

Renewable Electricity Transition, Energy Intensity, and Carbon Performance: A Cross-Country Business-Economics Analysis

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Received: 15 August 2025

Accepted: 09 November 2025

DOI: <https://doi.org/10.32479/ees.23969>

ABSTRACT

This paper investigates the hypothesis of renewable electricity transition as a stronger carbon performance in a business-economics context. Using a reproducible panel of 3772 country-year observations from 166 countries over 2000-2022, drawn from the public our world in data energy repository, the paper evaluates how renewable electricity share, income level, and energy intensity shape two environmental outcomes: electricity carbon intensity and greenhouse gas emissions per capita. The empirical design is a country and year fixed effect with country specific standard errors that are clustered around the country to ensure structural heterogeneity and time shocks are contained. The baseline results indicate that the renewable electricity share has a negative relationship with the electricity carbon intensity and the greenhouse gas emission per capita. The emissions model shows that GDP per capita and energy intensity are both positively related to emissions, but the correlation between the share of renewable electricity and income is not significant. Further robustness checks using lagged renewable penetration, balanced-panel estimation, winsorization, an added population control, and an alternative measure of low-carbon electricity affirm the overarching finding. The paper adds a clear and replicable business oriented model of electricity transition to environmental performance and provides strategy, investment and public policy implications.

Keywords: Renewable Electricity, Carbon Performance, Energy Intensity, Business Economics, Panel Data, Environmental Sustainability

JEL Classifications: Q2, Q43, Q56

1. INTRODUCTION

Electricity transition is a strategic concern to firms, investors, and policymakers since it will influence the cost of production, exposure to regulation, competitive advantage, and long-term environmental risk. The electricity mix composition is also important in a business context, both in terms of compliance or disclosure, but also in terms of operating resilience and capital allocation. On the macro level, the same problem lies in the core of the discussion of cleaner growth, industrial upgrading, and the cost of decarbonisation.

Current studies demonstrate that renewable energy is capable of enhancing the environmental performance, yet the empirical literature tends to focus on the overall energy consumption

instead of the makeup of electricity generation (Shafiei and Salim, 2014; Zoundi, 2017). An analogous line of work states that the environmental payoff of the energy transition is conditional upon more general economic factors, such as institutions, efficiency, and the makeup of output of the economy (Bhattacharya et al., 2017; Paramati et al., 2017). These observations underscore the necessity of a multidisciplinary empirical research that bridges the relationship between energy consumption, environmental performances, and economic viability in a single analytical framework.

The current study is inspired by three gaps. To begin with, numerous empirical studies continue to adopt total renewable energy consumption as opposed to renewable electricity share although the electricity mix is frequently the most practical transition

variable at the firm, utility, and regulatory levels. Second, a lot of research is region specific making cross country benchmarking of strategy and policy difficult. Third, reproducibility is not very balanced, as there are papers that use sources that are not publicly available or transparently transform.

This paper addresses those gaps using a fully public country-year panel constructed from the our world in data energy repository (Our World in Data, 2024). The analysis covers 166 countries over 2000-2022 and studies two complementary outcomes: The carbon intensity of electricity and greenhouse gas per capita. The main explanatory variables include renewable electricity share, GDP per capita, and energy intensity. The design is business oriented: the energy transition is not viewed as an engineering problem, but as an economic phenomenon that is strategic and depends on growth, efficiency, and environmental performance.

The paper makes three contributions. First, it offers an empirical design that is transparent and reproducible on the basis of an open dataset and which other scholars can directly test. Second, it is the combination of an outcome related to electricity system and an outcome related to the economy wide emissions, so that the analysis could differentiate between cleaner power generation and the decarbonization on a broader scale. Third, it addresses managers, investors, and policymakers by explaining that the deployment of renewable is a worthwhile idea, but most effective when combined with efficiency gains.

The rest of the paper has the following. Section 2 reviews the literature. Section 3 develops the hypotheses. Section 4 explains the data and empirical strategy. Section 5 reports the baseline results. Section 6 presents robustness checks. Section 7 discusses the broader implications Section 8 concludes.

