to reflect simple feedback from relative ESG-income positions to future emissions intensity or institutional capacity.

Finally, we estimate dynamic fixed-effects specifications that include lagged dependent variables. These models provide additional evidence on persistence and path dependence in the sustainability gap. They also help assess whether the baseline fixed-effects associations remain informative once the slow-moving nature of the dependent variable is taken into account.

These exercises do not establish strict causality. Their purpose is to evaluate whether the baseline results are robust to persistence, anticipatory dynamics, and possible reverse-causality concerns. The estimates are therefore interpreted as conditional empirical associations consistent with the transition-risk framework developed in the paper.

Additional robustness checks are reported in Appendix B. These include specifications that replace production-based CO_2 emissions per unit of GDP with CO_2 emissions per capita, specifications that replace Regulatory Quality with Control of Corruption, and supplementary models using the five-year change in the sustainability gap as the dependent variable. These exercises are not part of the main empirical sequence because the paper focuses on output-based carbon intensity, regulatory quality, and persistent differences in the level of the sustainability gap. They are used to assess whether the baseline patterns are sensitive to alternative emissions scaling, alternative governance measurement, or medium-term changes in the dependent variable.

Counterfactual analysis

We complement the regression analysis with regional counterfactual exercises for MENA and resource-rich MENA economies. These exercises assess the economic relevance of the estimated relationships; they are not forecasts. Using the fixed-effects estimates from the production-based carbon-intensity specification, we examine how the sustainability gap would change under alternative regulatory-quality and carbon-intensity benchmarks.

The first counterfactual holds carbon intensity fixed and replaces observed regulatory quality with external benchmarks, including the global mean and the advanced-economy mean. The second holds regulatory quality fixed and replaces observed carbon intensity with benchmark values from the global and advanced-economy distributions. In both cases, predicted changes are computed from the relevant estimated marginal effects.

These simulations are partial-equilibrium exercises. They do not model general-equilibrium adjustment, fiscal responses, investment dynamics, or political constraints. Their purpose is narrower: to compare the relative magnitude of institutional and structural channels within the estimated empirical framework.

7 Results and Discussion

Baseline sustainability gap results

Table 2 reports fixed-effects estimates for the sustainability gap using production-based CO_2 emissions per USD 10,000 of GDP as the baseline carbon-intensity measure. All specifications include country and year fixed effects and use the one-year lag structure described in Section 6.

Table 2. Fixed-Effects Estimates for the Sustainability Gap: CO_2 Intensity and Regulatory Quality

	(1)	(2)	(3)	(4)	(5)
$C_{j,t-1}$	0.123	-3.127***	4.703**	-4.837***	-5.068***
	[0.246]	[0.566]	[1.874]	[0.397]	[0.385]
$I_{j,t-1}$	0.079***	-0.101***	-0.020	-0.114***	-0.145***
	[0.016]	[0.025]	[0.048]	[0.023]	[0.020]
$C_{j,t-1} \times I_{j,t-1}$		0.071***	-0.001	0.096***	0.099***
		[0.008]	[0.021]	[0.006]	[0.006]
$C_{j,t-1} \times EMR_j$			-7.197***		
			[1.925]		
$I_{j,t-1} \times EMR_j$			0.005		
			[0.056]		
$C_{j,t-1} \times I_{j,t-1} \times EMR_j$			0.044*		
			[0.023]		
$C_{j,t-1} \times MENA_j$				3.311***	
				[0.563]	
$I_{j,t-1} \times MENA_j$				0.051	
				[0.036]	
$C_{j,t-1} \times I_{j,t-1} \times MENA_j$				-0.079***	
				[0.010]	
$C_{j,t-1} \times \text{RR MENA}_j$					3.764***
					[0.551]
$I_{j,t-1} \times \text{RR MENA}_j$					0.098**
					[0.043]
$C_{j,t-1} \times I_{j,t-1} \times \text{RR MENA}_j$					-0.081***
					[0.010]
Constant	-6.320***	3.051	-2.373	3.898***	5.718***
	[1.209]	[1.865]	[1.963]	[1.363]	[1.302]
Observations	1,670	1,670	1,670	1,670	1,670
Adjusted R-squared	0.9591	0.9653	0.9676	0.9677	0.9674
Country FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
F	12.86	48.47	50.64	58.02	58.38

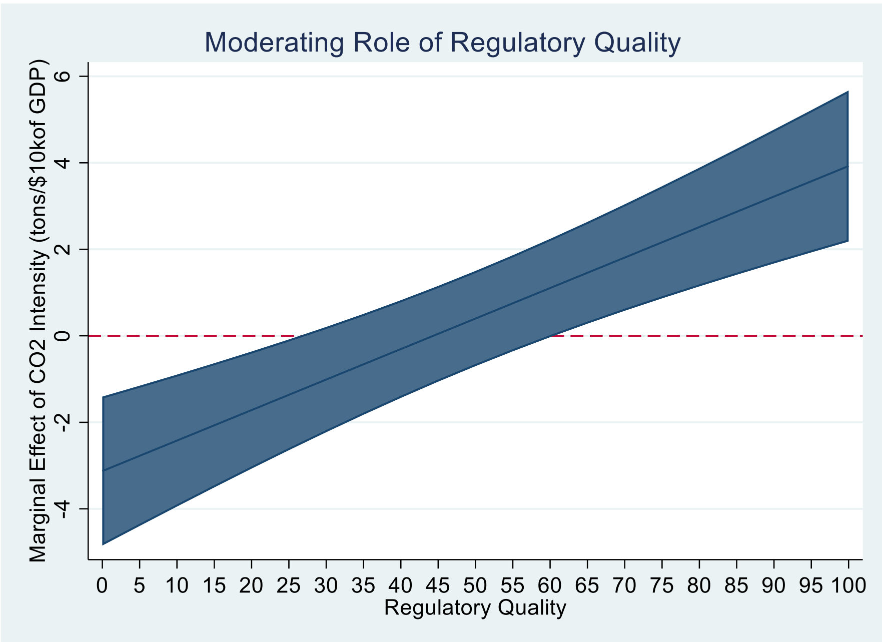
Notes: The dependent variable is the sustainability gap $G_{j,t}$, defined as the percentage deviation between ESG-implied GDP per capita and realized GDP per capita. Positive values indicate that the ESG-implied benchmark is above realized income; negative values indicate that realized income is above the ESG-implied benchmark. All explanatory variables enter with a one-year lag. Columns (3), (4), and (5) introduce group interactions for emerging economies, MENA economies, and resource-rich MENA economies, respectively. All models include country and year fixed effects. Standard errors clustered at the country level are reported in brackets. *** p<0.01, ** p<0.05, * p<0.10.

Column (1) shows that CO_2 intensity is not statistically significant when entered without the interaction term. Regulatory Quality is positive and statistically significant. This indicates that countries with stronger regulatory institutions tend to have higher sustainability gaps, corresponding to more favorable relative ESG-income positions.

Column (2) shows that the association between carbon intensity and the sustainability gap becomes conditional on Regulatory Quality once the interaction term is included. The coefficient on carbon intensity is negative and statistically significant, while the interaction coefficient is positive and statistically significant. The carbon-intensity coefficient of -3.13 implies that, at very low levels of Regulatory Quality, a one-standard-deviation increase in CO_2 intensity, equivalent to 1.35 additional tons of CO_2 per USD 10,000 of GDP, is associated with a reduction of about 4.2 percentage points in the sustainability gap. This corresponds to roughly one third of the standard deviation of the dependent variable.

The positive interaction coefficient of 0.071 indicates that this negative association weakens as Regulatory Quality increases. Evaluated at the sample mean of Regulatory Quality, 64.47, the implied marginal effect of carbon intensity is $-3.13 + 0.071 \times 64.47 = 1.45$. At one standard deviation below the mean of Regulatory Quality, the marginal effect remains negative, at approximately -0.47. These estimates suggest that carbon intensity is associated with less favorable relative ESG-income positions in weaker regulatory environments, while stronger regulatory institutions substantially attenuate this association.

Figure 3. Regulatory Quality and the Carbon Intensity–Sustainability Gap Association



Note: The figure plots the estimated marginal effect of lagged carbon intensity on the current sustainability gap across the distribution of lagged Regulatory Quality based on the fixed-effects specification reported in Table 2, Column (2). Shaded areas represent 95% confidence intervals. The horizontal dashed line indicates a zero marginal effect.

Figure 3 provides a graphical illustration of the interaction effect reported in Column (2) of Table 2. The figure plots the estimated marginal association between lagged carbon intensity and the current sustainability gap across the observed distribution of lagged Regulatory Quality. At low levels of Regulatory Quality, the estimated association is negative, indicating that carbon-intensive production structures are associated with less favorable relative ESG-income positions. As Regulatory Quality increases, the association becomes progressively weaker, approaches zero around the middle of the regulatory-quality distribution, and turns positive at higher levels. The figure provides visual support for Hypothesis 3 and suggests that the adverse association between carbon intensity and sustainability-gap positions is concentrated in weaker institutional environments.

