Research Article

Green Energy Transition and Development Outcomes in Emerging Economies

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Abstract: This paper investigates the economic and environmental effects of the green energy transition in emerging market economies. Focusing on ten major emerging countries from 2010 to 2022, we examine how renewable energy consumption relates to economic growth, sustainable development, and environmental outcomes. Using panel data and a two-way fixed effects model (with country and year fixed effects), we analyze three key dimensions of development: gross domestic product (GDP) per capita, broad-based sustainable development (measured via the Sustainable Development Goals (SDG) Index and Human Development Index (HDI), and environmental quality (per capita CO_2 emissions). The empirical results indicate that expanding renewable energy usage significantly reduces CO_2 emissions, but it may entail a modest short-term trade-off with economic growth. Renewable energy's impact on composite sustainable development indicators is less immediate: we find no clear short-run effect on the SDG index, even as renewable uptake shows a positive association with the HDI. Additionally, foreign direct investment (FDI) exhibits a negative relationship with carbon emissions (suggesting a potential "pollution halo" effect), whereas greater trade openness is associated with higher emissions. These findings highlight important policy implications for emerging economies — namely, while green energy transitions can yield substantial environmental benefits and support human development, complementary economic policies are needed to mitigate short-run growth costs and fully realize sustainable development gains.

Keywords: Green Energy Transition, Sustainable Development, Renewable Energy, Economic Growth
Jel Codes: Q42, Q56, O44

Gelişmekte Olan Ekonomilerde Yeşil Enerji Geçişi ve Kalkınma Sonuçları

Öz: Bu çalışma, gelişmekte olan piyasa ekonomilerinde yeşil enerji dönüşümünün ekonomik ve çevresel etkilerini incelemektedir. 2010–2022 dönemini kapsayan ve on önde gelen gelişmekte olan ülkeye odaklanan analizde, yenilenebilir enerji tüketiminin ekonomik büyüme, sürdürülebilir kalkınma ve çevresel sonuçlarla olan ilişkisi araştırılmaktadır. Ülke ve yıl sabit etkilerini içeren iki yönlü sabit etkiler modeli (two-way fixed effects model) ile panel veri kullanılarak kalkınmanın üç temel boyutu incelenmiştir: kişi başına düşen gayrisafi yurt içi hasıla (GSYH), sürdürülebilir kalkınmanın geniş tabanlı ölçütleri (Sürdürülebilir Kalkınma Amaçları (SKA) Endeksi ve İnsani Gelişme Endeksi (İGE) ile ölçülmüştür) ve çevresel kalite (kişi başına düşen CO_2 emisyonları). Ampirik bulgular, yenilenebilir enerji kullanımının artmasının CO_2 emisyonlarını anlamlı biçimde azalttığını, ancak kısa vadede ekonomik büyüme üzerinde sınırlı bir ödünleşme (trade-off) yaratabileceğini göstermektedir. Yenilenebilir enerjinin bileşik sürdürülebilir kalkınma göstergeleri üzerindeki etkisi ise daha dolaylıdır: Yenilenebilir enerji kullanımının artışı İGE ile pozitif bir ilişki gösterirken, SKA Endeksi üzerinde kısa vadeli belirgin bir etkisi gözlemlenmemiştir. Ayrıca, doğrudan yabancı yatırımların (DYY) karbon emisyonlarıyla negatif bir ilişki içinde olduğu (muhtemel bir "kirlilik hâlesi" etkisine işaret eden) tespit edilirken, dışa açıklığın artmasının daha yüksek emisyonlarla ilişkili olduğu bulunmuştur. Bu bulgular, gelişmekte olan ekonomiler açısından önemli politika çıkarımlarına işaret etmektedir. Buna göre, yeşil enerji dönüşümleri çevresel faydalar sağlayarak insani gelişimi destekleyebilse de, kısa vadeli büyüme maliyetlerini

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azaltmak ve sürdürülebilir kalkınma kazanımlarını tam anlamıyla gerçekleştirmek için tamamlayıcı ekonomik politikaların uygulanması gerekmektedir.

Anahtar Kelimeler: Yeşil Enerji Dönüşümü, Sürdürülebilir Kalkınma, Yenilenebilir Enerji, Ekonomik Büyüme
Jel Kodları: Q42, Q56, O44

1. Introduction

The global shift toward clean energy has become a defining challenge and opportunity of the 21st century. In response to worsening climate change and energy security concerns, countries worldwide are investing unprecedented resources in renewable energy. Global energy investment was projected to exceed $3 trillion in 2024, with over $2 trillion directed toward clean energy technologies (International Energy Agency (IEA), 2023). Alongside widespread pledges to achieve net-zero emissions by mid-century, this surge reflects a paradigm shift in development strategy. The green energy transition promises cleaner growth and long-run sustainability, yet it also raises difficult questions about short-term economic impacts — especially for emerging economies striving to industrialize.

Many emerging and developing countries face the dual mandate of accelerating economic growth to alleviate poverty while curbing carbon emissions to meet global climate goals. Historically, economic growth has been tightly coupled with rising emissions, underscoring the tension between growth and environmental sustainability. For example, a 1% increase in GDP has often been associated with roughly a 0.4% increase in CO_2 emissions, reflecting the traditional dependence of growth on fossil energy. The Environmental Kuznets Curve (EKC) hypothesis optimistically suggests that pollution will eventually decline after a certain income level is reached (Grossman & Krueger, 1995). In practice, however, evidence is mixed on whether emerging economies can rely on such automatic "grow-now-clean-later" patterns, or if deliberate policy intervention is needed to decouple growth from carbon intensity (Al-Mulali et al., 2015).