2. LITERATURE REVIEW

2.1. Renewable Energy and Environmental Performance

A large empirical literature finds that renewable energy generally helps reduce emissions, although the magnitude varies across regions and estimation strategies. Zoundi (2017) reports that renewable energy lowers carbon emissions in a panel cointegration framework. Similar evidence appears for the BRICS (Dong et al., 2017), Sub-Saharan Africa (Apergis et al., 2018; Salahuddin et al., 2020), African panels more broadly (Namahoro et al., 2021; Nathaniel and Iheonu, 2019), and the OECD (Shafiei and Salim, 2014). Global and multi-country studies like-wise document a negative renewable-emissions association (Adams and Nsiah, 2019; Sharif et al., 2019). From a business-economics perspective, these findings imply that the energy mix can shape transition risk and environmental competitiveness.

2.2. Energy Intensity, Scale Effects, and Cleaner Growth

Energy intensity matters because it links output generation to resource use. Higher energy intensity often signals weaker operational efficiency, slower technological upgrading, or a more carbon-intensive production structure. Several studies find that

energy intensity remains a strong positive driver of emissions even when renewable variables are included (Ali et al., 2022; Namahoro et al., 2021). Scale effects from income growth also tend to raise emissions when structural change and efficiency improvements do not keep pace (Bekun et al., 2019; Paramati et al., 2017). This makes energy intensity especially relevant for business analysis because it captures whether growth is becoming cleaner or merely larger.

2.3. Institutions, Innovation, and Transition Quality

The environmental payoff from renewable deployment depends on transition quality rather than fuel switching alone. Bhattacharya et al. (2017) show that renewable energy and institutional quality jointly shape output and emissions. Obobisa et al. (2022) show that green technological innovation and institutional settings matter for environmental performance in African countries. Other evidence also suggests that region-specific structural conditions can amplify or weaken renewable gains (Bekele et al., 2024; Farhani and Shahbaz, 2014). For strategy and policy, this means that renewable expansion should be complemented by efficient grids, capable institutions, and productivity-enhancing investments.

2.4. Research Gap and Positioning of the Present Study

Despite strong prior evidence, three limitations remain. First, the literature still leans more heavily toward aggregate renewable energy use than renewable electricity share. Second, many studies are region-bound, which is useful for local policy but less useful for broad benchmarking. Third, reproducibility is often weaker than desirable. The present study contributes by using a fully public dataset, focusing on electricity transition, and estimating a unified framework for both electricity-specific and economy-wide carbon outcomes. Selected empirical studies on renewable energy, emissions, and related economic drivers are presented in Table 1.

3. HYPOTHESES DEVELOPMENT

H_1 : Renewable electricity share is negatively associated with electricity carbon intensity. A higher renewable share directly changes the generation mix away from fossil-based electricity, so each kilowatt-hour should embody less carbon. This is the closest operational link between the energy transition and environmental performance, and prior renewable-emissions studies strongly support the expected negative sign (Shafiei and Salim, 2014; Zoundi, 2017).

H_2 : Renewable electricity share is negatively associated with greenhouse gas emissions per capita. Cleaner electricity can also lower economy-wide emissions per capita because electricity is a key input into households, services, and industry. The relationship is broader than H_1 because emissions also come from non-electric sources, but the expected sign remains negative (Adams and Nsiah, 2019; Salahuddin et al., 2020).

H_3 : GDP per capita is positively associated with greenhouse gas emissions per capita. Higher income can increase output, consumption, and transport demand, thereby expanding emissions through scale effects. Unless productivity and fuel substitution offset that expansion, richer economies may emit more per person (Bekun et al., 2019; Paramati et al., 2017).

Table 1: Selected empirical studies on renewable energy, emissions, and related economic drivers