Heterogeneity across country groups

Columns (3) to (5) of Table 2 examine whether the carbon-intensity association and the moderating role of Regulatory Quality differ across country groups. Column (3) introduces heterogeneity for emerging economies. The baseline carbon-intensity coefficient is 4.703 for non-emerging economies. A one standard deviation increase in CO_2 intensity is therefore associated with an increase of about 6.4 percentage points in the sustainability gap for the baseline group. The interaction with the emerging-economy indicator is -7.197, yielding an implied carbon-intensity association of 4.703 - 7.197 = -2.494 for emerging economies before accounting for the regulatory-quality interaction. This reversal indicates that carbon intensity is associated with lower sustainability gaps in emerging economies, while the association is positive for the baseline group.

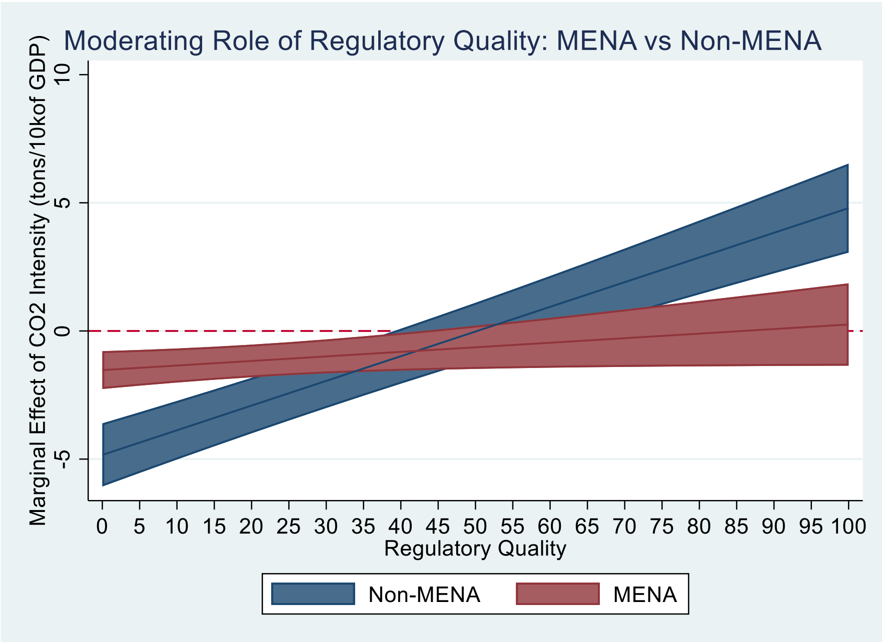
The triple interaction in Column (3) is positive and statistically significant. This suggests that Regulatory Quality weakens the negative carbon-intensity association more strongly in emerging economies than in the baseline group. In other words, institutional capacity appears to matter more for moderating carbon-intensity exposure in emerging economies, where production structures may be more vulnerable to transition-related adjustment pressures.

Column (4) introduces heterogeneity for MENA economies. The baseline carbon-intensity coefficient is -4.837, implying a reduction of about 6.5 percentage points in the sustainability gap for a one standard deviation increase in CO_2 intensity. The interaction with the MENA indicator is 3.311, so the corresponding coefficient for MENA economies is -4.837 + 3.311 = -1.526 before accounting for the regulatory-quality interaction. Thus, carbon intensity is associated with lower sustainability gaps both inside and outside MENA, but the direct carbon-intensity association is smaller in magnitude within MENA.

The key result in Column (4) concerns the triple interaction. It is negative and statistically significant. This indicates that the moderating role of Regulatory Quality is weaker in MENA economies than in the baseline group. In substantive terms, higher Regulatory Quality does not attenuate the carbon-intensity association in MENA to the same extent observed elsewhere. This result is consistent with the view that structural carbon dependence can limit the effectiveness of institutional capacity in shifting countries toward more favorable relative ESG-income positions.

Figure 4 further illustrates differences in the moderating role of Regulatory Quality across MENA and non-MENA economies. For non-MENA countries, the estimated association between lagged carbon intensity and the current sustainability gap becomes less negative as Regulatory Quality improves and eventually turns positive at higher levels. In contrast, the corresponding association for MENA economies remains comparatively flat across the regulatory-quality distribution. The figure reinforces the regression evidence that Regulatory Quality plays a more limited moderating role in MENA economies and suggests that institutional improvements alone may be insufficient to offset vulnerabilities associated with persistent carbon-intensive development structures in the region.

Figure 4. Regulatory Quality, Carbon Intensity, and Sustainability Gaps: MENA versus Non-MENA Economies



Note: The figure plots the estimated marginal effect of lagged carbon intensity on the current sustainability gap across the distribution of lagged Regulatory Quality based on the fixed-effects specification reported in Table 2, Column (4). The blue line represents non-MENA economies, while the red line represents MENA economies. Shaded areas denote 95% confidence intervals. The horizontal dashed line indicates a zero marginal effect.

Column (5) reports the heterogeneity specification for resource-rich MENA economies. The baseline carbon-intensity coefficient is -5.068, implying a reduction of about 6.8 percentage points in the sustainability gap for a one standard deviation increase in CO_2 intensity. The interaction with the resource-rich MENA indicator is 3.764, yielding an implied coefficient of -5.068 + 3.764 = -1.304 before accounting for the regulatory-quality interaction. This is close to the corresponding estimate for the broader MENA group.

The triple interaction in Column (5) is also negative and statistically significant. This indicates that the moderating role of Regulatory Quality is weaker in resource-rich MENA economies. Although Regulatory Quality is positively associated with the sustainability gap in this specification, it does not substantially offset the carbon-intensity association in resource-rich MENA. This finding is important from a transition-risk perspective. It suggests that institutional capacity can support transition management, but that it may not be sufficient when relative ESG-income positions are strongly shaped by carbon-intensive production structures.

Overall, the heterogeneity results support two conclusions. First, the association between carbon intensity and the sustainability gap differs across development levels and regions. Second, the moderating role of Regulatory Quality is not uniform. It appears stronger in emerging economies, but weaker in MENA and resource-rich MENA economies. This pattern reinforces the central argument of the paper: regulatory institutions matter, but their effectiveness is structurally bounded in economies where carbon dependence is deeply embedded in production systems.

Persistence and system GMM evidence

Table 3 reports the system GMM estimates for the sustainability gap. These specifications include the lagged dependent variable to account for persistence in countries' relative ESG-income positions. The results show that the sustainability gap is highly persistent. The coefficient on the lagged dependent variable ranges from 0.839 to 0.925 and is statistically significant at the 1 percent level across all columns. This indicates that the gap evolves slowly over time and reflects persistent structural conditions rather than short-run fluctuations.

Table 3. System GMM Estimates for the Sustainability Gap

	(1)	(2)	(3)	(4)	(5)
$G_{j,t-1}$	0.911***	0.902***	0.925***	0.854***	0.839***
	(0.041)	(0.047)	(0.056)	(0.058)	(0.056)
$C_{j,t-1}$	0.257	0.138	2.053	-0.909	-1.065
	(0.386)	(0.724)	(1.697)	(0.697)	(0.811)
$I_{j,t-1}$	0.026	0.008	0.012	-0.021	-0.019
	(0.016)	(0.025)	(0.026)	(0.025)	(0.025)
$C_{j,t-1} \times I_{j,t-1}$		0.006	-0.024	0.015	0.017
		(0.011)	(0.021)	(0.011)	(0.012)
$C_{j,t-1} \times EMR_j$			-2.087		
			(1.460)		
$I_{j,t-1} \times EMR_j$			-0.002		
			(0.024)		
$C_{j,t-1} \times I_{j,t-1} \times EMR_j$			0.026		
			(0.018)		
$C_{j,t-1} \times MENA_j$				-0.258	
				(0.392)	
$I_{j,t-1} \times MENA_j$				0.035	
				(0.045)	
$C_{j,t-1} \times I_{j,t-1} \times MENA_j$				-0.019	
				(0.018)	
$C_{j,t-1} \times \text{RR MENA}_j$					-0.341
					(0.433)
$I_{j,t-1} \times \text{RR MENA}_j$					-0.056
					(0.074)
$C_{j,t-1} \times I_{j,t-1} \times \text{RR MENA}_j$					0.003
					(0.019)
Constant	-2.706	-2.193	-1.920	2.833	1.206
	(1.706)	(1.877)	(2.447)	(1.873)	(1.592)
Observations	1,670	1,670	1,670	1670	1670
Instruments	34	38	51	51	51
AR1 p-value	0.0000	0.0000	0.0000	0.0000	0.0000
AR2 p-value	0.431	0.414	0.367	0.237	0.221
Hansen p-value	0.274	0.288	0.250	0.560	0.383

Notes: The dependent variable is the sustainability gap $G_{j,t}$, defined as the percentage deviation between ESG-implied GDP per capita and realized GDP per capita. All explanatory variables enter with a one-year lag. All models are estimated using two-step system GMM with Windmeijer-corrected robust standard errors and include year dummy variables. Standard errors are reported in parentheses. AR (1), AR (2), and Hansen test statistics are reported to assess serial correlation and instrument validity. *** p<0.01, ** p<0.05, * p<0.10.