Renewable energy has been promoted as a potential win–win solution that can fuel economic development with a smaller environmental footprint. Solar, wind, geothermal, and other renewables offer the prospect of expanding energy access and security without the heavy pollution associated with fossil fuels. Yet it remains unclear to what extent the green energy transition delivers on its multi-faceted promise in emerging market contexts. Key questions persist about its impacts across economic, social, and environmental dimensions. Does investment in renewable energy stimulate or slow down economic growth, or might it come at the expense of GDP per capita in the near term due to transitional costs? Can a shift to renewables improve broader sustainable development outcomes — such as education, health, and living standards captured by composite indices — or are the socio-economic benefits of the green transition limited so far? And does greater renewable energy utilization lead to a significant reduction in carbon emissions, thereby helping to mitigate climate change? Moreover, how do external factors like foreign direct investment (FDI) interact with this transition? For example, FDI inflows could potentially amplify the benefits of renewable energy by bringing in new technologies and capital or alternatively offset those gains through the scale effects of increased industrial activity. By investigating these issues together, our study probes the overarching question of whether emerging economies can achieve a greener development path that reconciles economic growth with sustainability.

This research contributes to literature by bridging several gaps between existing studies. Despite a growing body of work on renewable energy and development, much of the existing literature tends to focus on a single outcome—most often economic growth or, separately, environmental indicators. Studies that bring these dimensions together in a unified empirical framework remain relatively limited, particularly for emerging economies where the trade-offs of the green transition are likely to be more pronounced. In addition, the role of external factors such as FDI is usually treated in isolation, rather than as a potential channel through which renewable energy may shape broader development outcomes.

It takes a more integrated approach by examining economic, social, and environmental dimensions jointly, while also considering how foreign investment may interact with the renewable energy transition. In doing so, it moves beyond the standard growth–energy or emissions–energy nexus and tries to capture a more complete picture of development dynamics. The use of both composite indicators (such as the SDG Index and HDI) alongside traditional macroeconomic variables further adds to this perspective. While the approach is admittedly still constrained by data and time horizon, it offers a more nuanced view of how the green transition unfolds in emerging economies, where short-run adjustments and longer-term gains do not always align neatly.

Previous empirical work has typically examined isolated aspects of the renewable energy–development nexus. For instance, numerous studies have analyzed the renewable energy–GDP relationship, often finding that renewables support long-run growth or at least do not hinder it (Apergis & Payne, 2010; Sadorsky, 2009). Other works focus on environmental impacts, showing that a shift to renewables tends to reduce CO_2 emissions (Dogan & Seker, 2016; Bilgili et al., 2016). However, very few studies have evaluated economic, social, and environmental outcomes simultaneously within a unified framework. Notably, composite development indicators like the SDG Index have rarely been utilized in panel analyses of energy policy impacts, especially for emerging economies.

Our study aims to fill these gaps by providing an integrated empirical assessment of renewable energy's effects on multiple development dimensions. It is among the first to investigate how renewable energy deployment influences a country's performance on a comprehensive sustainable development index (such as the SDG Index) across a panel of emerging economies, alongside traditional metrics of income and emissions. Furthermore, we extend prior research by examining whether the benefits of renewable energy are conditioned by foreign capital flows. Responding to calls for analysis of globalization's role in sustainability, we include interaction terms to test how FDI might augment or moderate the impact of renewable energy. While earlier studies have examined FDI and trade as determinants of growth and emissions (e.g., Omri & Nguyen, 2014), the synergistic role of FDI in enhancing renewable energy's development benefits remains underexplored. By comparing our findings with prevailing theories (as reviewed in Section 2), we highlight areas of convergence and divergence. In doing so, this study offers a more comprehensive picture of the green transition's multifaceted outcomes in emerging markets and provides new evidence on the conditions under which renewable energy can lead to sustainable prosperity.

Methodologically, we utilize a panel dataset of ten major emerging economies over the period 2010–2022. These countries – including examples such as Türkiye, India, Kenya, Morocco, Vietnam, South Africa, and others – represent a diverse mix of upper-middle and lower-middle income nations undergoing significant energy transitions. We compile annual data on key indicators from reputable international sources (including the World Bank, Sustainable Development Solutions Network, and International Energy Agency). The dataset covers each country's renewable energy consumption (as a percentage of total final energy use), economic output (GDP per capita in constant 2015 US$), sustainable development performance (SDG Index scores, available from 2016 onward, and the Human Development Index), environmental quality (CO_2 emissions per capita), and various control variables such as FDI inflows (% of GDP), trade openness (trade as % of GDP), gross capital formation (% of GDP), and urbanization rate (% of population in urban areas).

Using this panel, we employ a two-way fixed effects regression approach that includes country fixed effects and year fixed effects to control for time-invariant national characteristics and global shocks. In essence, our econometric models exploit within-country variation over time to isolate the effects of changes in renewable energy uptake on the development outcomes. Three complementary model specifications are estimated, corresponding to the three outcome dimensions. The economic growth model uses the logarithm of GDP per capita as the dependent variable, regressed on renewable energy share and the set of control covariates (with fixed effects absorbing country-specific and year-specific influences). The sustainable development model uses the SDG index (a 0–100 composite measure of progress on the UN Sustainable Development Goals) as the outcome of interest, and the environmental model examines per capita CO_2 emissions as a function of renewable energy and the controls. We also include an interaction term between renewable energy and FDI in the growth model to test whether the impact of renewables on GDP is moderated by foreign investment. In additional robustness checks, we consider the HDI as an alternative development indicator and test for lagged effects of renewable energy to ensure our results are robust.