Study	Context/sample	Method	Main insight
Namahoro et al. (2021)	50 African countries, 1980-2018	CS-DL and causality analysis	Renewable energy mitigates CO ₂ emissions, while energy intensity generally increases emissions across African regions and income groups.
Paramati et al. (2017)	G20 countries	Panel econometrics	Renewable energy use is associated with lower emissions, while financial market expansion affects the growth- emissions trade-off.
Dong et al. (2017)	BRICS countries	Panel cointegration	Renewable energy and natural gas both help reduce CO ₂ emissions in the long run.
Nathaniel and Iheonu (2019)	African economies	Panel analysis	Renewable energy contributes to carbon abatement, whereas non-renewable energy consumption worsens emissions.
Zoundi (2017)	Global panel	Panel cointegration	Renewable energy lowers emissions and supports the environmental Kuznets perspective in a cross-country setting.
Adams and Nsiah (2019)	Multi-country panel	Dynamic panel analysis	Renewable energy helps reduce carbon emissions, though the size of the effect depends on broader structural conditions.
Bekun et al. (2019)	16 EU countries	Cointegration and causality tests	Renewable energy reduces environmental pressure, but resource rents and fossil energy raise emissions.
Sharif et al. (2019)	74 countries, 1990-2015	Heterogeneous panel estimators	Renewable energy is negatively linked to carbon emissions, while non-renewable energy remains emission-intensive.
Bhattacharya et al. (2017)	Multi-region global panel	Dynamic panel analysis	Renewable energy and stronger institutions jointly improve environmental outcomes and economic performance.
Apergis et al. (2018)	Sub-Saharan Africa	Panel estimators	Renewable energy consumption and health expenditures are both associated with lower carbon emissions.
Farhani and Shahbaz (2014)	MENA region	Panel cointegration	Renewable electricity supports initial emission mitigation, while conventional electricity consumption aggravates emissions.
Obobisa et al. (2022)	African countries, 2000-2018	Second-generation panel methods	Green technological innovation and renewable energy reduce CO ₂ , whereas weak institutional settings can undermine environmental gains.
Ali et al. (2022)	China, 1990-2019	Dynamic ARDL simulation	Renewable and non-renewable energy have differentiated effects on carbon intensity, highlighting transition complexity
Salahuddin et al. (2020)	Sub-Saharan Africa	Second generation panel estimators	Renewable energy improves environmental quality, but the magnitude varies across countries and structural conditions.
Shafiei and Salim (2014)	OECD countries	Comparative panel analysis	Renewable energy reduces CO ₂ emissions, while non-renewable energy has the opposite effect.
Bekele et al. (2024)	Sub-Saharan Africa	Heterogeneous macro-panel analysis	Renewable energy improves environmental sustainability, but heterogeneity across countries remains substantial.
Mukhtarov et al. (2022)	Azerbaijan	DOLS	Renewable energy consumption is negatively associated with consumption-based CO ₂ emissions in an oil-rich economy.

H₄: Energy intensity is positively associated with greenhouse gas emissions per capita. When more energy is needed to produce a unit of output, the economy is typically less efficient or more dependent on heavy industry and conventional fuels. Accordingly, higher energy intensity should be associated with worse environmental outcomes (Ali et al., 2022; Namahoro et al., 2021).

H₅: Renewable electricity share weakens the positive association between GDP per capita and greenhouse gas emissions per capita. If renewable electricity allows economies to meet rising output with a cleaner power base, the growth-emissions link may become weaker at higher renewable shares. However, because many emissions sources lie outside the power sector, the expected moderation effect is plausible but not guaranteed.

4. DATA, VARIABLES, AND METHODOLOGY

4.1. Data Source and Sample

The empirical analysis uses the public Our World in Data energy repository, which publishes annual country-level energy, electricity, emissions, population, and GDP indicators and documents variable definitions in a public codebook. The estimation sample includes 3772 country year observations for 166 countries over 2000-2022 after removing missing and invalid values. Restricting the panel to

sovereign-country observations and the modern period increases comparability while preserving broad international coverage.

4.2. Variable Construction

The first dependent variable is the natural logarithm of electricity carbon intensity, measured in grams of CO₂-equivalent per kilowatt-hour. The second is the natural logarithm of greenhouse gas emissions per capita, constructed from total greenhouse gas emissions divided by population. The key explanatory variable is renewable electricity share, measured as the percentage of electricity generation coming from renewable sources. GDP per capita is computed as GDP divided by population and entered in logarithms. Energy intensity is measured by energy use per unit of GDP and also entered in logarithms. The moderation term is the interaction between renewable electricity share and logged GDP per capita.

4.3. Empirical Specification

The baseline specifications are:

$$\ln(ECI_{it}) = \alpha + \beta_1 REN_{it} + \beta_2 \ln(GDP P C_{it}) + \beta_3 \ln(EINT_{it}) + \mu_i + \lambda_t + \varepsilon_{it} \quad (1)$$

$$\ln(GHGP C_{it}) = \alpha + \beta_1 REN_{it} + \beta_2 \ln(GDP P C_{it}) + \beta_3 \ln(EINT_{it}) + \mu_i + \lambda_t + \varepsilon_{it} \quad (2)$$