Once this persistence is explicitly modeled, the coefficients on CO_2 intensity, Regulatory Quality, and their interaction are no longer statistically significant. This result should not be interpreted as evidence that carbon intensity and regulatory quality are irrelevant. Rather, it suggests that their associations with the sustainability gap are largely embedded in the persistent component of relative ESG-income positions. Production structures, energy systems, institutional capacity, and ESG-implied income benchmarks co-evolve gradually, leaving limited additional explanatory power for annual changes in carbon intensity and Regulatory Quality once lagged sustainability-gap positions are included.

The diagnostic tests support the validity of the GMM specifications. The AR (1) tests reject the null of no first-order serial correlation, as expected in dynamic panel models, while the AR (2) tests fail to reject the null across all columns. This indicates no evidence of problematic second-order serial correlation. Hansen p-values range from 0.250 to 0.560, providing support for the validity of the instrument sets.

The GMM results therefore complement the fixed-effects estimates. The fixed-effects results show that carbon intensity and Regulatory Quality are systematically associated with the sustainability gap. The GMM estimates show that the gap itself is strongly path dependent. Taken together, the evidence suggests that the sustainability gap captures a slow-moving relative ESG-income position shaped by persistent carbon-intensive production structures and institutional conditions. This reinforces the interpretation of the sustainability gap as a transition-risk-relevant macro-financial indicator.

Endogeneity diagnostics

Table 4 reports endogeneity diagnostics for the sustainability-gap specification. The diagnostics examine whether the baseline fixed-effects results may be affected by anticipatory dynamics, reverse causality, or persistence in the dependent variable. These tests are not intended to establish strict causality. Their purpose is to evaluate whether the baseline associations remain informative under alternative timing assumptions.

Columns (1) and (2) report lead-variable specifications that include future values of CO_2 intensity, Regulatory Quality, and their interaction. The results show that some future values are statistically associated with the current sustainability gap. This indicates that the relationships among carbon intensity, regulatory quality, and the sustainability gap involve dynamic co-evolution rather than a purely one-directional contemporaneous relationship.

Column (3) includes both lagged and future explanatory variables. The lagged CO_2 intensity coefficient remains negative and statistically significant, and the lagged interaction between carbon intensity and Regulatory Quality remains positive and statistically significant. This suggests that the baseline lagged relationships are not fully absorbed by lead effects. In other words, the fixed-effects results are not driven solely by anticipatory dynamics or reverse timing.

Columns (4) and (5) report reverse-causality tests. The lagged sustainability gap does not significantly predict future carbon intensity. This weakens the concern that the baseline CO_2 intensity results mainly reflect feedback from the gap to subsequent emissions intensity. By contrast, the lagged sustainability gap is positively and significantly associated with future Regulatory Quality. This suggests that institutional capacity may evolve partly in response to sustainability-related macroeconomic positions.

The persistence specification confirms the slow-moving nature of the sustainability gap. The lagged dependent variable is positive and statistically significant, indicating substantial path dependence. This result is consistent with the system GMM evidence in Table 3 and reinforces the interpretation of the sustainability gap as a persistent relative ESG-income position.

Table 4. Endogeneity Diagnostics for the Sustainability Gap

	Panel A: Placebo			Panel B: Persistence	
	(1)	(2)	(3)	(4)	(5)
$C_{j,t-1}$			-2.091***		-1.788***
			[0.430]		[0.393]
$I_{j,t-1}$			-0.075***	-0.012***	
			[0.026]	[0.002]	
$C_{j,t-1} \times I_{j,t-1}$			0.043***		
			[0.008]		
$C_{j,t+1}$	0.175	-3.137***	-2.121***		
	[0.253]	[0.587]	[0.437]		
$I_{j,t+1}$	0.091***	-0.087***	-0.046*		
	[0.015]	[0.025]	[0.025]		
$C_{j,t+1} \times I_{j,t+1}$		0.070***	0.043***		
		[0.008]	[0.008]		
$G_{j,t-1}$				0.005	0.372***
				[0.005]	[0.059]
Constant	-7.273***	2.251	4.673***	3.053***	69.022***
	[1.166]	[1.874]	[1.501]	[0.123]	[0.911]
Observations	1,670	1,670	1,594	1,670	1,670
Adjusted R-squared	0.9605	0.9663	0.9684	0.9236	0.9645
Country FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
F	18.82	48.52	46.12	20.70	30.60

Notes: The table reports endogeneity diagnostics for the sustainability-gap specification. The dependent variable is the sustainability gap $G_{j,t}$, except in Columns (4) and (5), where the dependent variables are future CO_2 intensity and future Regulatory Quality, respectively. Columns (1) and (2) report lead-variable specifications using future values of the explanatory variables. Column (3) includes both lagged and future values. Columns (4) and (5) report reverse-causality tests. All regressions include country and year fixed effects. Robust standard errors clustered at the country level are reported in brackets. *** p<0.01, ** p<0.05, * p<0.10.

Taken together, the diagnostics support a cautious interpretation. The relationships among CO_2 intensity, regulatory quality, and the sustainability gap are dynamically interconnected. However, the baseline fixed-effects results are not explained solely by simple reverse causality. The evidence is therefore best interpreted as robust conditional associations consistent with the transition-risk framework.

Additional robustness checks

Appendix B reports additional robustness checks that are not part of the main empirical sequence. The first set examines whether the results depend on the scaling of the emissions variable. Table B.1 replaces production-based CO_2 emissions per unit of GDP with CO_2 emissions per capita, while retaining Regulatory Quality as the institutional variable. The estimates are weaker and less systematic than the baseline results, suggesting that the sustainability gap is more closely associated with output-based carbon intensity than with emissions scaled by population.

The second set examines whether the results depend on the choice of institutional-capacity measure. Tables B.2 and B.3 replace Regulatory Quality with Control of Corruption. Table B.2 uses CO_2 Intensity, while Table B.3 uses CO_2 per capita. The main coefficient patterns remain broadly consistent with the baseline results, indicating that the institutional channel is not specific to Regulatory Quality alone.

The third set examines medium-term changes in the dependent variable. Tables B.4 to B.7 use the five-year change in the sustainability gap as the dependent variable under alternative emissions and governance measures. These estimates are generally weaker than the level specifications, which is consistent with the high persistence of the sustainability gap documented in the system GMM results. Tables B.8 and B.9 provide additional dynamic-panel and diagnostic evidence for the five-year change specifications.

Overall, Appendix B results support the main empirical focus of the paper. The strongest and most systematic evidence concerns the level of the sustainability gap, production-based CO_2 Intensity, in other words emissions per unit of GDP, and Regulatory Quality. The robustness checks therefore reinforce the decision to treat output-based carbon intensity and regulatory quality as the central variables in the main analysis.

Regional Counterfactual Analysis: The Case of MENA

The regional patterns documented above raise a natural question: how much of the estimated sustainability-gap position of MENA and resource-rich MENA economies is associated with institutional conditions, and how much is associated with production-based carbon intensity? To address this question, we use the fixed-effects estimates in Table 2 to construct partial-equilibrium counterfactuals. These exercises should not be interpreted as causal forecasts. The system GMM and endogeneity diagnostics show that the sustainability gap is persistent and that carbon intensity, regulatory quality, and the gap evolve jointly over time. The counterfactuals therefore have a narrower purpose: they compare the relative empirical magnitude of the institutional and structural channels within the estimated fixed-effects framework.

The analysis relies on the production-based carbon-intensity specification in Table 2 because this is the main specification of the paper and directly captures emissions per unit of output. In this specification, each heterogeneity column identifies the marginal effects for a particular group relative to the rest of the sample: emerging economies in Column (3), MENA economies in Column (4), and resource-rich MENA economies in Column (5). The sample remains constant across columns, but the baseline against which each group is compared changes with the relevant group indicator. This setup allows us to compute implied changes in the sustainability gap under alternative institutional and structural benchmarks.

The counterfactual analysis proceeds in three steps. First, we construct the marginal effects implied by equation (6.2). The impact of carbon intensity on the sustainability gap is

$$ME_j^{(C)} = \beta_1 + \beta_3 R_j + \beta_4 D_j + \beta_6 I_j D_j,$$

while the impact of regulatory quality is

$$ME_j^{(I)} = \beta_2 + \beta_3 C_j + \beta_5 D_j + \beta_6 C_j D_j,$$

where D_j denotes the relevant group indicator. Because the sample remains constant across columns in Table 2, the baseline marginal effect corresponds to countries outside the group, and group-specific effects are obtained by adding the relevant interaction coefficients.

Second, we evaluate two sets of counterfactuals. For the regulatory-quality channel, we hold carbon intensity fixed and replace observed regulatory quality with benchmark values drawn from the global and advanced-economy distributions. The implied change in the gap is

$$\Delta G_j^{(I)} = (I_{cf} - I_j)\, ME_j^{(I)}.$$

For the carbon-intensity channel, we hold regulatory quality fixed and replace observed carbon intensity with benchmark values from the global and advanced-economy distributions. The implied change in the gap is

$$\Delta G_j^{(C)} = (C_{cf} - C_j)\, ME_j^{(C)}.$$

Third, we aggregate these implied changes at the group level and report country-level values for MENA economies. The exercise does not quantify policy effects. It decomposes the estimated fixed-effects associations into an institutional channel and a production-structure channel.