In preview, our empirical findings reveal nuanced trade-offs and co-benefits in the green transition. We find that increasing the renewable share of energy consumption yields significant environmental benefits and some social gains but may impose short-run economic costs. In particular, the analysis shows that greater use of renewables is associated with a significant reduction in CO_2 emissions and measurable improvements in human development (HDI), yet a slight decrease in GDP per capita and no immediate change in the composite SDG Index. We also observe that FDI and trade openness influence these dynamics: FDI inflows, when aligned with green investment, have the potential to reinforce the positive impacts of renewable energy (evidenced by a negative, albeit statistically weak, association with emissions), whereas expanding trade without adequate environmental safeguards tends to contribute to higher emissions. Taken together, these results align with some expectations from the literature while challenging others, underscoring the critical role of supportive policy frameworks in maximizing the benefits of the green energy transition.

This study asks a relatively straightforward but not entirely settled question: how does the increasing share of renewable energy in the energy mix shape economic growth, broader development outcomes, and environmental quality in emerging economies? Put slightly differently, do countries that expand renewable energy use experience measurable gains in sustainability and emissions reduction without compromising income growth, and how—if at all—do external factors such as FDI and trade openness alter these relationships?

Drawing on the literature, several expectations can be outlined. First, while renewable energy is often linked to long-run growth, the short-run effect may be weaker or even negative due to adjustment costs. Accordingly, hypothesis 1 is that renewable energy has a negative or modest effect on GDP per capita in the short run. Secondly, the environmental channel is more clear-cut in most empirical work. Hypothesis 2 is that a higher share of renewable energy is associated with lower CO_2 emissions per capita. Thirdly, the relationship with broader development indicators is less immediate and may depend on transmission channels. Hypothesis 3 is that renewable energy has a positive but potentially delayed or statistically weak effect on composite development indicators such as the SDG Index and HDI. External linkages matter, but not always in a uniform way. Hypothesis 4 is that FDI inflows do not necessarily enhance growth unless aligned with productive or green sectors, and their interaction with renewable energy may be positive but not systematically significant. Finally, standard macro controls are expected to behave in line with existing evidence. Hypothesis 5 is that trade openness and economic growth tend to increase emissions through scale effects, while capital formation and urbanization may have mixed or context-dependent impacts across models. Taken together, these hypotheses reflect a more nuanced view of the green transition—one where environmental gains are relatively immediate, but economic and broader development effects unfold more unevenly over time.

The remainder of the paper is structured as follows. Section 2 reviews the theoretical and empirical literature on the links between renewable energy, economic growth, sustainable development, and environmental quality. Section 3 describes the data and econometric methodology in detail and presents the results of the panel analysis. Section 4 concludes with a discussion of the key findings and their implications for economic policy in the context of sustainable development and the green transition.

2. Literature Review

2.1 Theoretical Foundations

The nexus between renewable energy, economic growth, and sustainability is grounded in several theoretical frameworks. Foremost, endogenous growth theory (Romer, 1990) emphasizes innovation and technological change as drivers of long-term economic growth. Clean energy technologies can be viewed as endogenous innovations that fuel economic growth while mitigating environmental constraints. Building on this foundation, the modern models of directed technical change show that economic policy can steer technological innovation toward clean technologies without sacrificing economic growth (Acemoglu et al., 2012). Another cornerstone is the Environmental Kuznets Curve (EKC) hypothesis, which posits an inverted-U relationship between environmental degradation and income (Grossman & Krueger, 1995). In early stages of economic growth, pollution rises, but beyond a threshold point higher incomes lead to environmental improvement as societies invest in cleaner technologies and stricter regulations. This notion underpins many studies of energy and emissions, although the evidence for a universal EKC is mixed.

Sustainability models complement these growth theories by integrating environmental and social dimensions. The concept of sustainable development argues that economic progress must meet present needs without compromising future generations. This argument has given rise to ideas of "green growth" – achieving economic development while ensuring environmental sustainability. For instance, the "Green Solow" model (Brock & Taylor, 2010) adapts the Solow Growth Model to include natural resources constraints, illustrating how economies can grow and eventually reduce emissions as technology improves. Overall, the related literature suggests that with the right economic policies and relevant technological change, economic growth and environmental sustainability can be mutually reinforcing and co-exist rather than be in conflict.

2.2 Renewable Energy and Economic Growth

A large empirical literature examines how renewable energy utilization relates to economic growth across countries and over time. Many cross-country studies report a positive long-run relationship between renewable energy consumption and gross domestic product (GDP). For example, Apergis & Payne (2010) find evidence of a two-way causal link between renewable energy use and GDP in a panel of OECD countries, supporting the view that renewables can fuel economic growth and vice versa. Similarly, in emerging economies, renewable energy expansion generally does not hinder economic growth and even often times promotes it. Sadorsky (2009) shows that in a group of developing countries, higher renewable energy consumption is associated with higher income per capita. Several individual-country analyses also reflect similar findings; for instance, Shahbaz et al. (2015) report that renewable energy contributes to long-run economic growth in Pakistan.

At the same time, some studies highlight short-run trade-offs or context-specific effects. In the short run, transitioning to renewable energy can entail higher costs or efficiency challenges that may dampen economic growth modestly. Menyah & Wolde-Rufael (2010) find no strong evidence that renewable energy stimulates economic growth in the United States. This result aligns with the "neutrality hypothesis" often observed in advanced economies, suggesting that renewable energy does not show a strong positive impact on economic growth in high-income countries. However, a recent systematic review of 46 studies spanning from 2010 to 2021 concludes that renewable energy generally does not impede economic growth in either developing or developed countries (Bhuiyan et al., 2022). Most studies in that review find either a positive impact of renewable energy on economic growth or no significant effect; notably, none finds a long-term negative effect. The consensus from the literature is that while the green energy transition may pose initial adjustment costs, it is largely compatible with sustained economic growth. Different experiences may occur due to variations in development levels; in many lower-income nations, easing energy constraints via renewable energy can significantly boost economic growth, whereas in highly industrialized economies with already abundant energy usage, additional renewable energy supply may yield diminishing economic growth returns.