Table 2: Descriptive statistics

Variable	Mean	SD	Min	Median	Max
Renewable electricity share (%)	34.032	33.129	0.000	21.770	100.000
Electricity carbon intensity (gCO ₂ e/kWh)	451.165	251.381	17.240	494.650	1306.720
GHG emissions per capita (tCO ₂ e/person)	1.654	2.467	0.001	0.758	21.005
GDP per capita (international- \$)	16467.281	18023.782	421.565	10190.086	163531.400
Energy intensity (kWh per international-\$)	1.344	0.953	0.078	1.122	10.141

Table 3: Correlation matrix

	(1)	(2)	(3)	(4)	(5)
(1) Renewables	1.000	-0.861	-0.544	-0.258	-0.358
(2) ln (Carbon intensity)	-0.861	1.000	0.514	0.150	0.289
(3) ln (GHG pc)	-0.544	0.514	1.000	0.841	0.737
(4) ln (GDP pc)	-0.258	0.150	0.841	1.000	0.527
(5) ln (Energy intensity)	-0.358	0.289	0.737	0.527	1.000

$$\ln(GHGP C_{it}) = \alpha + \beta_1 REN_{it} + \beta_2 \ln(GDP P C_{it}) + \beta_3 \ln(EINT_{it}) + \beta_4 (REN_{it} \times \ln(GDP P C_{it})) + \mu_i + \lambda_t + \quad (3)$$

Here, μ_i denotes country fixed effects and λ_t denotes year fixed effects. Country effects absorb time-invariant structural heterogeneity such as geography, industrial history, and baseline institutions. Year effects absorb common shocks such as global energy prices, macroeconomic conditions, and worldwide technology trends. Standard errors are clustered by country. The conceptual framework of the study is presented in Figure 1.

5. RESULTS

5.1. Descriptive Evidence

Table 2 reports the descriptive statistics. On average, renewable sources account for roughly one-third of electricity generation in the sample, but the dispersion is large. Mean electricity carbon intensity remains high, and the spread in GDP per capita and energy intensity confirms that the sample spans very different stages of development and production efficiency (Figures 2 and 3).

Table 3 provides the correlation matrix. Renewable electricity share is negatively correlated with both logged electricity carbon intensity and logged greenhouse gas emissions per capita. GDP per capita and energy intensity are positively correlated with logged emissions per capita, which is directionally consistent with H_3 and H_4 .

5.2. Baseline Fixed-Effects Results

Table 4 reports the baseline regressions. In Model 1, renewable electricity share is negative and highly significant ($\beta = -0.0218$, $P < 0.01$), supporting H_1 . The estimate implies that a one percentage-point increase in renewable electricity share is associated with a decline of roughly 2.2% in electricity carbon intensity, holding constant the fixed effects structure and the other covariates.

In Model 2, renewable electricity share remains negative and highly significant ($\beta = -0.0260$, $P < 0.01$), supporting H_2 . Logged GDP per capita is positive and significant ($\beta = 0.7072$, $P < 0.01$), which supports H_3 . Logged energy intensity is also positive and significant ($\beta = 0.6996$, $P < 0.01$), which supports

Table 4: Baseline fixed-effects regression results

Variables	Model 1 ln (Carbon intensity)	Model 2 ln (GHG pc)	Model 3 ln (GHG pc)
Renewable electricity share	-0.0218*** (0.0026)	-0.0260*** (0.0030)	-0.0357*** (0.0111)
ln (GDP per capita)	0.0466 (0.0654)	0.7072*** (0.1510)	0.6814*** (0.1542)
ln (Energy intensity)	0.1053 (0.0767)	0.6996*** (0.1520)	0.7025*** (0.1516)
Renewables × ln (GDP per capita)	-	-	0.0011 (0.0011)
Country fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Clustered SE by country	Yes	Yes	Yes
Observations	3772	3772	3772
R-squared	0.535	0.552	0.554

H_4 . Economically, the coefficients indicate that cleaner electricity systems are associated with lower emissions per person, but richer and more energy-intensive economies still face upward emissions pressure (Figure 4).

Model 3 introduces the interaction between renewable electricity share and logged GDP per capita. The interaction term is small and statistically insignificant ($\beta = 0.0011$, $P = 0.3129$), so H_5 is not supported. The main renewable-share coefficient remains negative and statistically significant, which suggests that the direct carbon benefit of renewable electricity is robust even if it does not fully neutralize the growth-emissions relationship (Figure 5).