Institutional Counterfactuals

Table 5 reports the implied changes in the sustainability gap under alternative regulatory-quality benchmarks. MENA and resource-rich MENA economies have average regulatory-quality levels of 44.88 and 43.35, respectively. These values are below the global mean of 64.47 and far below the advanced-economy mean of 88.98. Despite this distance from the benchmarks, the implied changes in the sustainability gap are small.

Table 5. Institutional Counterfactuals for MENA and RR-MENA

(Benchmark regulatory quality *levels: Global = 64.47, Advanced = 88.98)*

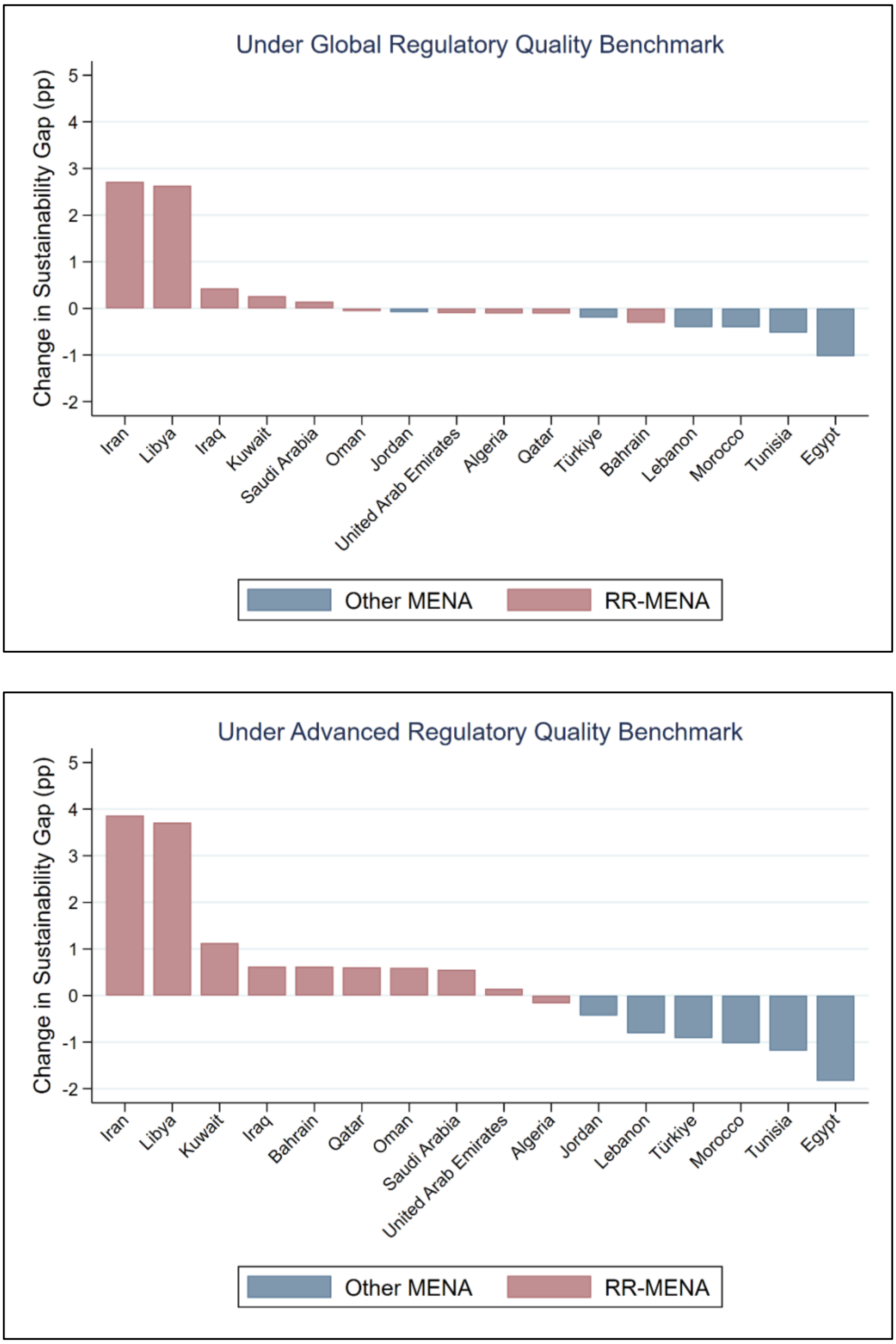
	MENA	RR-MENA
Mean regulatory quality $\bar{I}$	44.88	43.35
Mean carbon intensity $\bar{C}$	3.36	4.01
Marginal effect $ME^{(I)}$	–0.0059	0.0252
Baseline sustainability gap $\bar{G}$ (pp)	–17.37	–25.06
Predicted change under global benchmark $\Delta G^{I}_{\text{global}}$ (pp)	–0.12	+0.53
Predicted change under advanced benchmark $\Delta G^{(I)}_{\text{adv}}$ (pp)	–0.26	+1.15

For MENA, the estimated marginal effect of regulatory quality is close to zero, at -0.0059. Moving regulatory quality to the global benchmark is associated with a change of -0.12 percentage points in the sustainability gap. Moving to the advanced-economy benchmark is associated with a change of -0.26 percentage points. These values are negligible relative to the average MENA sustainability gap of -17.37 percentage points.

For resource-rich MENA, the estimated marginal effect of regulatory quality is positive, at 0.0252. Moving regulatory quality to the global benchmark is associated with a 0.53 percentage-point increase in the sustainability gap. Moving to the advanced-economy benchmark is associated with a 1.15 percentage-point increase. These changes are larger than those for the broader MENA group, but they remain modest relative to the average resource-rich MENA gap of -25.06 percentage points.

Figure 5 reports the country-level implied changes under the same regulatory-quality benchmarks. The pattern is consistent with the group-level results. At the group level, moving Regulatory Quality to the global benchmark changes the sustainability gap by only -0.12 percentage points for MENA and +0.53 percentage points for resource-rich MENA. Moving to the advanced-economy benchmark changes the gap by -0.26 and +1.15 percentage points, respectively. Country-level values follow the same pattern.

Figure 5. Improvements under Different Regulatory Quality Benchmarks



Resource-rich economies such as Qatar, Kuwait, Saudi Arabia, and the United Arab Emirates tend to show larger positive implied changes under the advanced-economy regulatory-quality benchmark because they combine low initial regulatory-quality values with high carbon intensity. However, even in these cases, the implied changes remain modest relative to baseline gaps. By contrast, Morocco, Tunisia, Jordan, and Turkey show smaller changes, often close to zero, because their estimated regulatory-quality channel is weak and their initial regulatory-quality values are closer to the global benchmark. Negative values for some countries should not be interpreted as deterioration in sustainability fundamentals. They reflect the application of a common benchmark when the estimated marginal effect of regulatory quality is close to zero or negative. Overall, the institutional counterfactuals indicate that regulatory quality, holding carbon intensity fixed, is associated with limited changes in the sustainability gap in MENA economies.

Structural Counterfactuals

Table 6 reports the corresponding counterfactuals for production-based carbon intensity. Average carbon intensity is 3.36 tons of CO_2 per USD 10,000 of GDP for MENA and 4.01 for resource-rich MENA. These values exceed both the global benchmark of 2.32 and the advanced-economy benchmark of 1.79. This confirms that the region, especially its resource-rich economies, has more carbon-intensive production structures than the benchmark groups used for comparison.

The marginal effect of carbon intensity on the sustainability gap, evaluated at group-mean regulatory quality, is -0.7631 for MENA and -0.5236 for resource-rich MENA. Holding regulatory quality fixed, replacing observed carbon intensity with the global benchmark is associated with a 0.80 percentage-point increase in the sustainability gap for MENA and a 0.89 percentage-point increase for resource-rich MENA. Replacing observed carbon intensity with the advanced-economy benchmark is associated with increases of 1.20 and 1.16 percentage points, respectively.