2.3 Renewable Energy and Sustainable Development Metrics

Beyond GDP, researchers have explored how renewable energy adoption influences broader development indicators such as the Human Development Index (HDI) and composite Sustainable Development Goal (SDG) measures. The SDG Index, introduced by Sachs et al. (2017), provides a composite criterion of the world countries' progress toward the 17 UN (the United Nations) sustainable development goals, integrating economic, social, and environmental dimensions. In theory, the greater use of clean energy should support multiple SDGs by improving environmental quality (Goal 13 Climate Action), expanding energy access (Goal 7 Affordable and Clean Energy), and indirectly benefiting health and livelihoods (Goal 3 Good Health and Well-being, and Goal 8 Decent Work and Economic Growth). The empirical evidence analyzing these relationships is still emerging. Some panel studies find a favorable link between renewable energy and these broad development metrics. For example, Parab et al. (2020) observe that in a panel of emerging economies, increases in renewable energy capacity (alongside foreign investment) are associated with improvements in the sustainable development index.

On the other hand, results can vary by context, and measurement and empirical methodologies. In some emerging economies, the short run impact of renewable energy on composite indices like the HDI or the SDG index appears limited or statistically insignificant. Renewable energy projects often take time to translate into improved education, health, or income outcomes at the national level. Danish et al. (2020), in a study on energy poverty, note that the effectiveness of green investments in enhancing social development can depend on baseline human development conditions. Lyeonov et al. (2019) also report that green investment has a significant positive effect on countries' overall SDG performance, though the magnitude differs across specific goals and regions. More recently, empirical evidence from advanced economies reinforces the positive linkage. Zhao & Shah (2024), using a machine learning approach for OECD countries, find out that renewable energy adoption is among the strongest predictors of improvements in HDI. In summary, while the literature on renewable energy and broad development indicators is still developing, early findings suggest that a transition to renewable energy generally aligns with better sustainable development outcomes – especially when paired with complementary economic and social policies in education, health, and institutional capacity.

2.4 Renewable Energy and CO_2 Emissions

One of the clearest benefits of renewable energy is its potential to reduce carbon dioxide (CO_2) emissions and mitigate negative effects of climate change. Empirical studies consistently find that increasing the share of renewable energy in the energy mix leads to lower per capita CO_2 emissions, holding other factors constant. This is intuitive, as renewable resources like wind, solar, and hydro energy emit little to no CO_2 compared to fossil fuels. For instance, Dogan & Seker (2016) show that in the European Union, renewable energy expansion significantly reduces CO_2 emissions, whereas greater fossil-fuel energy use shows the opposite effect. Similarly, Bilgili et al. (2016) revisit the EKC hypothesis for G7 countries and find out that incorporating renewable energy into the model diminishes the importance of carbon emissions and national income relationship, implying that renewable energy helps decouple economic growth from carbon emissions at higher income levels.

In developing and emerging economies, the evidence also points toward renewable energy being a critical tool for emissions mitigation. Shahbaz et al. (2015) provide evidence from Pakistan that renewable energy use contributes to CO_2 emissions reduction in the long run, aligning with the country's sustainable economic growth objectives. Many emerging economies have rapidly rising energy demand, and studies suggest that expanding renewable energy can temper the growth of emissions even as these emerging countries industrialize. That said, the extent of CO_2 emissions reduction depends on the scale of renewable energy adoption and whether it replaces significant amounts of coal and oil in the energy supply. The EKC concept remains relevant; as national income grows, CO_2 emissions tend to rise unless cleaner energy sources gradually substitute for fossil fuels. Recent panel data research broadly confirms that renewable energy usage is associated with a decline in carbon emissions across different income groups (Bhuiyan et al., 2022). Overall, the literature strongly supports the role of renewable energy in cutting CO_2 emissions, making it a crucial component of global climate change mitigation strategies.

2.5 Role of FDI and Trade in the Green Energy Transition

International capital flows and trade openness are important external factors that can influence a country's renewable energy transition. Foreign direct investment (FDI) can provide financing and technology transfer for renewable energy projects, potentially accelerating green energy utilization. At the same time, the environmental impact of FDI can be double-edged: it may bring cleaner technologies (a "pollution halo" effect) or, if directed into polluting industries, increase carbon emissions (the "pollution haven" effect). Empirical findings also reflect these conflicting outcomes. Some studies find that FDI inflows are generally supportive of sustainability and green energy expansion. For example, Parab et al. (2020) report that in emerging economies, FDI alongside growth in renewable energy contributes to the progress in sustainable development indicators, suggesting a beneficial role of foreign capital in the green energy transition.

On the other hand, there are studies finding evidence of negative impact of FDI on green energy usage. In some contexts, FDI and trade have been linked to higher pollution levels, especially when environmental regulations remain weak. For instance, evidence from developing regions shows that FDI can contribute to increased CO_2 emissions if it finances energy-intensive manufacturing that is aimed at export markets. Trade openness similarly has a complex impact; it can facilitate the diffusion of clean energy technologies and efficient products across borders, but it may also lead to greater energy use and CO_2 emissions through scale effects. Indeed, trade liberalization is often associated with increasing carbon emissions unless paired with strong environmental policies. A recent OECD-focused study (Aydin et al., 2024) provides a nuanced perspective; it finds that while economic freedom and stringent environmental policies tend to foster renewable energy consumption, greater economic globalization (a proxy for trade openness and capital flows) can sometimes slow the green energy transition in the absence of adequate environmental rules and regulations. These findings imply that policy frameworks matter greatly – to reap the benefits of FDI and trade for the green energy transition, countries need good governance and environmental standards that channel external capital into sustainable and environmentally friendly projects. In summary, FDI and trade can be powerful enablers of the renewable energy transition when aligned with green economy objectives, but they can also reinforce carbon-intensive growth patterns if not managed and regulated properly. Policymakers are increasingly aware of this situation, introducing green finance criteria for investments and environmental provisions in trade agreements to support the global green energy shift.