5.3. Robustness Checks

To strengthen the empirical interpretation, this section re-estimates the emissions specification under five alternative designs: A 1-year lag of renewable electricity share, a balanced-panel restriction, winsorization at the 1st and 99th percentiles, an added population control, and an alternative low-carbon electricity share measure.

Table 5 and Figure 6 show that the renewable-transition result is stable across all variants. The lagged renewable coefficient remains negative and statistically significant ($\beta = -0.0224$), which reduces concern that the baseline estimate is driven entirely by

Table 5: Robustness tests for the emissions specification

	(R1) Lagged REN ln (GHG pc)	(R2) Balanced panel ln (GHG pc)	(R3) Winsorized ln (GHG pc)	(R4) + Population ln (GHG pc)	(R5) Low-carbon share
Lagged renewable electricity share	-0.0224*** (0.0028)	-	-	-	-
Renewable electricity share	-	-0.0259*** (0.0030)	-0.0252*** (0.0029)	-0.0257*** (0.0030)	-
Low-carbon electricity share	-	-	-	-	-0.0260*** (0.0029)
ln (GDP per capita)	0.7865*** (0.1654)	0.7040*** (0.1533)	0.7060*** (0.1471)	0.7035*** (0.1517)	0.7195*** (0.1502)
ln (Energy intensity)	0.7347*** (0.1626)	0.6943*** (0.1539)	0.7283*** (0.1522)	0.6771*** (0.1566)	0.7427*** (0.1523)
ln (Population)	-	-	-	0.2714 (0.1689)	-
Country fixed effects	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	3606	3703	3772	3772	3772
R-squared	0.465	0.551	0.548	0.557	0.554

Figure 1: Conceptual framework and estimation logic

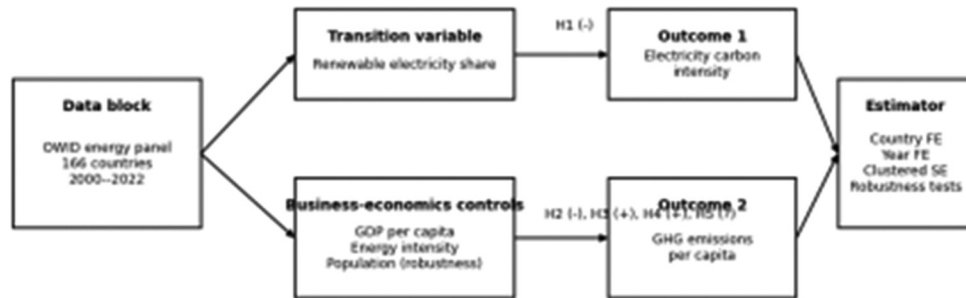


Figure 2: Indexed annual sample averages (2000=100)