Table 6. Structural Counterfactuals for MENA and RR-MENA

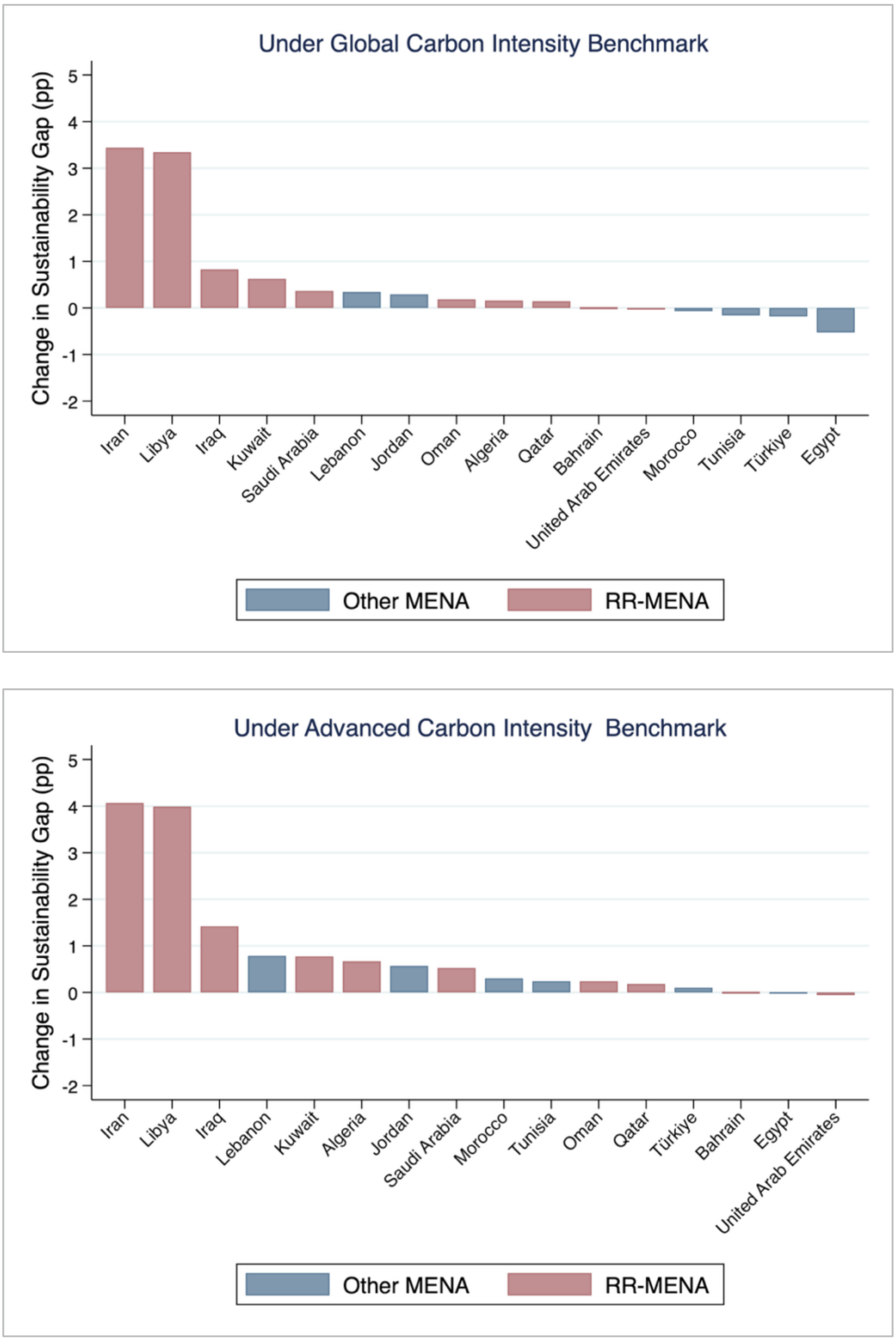
(Benchmark carbon-intensity levels: Global = 2.32, Advanced = 1.79)

	MENA	RR-MENA
Mean carbon intensity $\bar{C}$	3.36	4.01
Mean regulatory quality $\bar{I}$	44.88	43.35
Marginal effect $ME^{(C)}$	–0.7631	–0.5236
Baseline sustainability gap $\bar{G}$ (pp)	–17.37	–25.06
Predicted change under global benchmark $\Delta G^{(C)}_{\text{global}}$ (pp)	+0.80	+0.89
Predicted change under advanced benchmark $\Delta G^{(C)}_{\text{adv}}$ (pp)	+1.20	+1.16

These implied changes are larger than those obtained from the regulatory-quality counterfactuals. The comparison suggests that, within the estimated fixed-effects framework, the sustainability gap in MENA and resource-rich MENA economies is more closely associated with production-based carbon intensity than with regulatory quality alone.

Figure 6 reports the country-level implied changes under the carbon-intensity benchmarks. At the group level, moving carbon intensity to the global benchmark is associated with increases in the sustainability gap of +0.80 percentage points for MENA and +0.89 percentage points for resource-rich MENA. Moving to the advanced-economy benchmark is associated with increases of +1.20 and +1.16 percentage points, respectively. The country-level results show why the group averages mask substantial heterogeneity. Iran and Libya have carbon intensity levels above 5 tons of CO_2 per USD 10,000 of GDP, more than double the global benchmark of 2.32 and almost three times the advanced-economy benchmark of 1.79. For these countries, imposing benchmark carbon-intensity values implies changes of roughly 3 to 4 percentage points in the sustainability gap. Kuwait and Iraq, with carbon intensity above 4 tons per USD 10,000 of GDP, also show larger implied changes than the group average. By contrast, Tunisia, Morocco, Jordan, and Turkey are closer to the global benchmark, generally around 1.8 to 2.3 tons per USD 10,000 of GDP, so their implied changes are smaller and often close to zero. This variation indicates that the structural channel is concentrated in the most carbon-intensive economies rather than evenly distributed across the region.

Figure 6. Improvements under Different Carbon Intensity Benchmarks



In summary, the counterfactuals indicate that the institutional and structural channels differ in empirical magnitude. Regulatory quality remains relevant as part of transition-management capacity, but the implied changes associated with regulatory-quality benchmarks are modest in MENA. The larger implied changes arise from the carbon-intensity benchmarks, especially for highly carbon-intensive economies. This reinforces the interpretation that institutional capacity cannot substitute for structural transformation in production systems.

8 Conclusion and Policy Implications

This paper examined how production-based carbon intensity and regulatory quality are associated with countries' sustainability gaps. The sustainability gap is interpreted as a signed measure of relative ESG-income position, defined by the distance between realized GDP per capita and the ESG-implied income benchmark. Using a panel of 76 countries over the 2000-2023 period, the analysis focused on whether carbon-intensive production structures are associated with less favorable relative ESG-income positions and whether regulatory quality moderates this association.

The fixed-effects results show that production-based CO_2 emissions per unit of GDP are systematically associated with the sustainability gap. In the baseline specification, higher carbon intensity is associated with lower sustainability gaps when regulatory quality is weak. The positive interaction between carbon intensity and regulatory quality indicates that stronger regulatory institutions attenuate this negative association. This finding supports the central argument of the paper: transition-related exposure is not only a function of carbon-intensive production structures, but also of the institutional capacity available to manage transition pressures.

The heterogeneity results show that this moderating role is not uniform across country groups. Regulatory quality plays a stronger moderating role in emerging economies, where institutional capacity appears to matter for reducing the adverse association between carbon intensity and the sustainability gap. In contrast, the moderating role is weaker in MENA and resource-rich MENA economies. This pattern suggests that, in carbon-dependent regions, institutional capacity may be structurally bounded. Credible and effective regulation can support transition management, but it may not fully offset the constraints created by fossil-fuel-intensive production systems, energy structures, and export specialization.

The dynamic and diagnostic results reinforce this interpretation. System GMM estimates show that the sustainability gap is highly persistent. Once lagged gap positions are included, carbon intensity, regulatory quality, and their interaction lose additional explanatory power. This does not imply that these variables are irrelevant. Rather, it indicates that their associations with the gap are embedded in slow-moving structural and institutional trajectories. Endogeneity diagnostics similarly suggest that carbon intensity, regulatory quality, and the sustainability gap evolve jointly over time. The results therefore support a cautious interpretation: the estimates should be read as robust conditional associations consistent with the transition-risk framework, not as strict causal effects.

Additional robustness checks reported in Appendix B support the main empirical focus. Specifications using CO_2 emissions per capita are weaker and less systematic than those using CO_2 emissions per unit of GDP, indicating that the sustainability gap is more closely associated with output-based carbon intensity than with population-scaled emissions. Replacing Regulatory Quality with Control of Corruption yields broadly similar patterns, suggesting that the institutional channel is not specific to a single governance indicator. Five-year change specifications are also weaker than the level specifications, consistent with the high persistence of the sustainability gap.

The regional counterfactual exercises provide further insight into the relative empirical magnitude of the institutional and structural channels. These exercises are not causal forecasts. They are partial-equilibrium decompositions based on the estimated fixed-effects relationships. For MENA and resource-rich MENA economies, moving regulatory quality toward global or advanced-economy benchmarks is associated with relatively small implied changes in the sustainability gap. By contrast, moving production-based carbon intensity toward benchmark levels is associated with larger implied changes, especially for the most carbon-intensive economies. This comparison suggests that regulatory quality is an important enabling condition, but that improvements in relative ESG-income positions in carbon-dependent economies are more closely linked to reducing the carbon intensity of production.

Three policy implications follow. First, regulatory quality remains important. Predictable, credible, and effective regulatory frameworks can reduce uncertainty, support sustainable investment, and improve the coordination of transition policies. However, institutional strengthening should not be interpreted as a substitute for structural change. Second, reducing production-based carbon intensity should be a central component of transition strategy, particularly in economies where fossil-fuel dependence and energy-intensive production remain deeply embedded. Policies that support energy efficiency, clean technology adoption, industrial upgrading, and economic diversification are likely to be essential for shifting countries toward more favorable relative ESG-income positions. Third, the persistence of sustainability gaps points to the need for long policy horizons. Because relative ESG-income positions evolve gradually, effective transition strategies require sustained institutional development and structural transformation rather than short-term policy adjustments.