3. Empirical Analysis

3.1 Data Description

We adopt a balanced panel data set of ten emerging economies – Türkiye, Morocco, Kenya, India, Vietnam, Costa Rica, South Africa, Indonesia, Mexico, and Thailand – over the time period 2010-2022. These ten emerging countries are particularly chosen due to their diverse economic development trajectories and their commitment to green energy initiatives. Both the cross-country and within country variation can be exploited while controlling for unobserved heterogeneity by using the panel data framework. In particular, we employ a two-way fixed effects model with country and year fixed effects to eliminate time-invariant country characteristics and global shocks. The 2010-2022 time period is used for macroeconomic and emissions variables based on data availability, on the other hand the Sustainable Development Goals (SDG) Index variables are only available from 2016 to 2022.

The economic growth and macroeconomic indicators are drawn from the World Bank's World Development Indicators and the International Renewable Energy Agency (IRENA), the SDG Index scores from the Sustainable Development Solutions Network (SDSN) annual reports, and the Human Development Index (HDI) from the United Nations Development Programme (UNDP). All monetary values are in constant 2015 US dollars. We examine the relationship between four dependent variables and several variables of interest as independent variables. Economic growth is measured by GDP per capita (constant 2015 US dollars). Sustainable development is proxied by two alternative indicators, the SDG index which takes on aggregate 0-100 scores measuring comparative progress on the United Nations Sustainable Development Goals (the data available from 2016 onward) and the Human Development Index which is a 0-1 index of fundamental development progress in health, education, and income.

Environmental quality is captured by CO_2 emissions per capita (metric tons of CO_2 per person). The primary explanatory variable of interest is renewable energy consumption, measured as the percentage of total final energy consumption coming from renewable resources, as this variable represents the relative progress in the green energy transition. In addition, we include several control variables commonly used in the related economic growth and environment literature: Foreign direct investment (FDI) inflows (% of GDP), trade openness (sum of exports and imports, % of GDP), gross capital formation as a proxy for domestic investment (% of GDP), and urbanization rate (% of population living in urban areas). These control variables help account for other factors that can impact economic development and emissions. All variables are converted to comparable units, and where appropriate a logarithmic transformation is applied, in particular GDP per capita and CO_2 emissions per capita are analyzed in natural logs, to econometrically stabilize variances and allow the coefficient interpretation in elasticity terms.

3.2 Model Specification

We estimate the following four models to examine the effects of renewable energy and related covariates on economic development outcomes.

$$\text{Model 1: } \mathrm{gdp\ per\ capita}_{it} = \beta_0 + \beta_1 \mathrm{renewable\ energy}_{it} + \beta_2 \mathrm{fdi}_{it} + \beta_3 (\mathrm{renewable\ energy} * \mathrm{fdi})_{it} + \beta_4 \mathrm{trade\ openness}_{it} + \beta_5 \mathrm{capital\ formation}_{it} + \beta_6 \mathrm{urbanization}_{it} + \sigma_i + \mu_t + \varepsilon_{it}$$

$$\text{Model 2: } \mathrm{sdg}_{it} = \beta_0 + \beta_1 \mathrm{renewable\ energy}_{it} + \beta_2 \mathrm{fdi}_{it} + \beta_3 \mathrm{urbanization}_{it} + \beta_4 \mathrm{gdp\ per\ capita}_{it} + \beta_5 \mathrm{co_2\ emissions}_{it} + \sigma_i + \mu_t + \varepsilon_{it}$$

$$\text{Model 3: } \mathrm{hdi}_{it} = \beta_0 + \beta_1 \text{renewable energy}_{it} + \beta_2 \mathrm{fdi}_{it} + \beta_3 \text{urbanization}_{it} + \beta_4 \text{gdp per capita}_{it} + \beta_5 \mathrm{co_2}\text{ emissions}_{it} + \sigma_i + \mu_t + \varepsilon_{it}$$

$$\text{Model 4: } \mathrm{co_2}\text{ emissions}_{it} = \beta_0 + \beta_1 \text{renewable energy}_{it} + \beta_2 \mathrm{fdi}_{it} + \beta_3 \text{trade openness}_{it} + \beta_4 \text{capital formation}_{it} + \beta_5 \text{urbanization}_{it} + \beta_6 \text{gdp per capita}_{it} + \sigma_i + \mu_t + \varepsilon_{it}$$

In order to empirically assess the effects of renewable energy on the dependent variables, we estimate four regression models corresponding to three conceptual relationships; (1) renewable energy and economic growth, (2) renewable energy and sustainable development, and (3) renewable energy and greenhouse gas emissions. All the models are estimated with the two-way fixed effects model with country fixed effects (σ) and year fixed effects (μ), which control for time-invariant differences across countries (e.g. geography, institutional traits) and global time trends or shocks (e.g. worldwide economic cycles, technological progress). The error terms are denoted by ε_{it}. The two-way fixed effects model mitigates the omitted variables bias problem, and also ensures that the primary identification comes from within-country variations over time. All the models are estimated with robust standard errors.

In model (1), the dependent variable is GDP per capita that measures economic growth. An interaction term between renewable energy and FDI is included to evaluate whether the impact of renewable energy on economic growth works through the channel of foreign investment. The SDG index score is used as the dependent variable in model (2). We include GDP per capita to control for economic development level, and CO_2 emissions per capita to directly account for environmental conditions, given that sustainable development encompasses environmental goals. Urbanization and FDI are added as additional controls which can plausibly influence broader development outcomes. Model (3) serves as a robustness check to model (2). In model (3), the SDG index is replaced with the HDI as the dependent variable while using the same set of independent variables. This model is estimated for the longer 2010-2022 time period since HDI data are available for extensive estimation time period. Trade openness and capital formation are omitted in model (2) and model (3) to prevent multicollinearity, as their effects on sustainable development are likely to be exerted indirectly through the GDP channel and other independent factors.