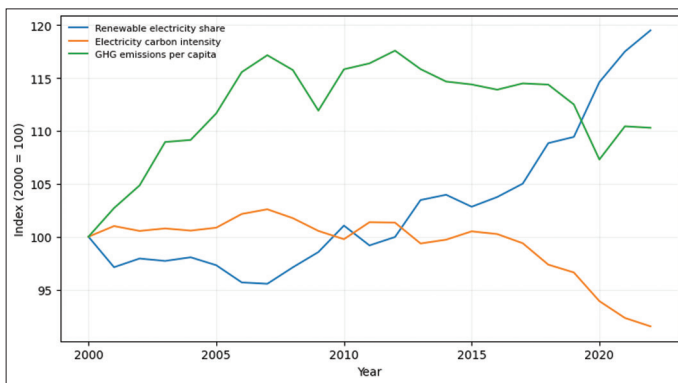


Figure 4: Key coefficients with 95% confidence intervals

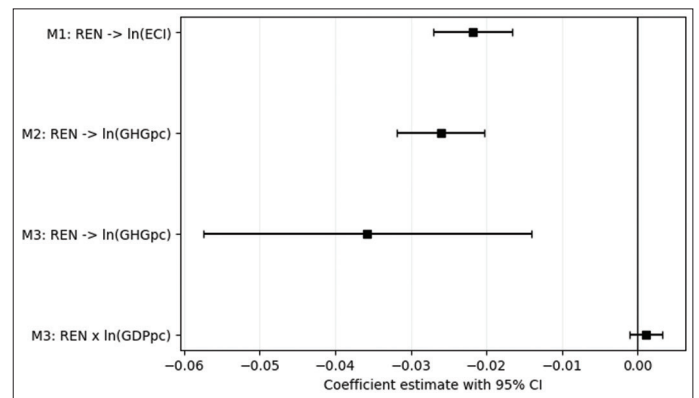
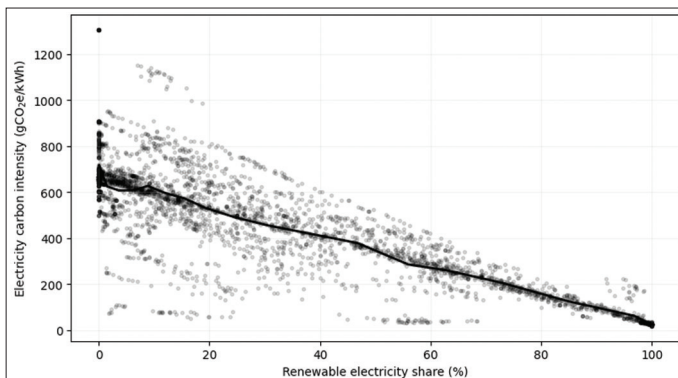


Figure 3: Renewable electricity share and electricity carbon intensity across country-years.



contemporaneous co-movement. The balanced-panel coefficient ($\beta = -0.0259$) is almost identical to the baseline estimate. The winsorized specification ($\beta = -0.0252$) confirms that extreme observations do not drive the 10 result. Adding logged population leaves the renewable coefficient negative ($\beta = -0.0257$), and the alternative low-carbon electricity-share specification also remains negative ($\beta = -0.0260$). Overall, the sign, significance, and approximate magnitude of the central result are stable.

6. DISCUSSION

The facts help to interpret the transition to electricity in a business-economics frame in a more qualitative way. First, renewable

Figure 5: Greenhouse gas emissions per capita across GDP per capita quartiles

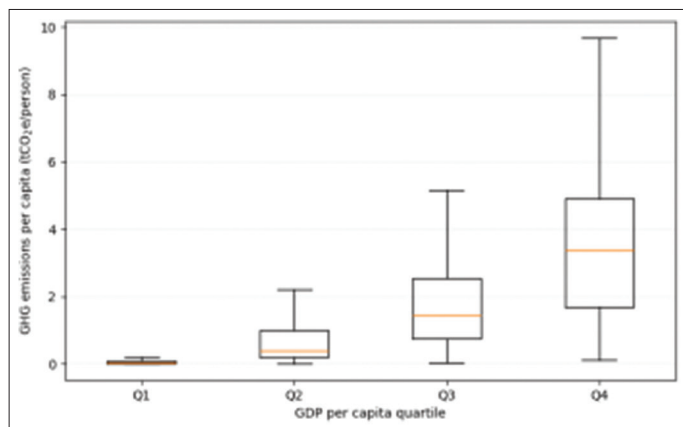
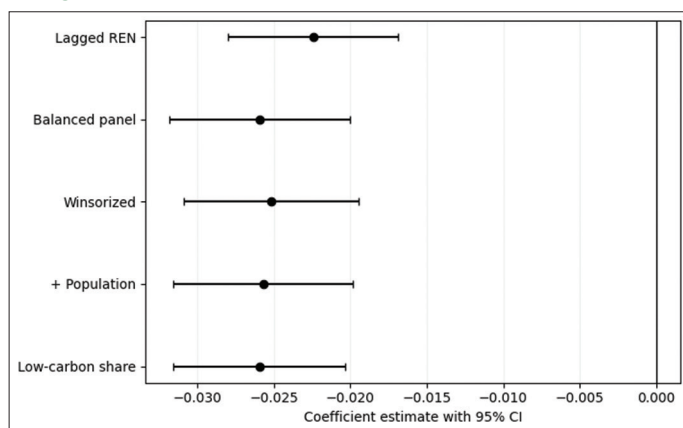


Figure 6: Robustness coefficients with 95% confidence intervals



electricity share is most strongly linked to cleaner electricity system performance, which is exactly where one would expect the clearest mechanical effect. The negative sign on the electricity carbon-intensity model thus is statistically and conceptually convincing. It states that the decarbonization of generation mix can even be observed in the carbon content of electricity itself.

Second, the renewable coefficient is negative when the dependent variable is the greenhouse gas emissions per capita. This larger finding is important as it demonstrates that the electricity transition is linked to more than a technical fix in generation that is limited. Cleaner electricity seems to spill into broader environmental performance in strategic terms, although the impact must be necessarily diluted through transport, industry, agriculture and land-use channels which are beyond the electricity generation.