Overall, the findings support the interpretation of sustainability gaps as macro-financial indicators of transition-related structural vulnerability. Carbon intensity captures an important dimension of exposure to transition risk, while regulatory quality captures part of the capacity to manage that exposure. The evidence suggests that successful low-carbon transitions require both credible institutions and changes in the structure of production. For MENA and resource-rich MENA economies, the results are especially clear: regulatory quality can support transition management, but durable movement toward more favorable relative ESG-income positions is likely to depend on reducing the carbon intensity of output.

Future research could extend this framework in several directions. One avenue is to examine whether sustainability gaps are priced in sovereign bond spreads, credit-default-swap markets, or sovereign ESG assessments. Another is to study how carbon-border-adjustment mechanisms and other climate-policy instruments interact with carbon intensity and institutional capacity. Finally, linking country-level sustainability gaps to firm-level transition-risk exposures could provide deeper insight into the channels through which structural and institutional vulnerabilities affect financial and economic outcomes.

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Appendix A. Data and variables

Table A.1. Definition of Variables

Variable Type& Name	Definition & Source
Dependent Variables	
Sustainability gap	Global Sustainable GDP gap compared to reported GDP (%). This is an efficiency metric that makes countries comparable whatever their positioning in the development pathway. A positive (resp. Negative) figure means that the country has a better (resp. worse) than expected ESG level.
Five-year change of the sustainability gap	Global Sustainable gap compared to reported GDP/5 years variation reflects the medium term adjustment in the country's sustainability gap.
Carbon Intensity Variables	
$\text{CO2/GDP}_{j,t}^{(10k)}$	Production-based fossil CO_2 emissions per USD 10,000 of GDP. Data are obtained from the EDGAR database and reported in GHG emissions of all world countries – JRC/IEA 2024 Report (Crippa et al., 2024). Original data expressed in t CO2eq/kUSD/yr- Converted to CO2eq/10kUSD/yr for presentation purposes.
CO2 per capita	Production-based fossil CO_2 emissions per capita (tons of CO_2 per person). Data are obtained from the EDGAR database and reported in GHG emissions of all world countries – JRC/IEA 2024 Report (Crippa et al., 2024).
Institutional-Capacity Variables	
Regulatory Quality	Regulatory Quality (Percentile Rank) captures perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development.
Control of Corruption	Control of Corruption(Percentile Rank) captures perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as "capture" of the state by elites and private interests.
Other Control Variables	
EMER	1 if country j is an emerging or developing economy, and 0 otherwise.
MENA	1 if country j belongs to the Middle East and North Africa region, and 0 otherwise.
RR MENA	1 if country j is a resource-rich MENA economy, and 0 otherwise.

Notes: The table describes the variables used in the study. Sustainability-gap variables are obtained from LSEG Sovereign Sustainability Data (https://www.lseg.com/en/data-analytics/sustainable-finance/sovereign-climate-data#overview). Fossil CO_2 variables are obtained from the EDGAR database as reported in Crippa et al. (2024) [2], GHG Emissions of All World Countries – JRC/IEA 2024 Report. Regulatory Quality and Control of Corruption are taken from the Worldwide Governance Indicators (WGI).

Table A.2. Pairwise correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)
(1) Sustainability gap	1.00					
(2) Five-year change of the sustainability gap	0.02	1.00				
(3) CO_2 emissions per capita	-0.47	-0.11	1.00			
(4) CO_2 intensity (CO_2 emissions per GDP)	-0.51	0.02	0.47	1.00		
(5) Regulatory Quality	0.37	-0.26	0.32	-0.29	1.00	
(6) Control of Corruption	0.28	-0.27	0.39	-0.22	0.92	1.00

[2] Crippa M., Guizzardi D., Pagani F., Banja M., Muntean M., Schaaf E., Becker, W., Monforti-Ferrario F., Quadrelli, R., Risquez Martin, A., Taghavi-Moharamli, P., Grassi, G., Rossi, S., Melo, J., Oom, D., Branco, A., San-Miguel, J., Manca, G., Pisoni, E., Vignati, E., Pekar, F., GHG emissions of all world countries – JRC/IEA 2024 Report, Luxembourg, 2024, https://data.europa.eu/doi/10.2760/4002897, JRC138862.

Table A.3. Countries by Development Level

Advanced Countries (31 Countries)		
Australia	Iceland	Portugal
Austria	Ireland	Singapore
Belgium	Israel	Slovakia
Canada	Italy	Slovenia
Czechia	Japan	South Korea
Denmark	Luxembourg	Spain
Finland	Malta	Sweden
France	Netherlands	Switzerland
Germany	New Zealand	United Kingdom
Greece	Norway	United States
Hong Kong		

Emerging Countries (45 Countries)		
Resource Rich MENA (10 Countries)	**Emerging Excl. MENA (29 Countries)**	
Algeria	Argentina	Pakistan
Bahrain	Bangladesh	Panama
Iran	Brazil	Peru
Iraq	Bulgaria	Philippines
Kuwait	Chile	Poland
Libya	China	Romania
Oman	Colombia	Russian Federation
Qatar	Hungary	South Africa
Saudi Arabia	India	Sri Lanka
United Arab Emirates	Indonesia	Thailand
	Kazakhstan	Uganda
Other MENA	Kenya	Ukraine
Egypt	Malaysia	Viet Nam
Jordan	Mexico	Zimbabwe
Lebanon	Nigeria	
Morocco		
Tunisia		
Turkey		

Note: Table presents countries by country group. We identify the advanced countries based on IMF classification[3].

[3] https://www.imf.org/en/Publications/WEO/weo-database/2023/April/groups-and-aggregates#ae

Appendix B. Additional robustness checks

Table B.1. Fixed-Effects Estimates for the Sustainability Gap with CO_2 per Capita and Regulatory Quality

	(1)	(2)	(3)	(4)	(5)
$C_{j,t-1}$	0.337***	0.397***	2.754***	1.009***	0.781***
	[0.058]	[0.126]	[0.546]	[0.239]	[0.235]
$I_{j,t-1}$	0.079***	0.085***	0.074	0.146***	0.098***
	[0.015]	[0.019]	[0.054]	[0.025]	[0.022]
$C_{j,t-1} \times I_{j,t-1}$		-0.001	-0.022***	-0.006**	-0.003
		[0.002]	[0.006]	[0.003]	[0.003]
$C_{j,t-1} \times EMR_j$			-2.351***		
			[0.560]		
$R_{j,t-1} \times EMR_j$			0.065		
			[0.058]		
$C_{j,t-1} \times I_{j,t-1} \times EMR_j$			0.018***		
			[0.006]		
$C_{j,t-1} \times MENA_j$				-0.867***	
				[0.279]	
$I_{j,t-1} \times MENA_j$				-0.141***	
				[0.035]	
$C_{j,t-1} \times I_{j,t-1} \times MENA_j$				0.004	
				[0.004]	
$C_{j,t-1} \times \text{RR MENA}_j$					-0.430
					[0.289]
$I_{j,t-1} \times \text{RR MENA}_j$					0.011
					[0.046]
$C_{j,t-1} \times I_{j,t-1} \times \text{RR MENA}_j$					-0.002
					[0.004]
Constant	-8.628***	-8.998***	-10.92***	-11.92***	-10.40***
	[1.094]	[1.316]	[2.109]	[1.421]	[1.403]
Observations	1,670	1,670	1,670	1,670	1,670
Adjusted R-squared	0.9603	0.9603	0.9620	0.9615	0.9609
Country FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
F	29.12	19.62	19.01	17.77	14.60

Notes: The dependent variable is the sustainability gap $G_{j,t}$, defined as the percentage deviation between ESG-implied GDP per capita and realized GDP per capita. Positive values indicate that the ESG-implied benchmark is above realized income; negative values indicate that realized income is above the ESG-implied benchmark. (. All explanatory variables enter with a one-year lag. Columns (3), (4), and (5) introduce group interactions for emerging economies, MENA economies, and resource-rich MENA economies, respectively. All models include country and year fixed effects. Standard errors clustered at the country level are reported in brackets. *** p<0.01, ** p<0.05, * p<0.10.