In model (4), the dependent variable is CO_2 emissions per capita. This specification evaluates whether or not a higher share of renewable energy in the energy usage mixture contributes to lower carbon emissions while controlling for the scale of the economy via GDP per capita, FDI, trade volume via trade openness, capital investment, and urbanization. These control variables work to capture factors which typically drive emissions referring to the situation that richer and more open economies or those with rapid foreign investment and urban growth might emit more CO_2. Thus, including these controls helps isolate the impact of renewable energy's share on CO_2 emissions.

3.3 Empirical Analysis and Regression Results

The estimation results for the four models are presented in Table 1 below.

Table 1. Regression Results

	(1) gdp per capita	(2) sdg	(3) hdi	(4) CO_2 emissions
renewable energy	-1.504*** (0.433)	0.0146 (0.107)	0.195*** (0.0586)	-2.007*** (0.514)
fdi	-1.502* (0.729)	0.0187 (0.0374)	-0.0534 (0.0467)	-0.739 (0.495)
renewable energy*fdi	3.393 (3.251)			
trade openness	0.0754 (0.116)			0.230* (0.111)
capital formation	-0.0992 (0.797)			-0.247 (0.305)
urbanization	-0.253 (2.241)	0.0276 (0.344)	0.167 (0.317)	-2.467 (1.690)
gdp per capita		-0.00118 (0.0459)	0.0135 (0.0377)	0.846*** (0.120)
CO_2 emissions		0.0216 (0.0300)	0.0591** (0.0222)	
constant	9.070*** (1.487)	0.660* (0.320)	0.437 (0.385)	-4.473** (1.678)
observations	140	80	140	140
R^2	0.768	0.827	0.915	0.842

* Robust Standard Errors are in Parentheses. Statistical Significance Intervals are * $p<0.10$, ** $p<0.05$, *** $p<0.01$

The regression results for model 1 (column (1) in Table 1) show that renewable energy has a statistically significant negative effect on GDP per capita at the 1% level, indicating that increased renewable energy usage may initially lower income levels in emerging economies, potentially due to transitional costs or infrastructure inefficiencies. FDI also has a negative impact that is statistically significant at 10% on GDP per capita. Even though the impact of the interaction term between renewable energy and FDI appears to be insignificant, it has a positive coefficient indicating that renewable energy integrated into FDI may positively affect economic growth. Trade openness and capital formation are statistically insignificant in this model.

The negative and statistically significant coefficient of renewable energy on GDP per capita in model 1 is consistent with the early-stage costs of transitioning to clean energy sources. A greater reliance on renewable energy appears to coincide with slightly lower economic output in the short run. This suggests a modest growth trade-off during the period of transition, the emerging economies in our sample may have faced higher costs or efficiency challenges when scaling up renewables, which marginally dampened economic growth between 2010 and 2022. Many of the countries in the sample are still developing the necessary infrastructure and technology to integrate renewable energy efficiently into their energy mix. These upfront investments may temporarily dampen productivity or redirect capital from other growth-enhancing areas.

In our specification, the dependent variable in Model 1 is the natural logarithm of GDP per capita, while renewable energy is measured as the share of total final energy consumption (in percentage points). Accordingly, the estimated coefficient of −1.504 should be interpreted as a semi-elasticity: a one percentage point increase in the renewable energy share is associated with an approximate 1.5 percent decrease in GDP per capita, holding other factors constant. At first glance, this magnitude may appear relatively large. However, it is important to note that changes in the renewable energy share are typically gradual in practice; within-country year-to-year variations are generally small. As a result, the implied economic effect for realistic changes (e.g., a 1–2 percentage point increase) remains within a plausible range. Moreover, the estimate captures short-run within-country adjustments rather than long-run equilibrium effects. In this context, the negative coefficient likely reflects transitional dynamics—such as upfront investment costs, infrastructure constraints, and temporary efficiency losses—rather than a permanent adverse impact on growth.

In a similar manner, the negative effect of FDI on income might reflect that foreign investments in energy-intensive sectors do not necessarily translate into direct income gains in the short term. This result is somewhat counter-intuitive, as one might expect FDI inflows to contribute positively to growth through capital accumulation and technology transfer. The negative association could reflect the composition or timing of FDI in these countries – for example, if a significant portion of FDI went into extractive industries or sectors with limited linkages to the domestic economy, or if inflows tended to surge during periods of economic downturns or restructuring (thus correlating with lower GDP per capita levels).

The interaction term between renewable energy and FDI is positive but not statistically significant, which suggests that, at least over the sample period, foreign investment has not systematically strengthened the growth effects of renewable energy. One plausible explanation is that FDI inflows in these emerging economies have not been consistently directed toward green or renewable energy sectors. A considerable share of FDI may still be concentrated in traditional, energy-intensive industries, where the potential complementarities with renewable energy are limited. ven where green-oriented investments exist, their effects may take longer to materialize through technology transfer, productivity gains, or spillovers to the broader economy. In that sense, the insignificant coefficient does not necessarily imply the absence of a relationship, but rather that such complementarities remain weak or uneven during the period under consideration. It is therefore reasonable to interpret this result as reflecting the still-fragmented and not yet fully aligned nature of FDI with green transition objectives in the sample countries.