Third, a positive coefficient of the GDP per capita cannot be interpreted in a straight forward way as an anti-growth argument. Rather, it is a pointer that the pressure of emissions is present in economic expansion where structural composition of production, mobility, and consumption is carbon intensive. This is a key aspect to journal readers who care about energy, environment, and economics in one package: Renewable deployment alone does not lead to clean growth. It also relies on the fact that productivity gains, quality of electrification, and industrial upgrading is robust in terms of counterbalancing scale effects.

Fourth, a central conditioning variable develops as energy intensity. In practice, the paper recommends that the advantage of renewable electricity is the greatest when the economy is more productively using the energy. This is of obvious managerial interest. By treating renewable procurement as a separate sustainability instrument, firms could minimise Scope 2 exposure, although the overall environmental and economic benefit will not be as substantial when the underlying processes of production are energy intensive. The findings thus advocate a two-pillar approach involving cleaner electricity with efficiency-based operational change.

The insignificant interaction term is another term that should be interpreted instead of being rejected. It indicates that an increase in renewable penetration is not yet systematically reducing the growth-emissions relationship among the countries. The first reason is sectoral composition: Nations can decarbonize electricity and nevertheless produce emissions in terms of transport fleets, heavy manufacturing, buildings, and logistics related to trade. The second reason is the mismatch of time. Renewable implementation is capable of rapid adjustments, but capital stock of industry and transport is slower to adjust. A third reason is that data at country level is an aggregate of institutional and sectoral differences, which are relevant to the translation of renewable electricity to economy-wide abatement.

The soundness analysis hones this interpretation. That the association is not just contemporaneous is implied by the fact that the result persists even when lagged renewables are used. The balanced-panel and winsorized estimates indicate that the baseline is not due to sample composition or outliers. The population-control model suggests that the outcome is not merely a demographic artifact, and the low-carbon-share specification that the core finding is extended to a more general electricity decarbonization concept. Collectively, these checks make us feel confident that the result of the main finding is not weak economically

7. CONCLUSION AND IMPLICATIONS

This study examined whether renewable electricity transition is associated with stronger carbon performance in a reproducible cross-country business-economics framework. Using 3772 country-year observations from 166 countries over 2000-2022, the baseline fixed-effects models show that renewable electricity share is negatively associated with both electricity carbon intensity and greenhouse gas emissions per capita. Emissions per capita are positively correlated with GDP per capita and energy intensity, but there is no statistically significant interaction between renewable-income and emissions per capita.

The analysis enhances the evidence with five strong checks. The negative effect between the transition to electricity and the burden on the environment is consistent across the lagged, balanced-panel, winsorized, population-controlled, and other low-carbon-share specification. The general takeaway is that renewable electricity growth is a viable way to achieve cleaner growth, but its economic and environmental benefits will be maximized only with energy intensity reductions.

Limitations to the study still exist. There is no direct observation of firm-level strategy, sectoral heterogeneity, or institutional micro-mechanisms using country-level data. The design could be expanded in the future in sector panel, firm data or transition-finance variables. Despite this, the current analysis provides a clear and reproducible policy and business debate foundation in the intersecting areas of energy, environment, and economics.

The implications of the findings have direct implications on business decision making. Renewable electricity sourcing by firms should be considered as a strategic cost management and transition-risk positioning issue in addition to being a disclosure item. Companies that work in cleaner grids or buy renewable energy will be able to reduce exposure to indirect emissions and enhance competitiveness in an environment with stricter sustainability requirements. The positive role of energy intensity, however, suggests that the renewable sourcing is to be paired with process redesign, demand management, and energy-efficiency investment.

To investors, the findings indicate that indicators of electricity-mix can be used to inform the screening of country risk and portfolio tilts. The share of renewable electricity in countries or sectors might be lower, which means reduced medium-term transition risk, though the same investors are advised to keep an eye on energy intensity since inefficient systems will be subject to volatility of costs and tightening of carbon policies.

The paper advocates policy packages instead of single instruments to the policymakers. The deployment of renewables is imperative, but the findings suggest that decarbonization in the power sector should be complemented with efficiency requirements, grid modernization, industrial up-grades, and finance schemes that result in less expensive clean capital. That is, the empirical data supports a combined approach between renewable growth and energy productivity.

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