Table B.2. Fixed-Effects Estimates for the Sustainability Gap with CO_2 Intensity and Control of Corruption

	(1)	(2)	(3)	(4)	(5)
$C_{j,t-1}$	0.322	-2.023***	5.099***	-2.626***	-2.786***
	[0.243]	[0.260]	[1.464]	[0.226]	[0.223]
$I_{j,t-1}$	0.113***	-0.072***	0.073**	-0.069***	-0.089***
	[0.014]	[0.017]	[0.036]	[0.019]	[0.017]
$C_{j,t-1} \times I_{j,t-1}$		0.065***	-0.004	0.082***	0.083***
		[0.004]	[0.017]	[0.004]	[0.004]
$C_{j,t-1} \times EMR_j$			-7.076***		
			[1.483]		
$I_{j,t-1} \times EMR_j$			-0.101**		
			[0.042]		
$C_{j,t-1} \times I_{j,t-1} \times EMR_j$			0.050***		
			[0.018]		
$C_{j,t-1} \times MENA_j$				1.220***	
				[0.445]	
$I_{j,t-1} \times MENA_j$				0.067*	
				[0.037]	
$C_{j,t-1} \times I_{j,t-1} \times MENA_j$				-0.063***	
				[0.008]	
$C_{j,t-1} \times \text{RR MENA}_j$					1.666***
					[0.468]
$I_{j,t-1} \times \text{RR MENA}_j$					0.109**
					[0.046]
$C_{j,t-1} \times I_{j,t-1} \times \text{RR MENA}_j$					-0.066***
					[0.009]
Constant	-8.388***	-0.386	-6.311***	-0.800	0.126
	[1.076]	[1.134]	[1.405]	[1.011]	[0.991]
Observations	1,670	1,670	1,670	1,670	1,670
Adjusted R-squared	0.9603	0.9668	0.9687	0.9690	0.9685
Country FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
F	33.28	100	78.54	102.5	103.6

Notes: The dependent variable is the sustainability gap $G_{j,t}$, defined as the percentage deviation between ESG-implied GDP per capita and realized GDP per capita. Positive values indicate that the ESG-implied benchmark is above realized income; negative values indicate that realized income is above the ESG-implied benchmark. (. All explanatory variables enter with a one-year lag. Columns (3), (4), and (5) introduce group interactions for emerging economies, MENA economies, and resource-rich MENA economies, respectively. All models include country and year fixed effects. Standard errors clustered at the country level are reported in brackets. *** p<0.01, ** p<0.05, * p<0.10.

Table B.3. Fixed-Effects Estimates for the Sustainability Gap with CO_2 per Capita and Control of Corruption

	(1)	(2)	(3)	(4)	(5)
$C_{j,t-1}$	0.334***	0.174	1.604***	0.209	0.102
	[0.055]	[0.121]	[0.507]	[0.203]	[0.201]
$I_{j,t-1}$	0.107***	0.091***	0.187***	0.114***	0.088***
	[0.013]	[0.017]	[0.049]	[0.020]	[0.018]
$C_{j,t-1} \times I_{j,t-1}$		0.002	-0.011**	0.004*	0.006**
		[0.001]	[0.005]	[0.002]	[0.002]
$C_{j,t-1} \times EMR_j$			-1.505***		
			[0.522]		
$I_{j,t-1} \times EMR_j$			-0.086*		
			[0.052]		
$C_{j,t-1} \times I_{j,t-1} \times EMR_j$			0.012**		
			[0.006]		
$C_{j,t-1} \times MENA_j$				-0.350	
				[0.251]	
$I_{j,t-1} \times MENA_j$				-0.102***	
				[0.035]	
$C_{j,t-1} \times I_{j,t-1} \times MENA_j$				-0.001	
				[0.003]	
$C_{j,t-1} \times \text{RR MENA}_j$					-0.025
					[0.282]
$I_{j,t-1} \times \text{RR MENA}_j$					-0.006
					[0.052]
$C_{j,t-1} \times I_{j,t-1} \times \text{RR MENA}_j$					-0.005
					[0.004]
Constant	-9.948***	-8.981***	-12.958***	-9.651***	-9.200***
	[0.912]	[1.124]	[1.881]	[1.120]	[1.142]
Observations	1,670	1,670	1,670	1,670	1,670
Adjusted R-squared	0.9614	0.9614	0.9619	0.9624	0.9621
Country FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
F	50.59	33.50	19.87	23.23	21.60

Notes: The dependent variable is the sustainability gap $G_{j,t}$, defined as the percentage deviation between ESG-implied GDP per capita and realized GDP per capita. Positive values indicate that the ESG-implied benchmark is above realized income; negative values indicate that realized income is above the ESG-implied benchmark. (. All explanatory variables enter with a one-year lag. Columns (3), (4), and (5) introduce group interactions for emerging economies, MENA economies, and resource-rich MENA economies, respectively. All models include country and year fixed effects. Standard errors clustered at the country level are reported in brackets. *** p<0.01, ** p<0.05, * p<0.10.

Table B.4. Fixed-Effects Estimates for the Five-Year Change in the Sustainability Gap with CO_2 Intensity per GDP and Regulatory Quality

	(1)	(2)	(3)	(4)	(5)
$C_{j,t-1}$	0.810***	1.607***	-0.599	1.106***	1.021**
	[0.244]	[0.405]	[1.787]	[0.419]	[0.425]
$I_{j,t-1}$	-0.030**	0.014	-0.064	0.012	-0.003
	[0.015]	[0.022]	[0.064]	[0.024]	[0.022]
$C_{j,t-1} \times I_{j,t-1}$		-0.017**	0.004	-0.012*	-0.012*
		[0.007]	[0.022]	[0.007]	[0.007]
$C_{j,t-1} \times EMR_j$			2.160		
			[1.839]		
$I_{j,t-1} \times EMR_j$			0.075		
			[0.069]		
$C_{j,t-1} \times I_{j,t-1} \times EMR_j$			-0.016		
			[0.023]		
$C_{j,t-1} \times MENA_j$				0.978	
				[0.803]	
$I_{j,t-1} \times MENA_j$				-0.016	
				[0.053]	
$C_{j,t-1} \times I_{j,t-1} \times MENA_j$				-0.004	
				[0.015]	
$C_{j,t-1} \times \text{RR MENA}_j$					1.465*
					[0.850]
$I_{j,t-1} \times \text{RR MENA}_j$					0.048
					[0.068]
$C_{j,t-1} \times I_{j,t-1} \times \text{RR MENA}_j$					-0.006
					[0.016]
Constant	0.930	-1.414	1.537	-1.146	-0.491
	[1.142]	[1.417]	[2.395]	[1.370]	[1.327]
Observations	1,290	1,290	1,290	1,290	1,290
Adjusted R-squared	0.3584	0.3623	0.3630	0.3631	0.3642
Country FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
F	8.152	7.183	4.426	4.092	4.365

Notes: The dependent variable is the five-year change in the sustainability gap $\Delta^5 G_{j,t}$, defined as the change in $G_{j,t}$ over the preceding five years. Positive values indicate an upward movement in the sustainability gap; negative values indicate a downward movement. All explanatory variables enter with a one-year lag. Columns (3), (4), and (5) introduce group interactions for emerging economies, MENA economies, and resource-rich MENA economies, respectively. All models include country and year fixed effects. Standard errors clustered at the country level are reported in brackets. *** p<0.01, ** p<0.05, * p<0.10.

Table B.5. Fixed-Effects Estimates for the Five-Year Change in the Sustainability Gap with CO_2 per Capita and Regulatory Quality

	(1)	(2)	(3)	(4)	(5)
$C_{j,t-1}$	0.236***	0.376**	-0.271	0.380	0.335
	[0.067]	[0.157]	[0.658]	[0.261]	[0.259]
$I_{j,t-1}$	-0.044***	-0.027	-0.077	-0.009	-0.026
	[0.015]	[0.018]	[0.070]	[0.022]	[0.019]
$C_{j,t-1} \times I_{j,t-1}$		-0.002	0.003	-0.003	-0.003
		[0.002]	[0.007]	[0.003]	[0.003]
$C_{j,t-1} \times EMR_j$			0.634		
			[0.681]		
$I_{j,t-1} \times EMR_j$			0.042		
			[0.072]		
$C_{j,t-1} \times I_{j,t-1} \times EMR_j$			-0.003		
			[0.007]		
$C_{j,t-1} \times MENA_j$				-0.067	
				[0.327]	
$I_{j,t-1} \times MENA_j$				-0.060	
				[0.042]	
$C_{j,t-1} \times I_{j,t-1} \times MENA_j$				0.003	
				[0.004]	
$C_{j,t-1} \times \text{RR MENA}_j$					0.033
					[0.338]
$I_{j,t-1} \times \text{RR MENA}_j$					-0.012
					[0.060]
$C_{j,t-1} \times I_{j,t-1} \times \text{RR MENA}_j$					0.002
					[0.004]
Constant	1.844*	0.926	3.297	0.594	1.140
	[0.981]	[1.241]	[2.730]	[1.348]	[1.325]
Observations	1,290	1,290	1,290	1,290	1,290
Adjusted R-squared	0.3596	0.3602	0.3614	0.3606	0.3597
Country FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
F	8.964	6.599	4.128	3.843	3.589

Notes: The dependent variable is the five-year change in the sustainability gap $\Delta^5 G_{j,t}$, defined as the change in $G_{j,t}$ over the preceding five years. Positive values indicate an upward movement in the sustainability gap; negative values indicate a downward movement. All explanatory variables enter with a one-year lag. Columns (3), (4), and (5) introduce group interactions for emerging economies, MENA economies, and resource-rich MENA economies, respectively. All models include country and year fixed effects. Standard errors clustered at the country level are reported in brackets. *** p<0.01, ** p<0.05, * p<0.10.