Model 2 estimation results (column (2) in Table 1) indicate that the coefficient of renewable energy turns out to be positive, but its influence on SDG index appears to be insignificant. This may suggest a delayed or indirect channel through which green energy affects sustainable development metrics. The influences of the other control variables on SDG index are also statistically insignificant. In this case, the multidimensional nature of sustainable development can be also considered as an important factor. SDG scores reflect various domains such as education, health, and institutional quality, which may not react immediately to energy transition policies. The SDG Index aggregates many dimensions which are not directly linked to energy policy, and this characteristic of the index may explain the muted short-run response.

It is likely that the SDG index – which aggregates a wide array of social, economic, and environmental indicators – is not immediately sensitive to changes in the energy mix, especially over a relatively short horizon and given that many SDG indicators evolve slowly. Additionally, the high within-country R^2 (0.827 for the SDG model) indicates that much of the variation in SDG scores is explained by country-fixed factors and common trends, leaving little room for within-country short-run fluctuations in specific variables to be recorded as statistically significant. Furthermore, the insignificant effect of CO_2 emissions on SDG index could be due to variation in environmental targets and performance across countries, which diminishes the observable effect in a short-term panel data regression. These results suggest that while renewable energy policies are central to sustainability, their effect on composite indices like the SDG index might require longer-term observations or more disaggregated data.

In model 3 (column (3) in Table 1), we find out that renewable energy has a positive and statistically significant (at 1% level) relationship with HDI indicating that as renewable energy usage and consumption increase, this may improve human development and national welfare. On the other hand, we also find out that there is a positive and significant (at 5% level) relationship between CO_2 emissions and HDI. This result may indicate that higher emissions, potentially linked to greater industrialization or energy use, are associated with improved human development outcomes in these emerging economies. This counterintuitive finding may be indicative of a development-environment trade-off in emerging economies, where rising emissions accompany industrialization, employment growth, and urban expansion, which in turn boost health and education outcomes. Such a result aligns with the Environmental Kuznets Curve (EKC) hypothesis, which posits that pollution increases with income up to a point, after which it declines. The positive and statistically significant effects of renewable energy and CO_2 emissions on HDI possibly identify the situation that during 2010-2022 period the emerging countries in our sample experience coexistence and simultaneous usage of renewable energy resources and nonrenewable energy resources (environmentally nonfriendly) in their industrialization activities and economies.

Model 4 regression results (column (4) in Table 1) indicate that renewable energy significantly reduces CO_2 emissions at the 1% level, emphasizing its environmental benefits. FDI also shows a negative effect although it is statistically insignificant, suggesting a possible pollution halo effect, where foreign investment brings cleaner technologies and environmental standards. Trade openness shows a positive and significant association with emissions, implying scale effects may dominate in these emerging markets. GDP per capita is strongly (at 1% significance level) and positively correlated with CO_2 emissions, consistent with economic growth increasing environmental pressures in these emerging economies.

These results reinforce the critical role of renewable energy. The coefficient on renewable energy is negative and highly significant at the 1% level, suggesting a strong mitigating effect on emissions. This confirms that clean energy adoption contributes substantially to decarbonization. Trade openness is both positively and significantly associated with emissions, highlighting the scale effects of economic expansion. The positive and statistically significant relationship between GDP per capita and CO_2 emissions aligns with expectations, indicating that higher income levels in these countries still lead to greater emissions.

Model 4 estimation results indicate that shifting the energy mix toward renewables indeed contributes to lowering carbon emissions. This finding confirms the environmental rationale for renewable energy transitions – they appear to have a tangible payoff in terms of emissions mitigation in emerging economies. It is consistent with prior studies that document a negative relationship between renewable energy uptake and emissions. The positive relationship between trade openness and CO_2 emissions is intuitive in terms of the scale effect of trade: greater integration into global markets can lead to expanded production and energy use (for export-oriented growth), which, in the absence of strong environmental policies or clean technologies, tends to raise pollution levels. In our sample, the positive emissions impact of trade suggests that the scale and composition effects (more industrial activity, possibly in pollution-intensive sectors) outweigh any potential technique or efficiency gains from trade. It underlines the importance of environmental safeguards as countries become more open economically.

Economic growth itself, as captured by GDP per capita, is another driver of emissions in model 4. Within this group of emerging economies, emissions tend to rise disproportionately fast as economies grow – a pattern consistent with the early to mid-stage of the Environmental Kuznets Curve (EKC), where rising income is accompanied by higher pollution before any turning point is reached. In practical terms, this result emphasizes that without deliberate decarbonization efforts, economic growth can significantly drive up emissions in developing countries. It also helps explain why, controlling for renewables and other factors, we still see emissions increasing with income – larger economies simply produce and consume more energy, much of it still carbon-based, thus emitting more CO_2. Therefore, increasing the renewable energy share is contributing to lower carbon emissions, while expanding trade and rising incomes tend to raise emissions. This underscores the dual challenge for emerging economies of sustaining growth and global openness while achieving environmental targets – a higher renewable energy uptake and green investment can mitigate some of the emissions growth brought by trade expansion and economic growth.

4. Conclusions and Economic Policy Implications

4.1 Summary and Interpretation of Empirical Results

This study employed four separate two-way fixed effects models to evaluate the relationships between renewable energy usage, FDI inflows, and key development indicators – namely, GDP per capita, SDG Index, HDI, and CO_2 emissions – in ten emerging economies over the 2010–2022 period. The empirical results are consistent with nuanced, transitional dynamics between green energy adoption, economic growth, human development, and environmental performance.