Table B.6. Fixed-Effects Estimates for the Five-Year Change in the Sustainability Gap with CO_2 Intensity and Control of Corruption

	(1)	(2)	(3)	(4)	(5)
$C_{j,t-1}$	0.790***	1.272***	-0.388	1.115***	1.075***
	[0.244]	[0.312]	[1.225]	[0.300]	[0.301]
$I_{j,t-1}$	-0.033**	0.002	-0.039	0.023	0.020
	[0.015]	[0.020]	[0.050]	[0.020]	[0.019]
$C_{j,t-1} \times I_{j,t-1}$		-0.013**	0.002	-0.017***	-0.018***
		[0.005]	[0.016]	[0.005]	[0.005]
$C_{j,t-1} \times EMR_j$			1.645		
			[1.270]		
$I_{j,t-1} \times EMR_j$			0.030		
			[0.057]		
$C_{j,t-1} \times I_{j,t-1} \times EMR_j$			-0.009		
			[0.017]		
$C_{j,t-1} \times MENA_j$				0.207	
				[0.836]	
$I_{j,t-1} \times MENA_j$				-0.100*	
				[0.058]	
$C_{j,t-1} \times I_{j,t-1} \times MENA_j$				0.022	
				[0.014]	
$C_{j,t-1} \times \text{RR MENA}_j$					0.227
					[0.946]
$I_{j,t-1} \times \text{RR MENA}_j$					-0.127*
					[0.075]
$C_{j,t-1} \times I_{j,t-1} \times \text{RR MENA}_j$					0.029*
					[0.016]
Constant	1.009	-0.547	1.213	-0.663	-0.424
	[1.157]	[1.271]	[1.854]	[1.219]	[1.207]
Observations	1,290	1,290	1,290	1,290	1,290
Adjusted R-squared	0.3590	0.3619	0.3625	0.3661	0.3682
Country FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
F	9.010	7.676	4.571	5.675	6.034

Notes: The dependent variable is the five-year change in the sustainability gap $\Delta^5 G_{j,t}$, defined as the change in $G_{j,t}$ over the preceding five years. Positive values indicate an upward movement in the sustainability gap; negative values indicate a downward movement. All explanatory variables enter with a one-year lag. Columns (3), (4), and (5) introduce group interactions for emerging economies, MENA economies, and resource-rich MENA economies, respectively. All models include country and year fixed effects. Standard errors clustered at the country level are reported in brackets. *** p<0.01, ** p<0.05, * p<0.10.

Table B.7. Fixed-Effects Estimates for the Five-Year Change in the Sustainability Gap with CO_2 per Capita and Control of Corruption

	(1)	(2)	(3)	(4)	(5)
$C_{j,t-1}$	0.222***	0.406***	0.250	0.550**	0.553**
	[0.066]	[0.134]	[0.594]	[0.227]	[0.225]
$I_{j,t-1}$	-0.042***	-0.021	-0.028	-0.000	-0.003
	[0.015]	[0.017]	[0.062]	[0.018]	[0.018]
$C_{j,t-1} \times I_{j,t-1}$		-0.003	-0.003	-0.006**	-0.006**
		[0.002]	[0.007]	[0.003]	[0.003]
$C_{j,t-1} \times EMR_j$			0.170		
			[0.609]		
$I_{j,t-1} \times EMR_j$			-0.002		
			[0.065]		
$C_{j,t-1} \times I_{j,t-1} \times EMR_j$			0.002		
			[0.007]		
$C_{j,t-1} \times MENA_j$				-0.284	
				[0.297]	
$I_{j,t-1} \times MENA_j$				-0.080*	
				[0.047]	
$C_{j,t-1} \times I_{j,t-1} \times MENA_j$				0.007*	
				[0.004]	
$C_{j,t-1} \times \text{RR MENA}_j$					-0.417
					[0.330]
$I_{j,t-1} \times \text{RR MENA}_j$					-0.128*
					[0.069]
$C_{j,t-1} \times I_{j,t-1} \times \text{RR MENA}_j$					0.009**
					[0.004]
Constant	1.661	0.551	1.375	0.458	0.680
	[1.032]	[1.166]	[2.347]	[1.134]	[1.169]
Observations	1,290	1,290	1,290	1,290	1,290
Adjusted R-squared	0.3596	0.3610	0.3626	0.3633	0.3644
Country FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
F	9.876	7.312	4.594	4.592	4.806

Notes: The dependent variable is the five-year change in the sustainability gap $\Delta^5 G_{j,t}$, defined as the change in $G_{j,t}$ over the preceding five years. Positive values indicate an upward movement in the sustainability gap; negative values indicate a downward movement. All explanatory variables enter with a one-year lag. Columns (3), (4), and (5) introduce group interactions for emerging economies, MENA economies, and resource-rich MENA economies, respectively. All models include country and year fixed effects. Standard errors clustered at the country level are reported in brackets. *** p<0.01, ** p<0.05, * p<0.10.

Table B.8. System GMM Estimates for the Five-Year Change in the Sustainability Gap

	(1)	(2)	(3)	(4)	(5)
$\Delta^5 G_{j,t-1}$	0.941***	0.922***	0.881***	0.863***	0.884***
	(0.074)	(0.087)	(0.070)	(0.058)	(0.059)
$C_{j,t-1}$	0.006	-0.756	1.148	0.551	1.966
	(1.019)	(3.013)	(1.714)	(0.675)	(1.241)
$I_{j,t-1}$	-0.013	0.002	0.023	0.013	0.059
	(0.033)	(0.057)	(0.025)	(0.023)	(0.039)
$C_{j,t-1} \times I_{j,t-1}$		0.004	-0.020	-0.010	-0.031
		(0.031)	(0.021)	(0.013)	(0.020)
$C_{j,t-1} \times EMR_j$			-1.675		
			(1.641)		
$I_{j,t-1} \times EMR_j$			0.020		
			(0.046)		
$C_{j,t-1} \times I_{j,t-1} \times EMR_j$			0.024		
			(0.018)		
$C_{j,t-1} \times MENA_j$				-0.399	
				(0.498)	
$I_{j,t-1} \times MENA_j$				-0.006	
				(0.036)	
$C_{j,t-1} \times I_{j,t-1} \times MENA_j$				0.010	
				(0.012)	
$C_{j,t-1} \times \text{RR MENA}_j$					-0.949
					(0.624)
$I_{j,t-1} \times \text{RR MENA}_j$					-0.011
					(0.101)
$C_{j,t-1} \times I_{j,t-1} \times \text{RR MENA}_j$					0.024
					(0.029)
Constant	0.061	0.778	-1.089	-0.493	-3.764
	(3.370)	(5.896)	(2.104)	(1.213)	(2.513)
Observations	1366	1,366	1,366	1,366	1366
Instruments	30	34	47	47	47
AR1 p-value	0.0000	0.0000	0.0000	0.0000	0.0000
AR2 p-value	0.131	0.128	0.132	0.142	0.151
Hansen p-value	0.0332	0.0628	0.0630	0.222	0.492

Notes: The dependent variable is the five-year change in the sustainability gap, $\Delta^5 G_{j,t}$. $\Delta^5 G_{j,t-1}$ denotes the lagged dependent variable. All models are estimated using two-step system GMM with Windmeijer-corrected robust standard errors and include year dummy variables. Standard errors are reported in parentheses. AR (1), AR (2), and Hansen test statistics are reported to assess serial correlation and instrument validity. *** p<0.01, ** p<0.05, * p<0.10.

Table B.9. Endogeneity Diagnostics for the Five-Year Change in the Sustainability Gap

	Panel A: Placebo			Panel B: Persistence	
	(1)	(2)	(3)	(4)	(5)
$C_{j,t-1}$			-0.355		-1.594***
			[0.336]		[0.477]
$I_{j,t-1}$			-0.023	-0.008***	
			[0.027]	[0.002]	
$C_{j,t-1} \times I_{j,t-1}$			0.006		
			[0.008]		
$C_{j,t+1}$	-0.717***	-1.239**	-1.114**		
	[0.256]	[0.522]	[0.543]		
$I_{j,t+1}$	0.032**	0.002	0.013		
	[0.016]	[0.023]	[0.027]		
$C_{j,t+1} \times I_{j,t+1}$		0.012	0.009		
		[0.008]	[0.010]		
$\Delta^5 G_{j,t-1}$				-0.013***	0.131**
				[0.004]	[0.058]
Constant	0.329	1.790	2.661	2.725***	67.987***
	[1.210]	[1.653]	[1.646]	[0.137]	[1.065]
Observations	1,366	1,366	1,366	1,366	1,366
Adjusted R-squared	0.3368	0.3390	0.3382	0.9395	0.9698
Country FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
F	6.758	3.894	2.950	11.99	8.093

Notes: The table reports endogeneity diagnostics for the five-year change in the sustainability gap. The dependent variable is $\Delta^5 G_{j,t}$, except in Columns (4) and (5), where the dependent variables are future carbon intensity and future Regulatory Quality, respectively. Columns (1) and (2) report lead-variable specifications using future values of the explanatory variables. Column (3) includes both lagged and future values. Columns (4) and (5) report reverse-causality tests. All regressions include country and year fixed effects. Robust standard errors clustered at the country level are reported in brackets. *** p<0.01, ** p<0.05, * p<0.10.