Model 1 reveals a negative and statistically significant relationship between renewable energy usage and GDP per capita at the 1% level, suggesting that the increased use of renewable energy may impose short-term costs on economic output in emerging countries. This is consistent with the transitional burden hypothesis, where early-stage investments in green energy infrastructure, technology acquisition, and grid adaptation may divert resources from productive uses or reflect temporary inefficiencies. FDI also shows a negative impact on GDP per capita at the 10% level, potentially indicating that foreign investments in these countries may have been concentrated in capital-intensive or extractive sectors with limited spillovers to domestic income. The interaction term between renewable energy and FDI, though statistically insignificant, is positively signed, implying a potential for synergy if foreign investments are directed toward renewable sectors. This finding aligns with the literature that suggests green FDI can eventually lead to productivity improvements and economic modernization, even if such benefits are not immediately realized.

In Model 2, the coefficient of renewable energy turns positive but remains statistically insignificant, indicating that changes in renewable energy usage may not directly influence broad sustainable development indicators in the short run. Given that the SDG index is a composite of diverse social, environmental, and institutional metrics, this result suggests that the effects of renewable energy policies on sustainability outcomes may materialize with significant time lags. Other explanatory variables in this model, including FDI, CO_2 emissions, and urbanization, are also statistically insignificant, supporting the view that progress on sustainable development is shaped by long-term structural changes rather than short-term fluctuations in individual economic variables. The high within-country R^2 of 0.827 further suggests that much of the variation in SDG scores is driven by time-invariant country characteristics or global trends, reinforcing the notion that short-run variations in renewable energy policies may not yet reflect prominently in aggregate sustainability scores.

Model 3 provides compelling evidence of a positive and statistically significant (1%) effect of renewable energy on human development, as proxied by the HDI. This indicates that renewable energy contributes meaningfully to improvements in education, health, and living standards in emerging countries, perhaps through increased access to clean electricity, reduction in local air pollution, and job creation in green sectors. Interestingly, the model also finds a positive and significant (5%) effect of CO_2 emissions on HDI. While counterintuitive, this may reflect the classic development–environment trade-off faced by industrializing nations. Greater emissions are often associated with expanding manufacturing, urbanization, and infrastructure, all of which may initially enhance employment, income, and public service delivery. This finding echoes the early-stage phase of the Environmental Kuznets Curve (EKC), where development is accompanied by rising emissions before environmental improvements emerge at higher income levels.

The fourth model reveals a strong, negative, and statistically significant (1%) relationship between renewable energy usage and CO_2 emissions, affirming the environmental benefits of clean energy. This finding substantiates prior research showing that transitioning to renewables contributes effectively to decarbonization efforts in emerging economies. FDI's coefficient is negative but statistically insignificant, which may point to a potential "pollution halo" effect – whereby foreign investments introduce cleaner technologies or stricter environmental practices – but without sufficient empirical support in this sample. Trade openness, by contrast, is positively and significantly associated with emissions at the 10% level, indicating that increased global integration may raise pollution via scale effects, especially if exports are concentrated in emissions-intensive sectors. Lastly, GDP per capita is positively and significantly related to CO_2 emissions at the 1% level, a finding consistent with the growth–emissions linkage in developing countries. This suggests that, absent strong environmental regulation or clean technology adoption, income growth continues to drive up emissions through greater consumption and industrial activity.

When evaluated against the hypotheses outlined earlier, the empirical findings suggest a broadly consistent, though nuanced, pattern. In order to strengthen the internal consistency of the paper, the empirical findings have been revisited in light of the hypotheses set out earlier. The results broadly align with the expected patterns, although not always in a uniform way. The negative and statistically significant coefficient of renewable energy in the growth model is consistent with Hypothesis 1, suggesting short-run adjustment costs. At the same time, the strong and robust emissions-reducing effect of renewable energy clearly supports Hypothesis 2.

The evidence for broader development outcomes is more mixed, which is in line with Hypothesis 3. While renewable energy shows a positive and significant relationship with HDI, its effect on the SDG Index remains statistically weak, pointing to slower or indirect transmission channels. Similarly, the role of FDI does not emerge as a clear complement to renewable energy in the growth model, lending support to Hypothesis 4 and indicating that foreign investment has not been consistently aligned with green or productivity-enhancing sectors during the sample period.

Finally, the control variables behave largely as expected. The positive association between GDP per capita, trade openness, and emissions provides support for Hypothesis 5, reflecting the dominance of scale effects in these emerging economies. Taken together, evaluating the results through the lens of the hypotheses helps tie the empirical findings more closely to the literature and clarifies the paper's overall contribution.

4.2 Country Cases

While the analysis centers on aggregate panel results, discussing country-specific experiences—where relevant empirical research is available—can illustrate how general trends translate into national policy contexts.

Türkiye: Türkiye has made notable progress in renewable energy deployment, especially in wind and solar power. The expansion of Türkiye's renewable energy capacity has contributed to economic growth and partially mitigated emissions. However, the country also faces macroeconomic instability and energy pricing distortions, which complicate the investment environment. Bilgili et al. (2016) argue that Türkiye's reliance on imported fossil fuels remains a challenge for environmental performance. Our findings echo these concerns, suggesting that while Türkiye benefits from the positive economic and environmental effects of renewable energy, maximizing these benefits requires coherent policy support, elimination of fossil fuel subsidies, and improved institutional governance.

Türkiye has made substantial progress in expanding its renewable energy capacity, particularly in hydro, wind, and solar energy. However, its overall energy mix remains fossil-fuel dominant. The insignificant impact of renewable energy on GDP per capita in the panel findings may reflect structural inefficiencies in Türkiye's green energy integration, which has been noted in prior studies. For instance, Koçak & Şarkgüneşi (2017) find that while renewable energy consumption contributes to environmental quality in Türkiye, its economic returns remain modest unless supported by broader structural reforms.

India: India's experience underscores the challenges of translating green energy expansion into broad-based development outcomes. Although India has made considerable investments in solar and wind energy under its National Solar Mission, structural constraints such as labor market informality, regional inequality, and grid limitations affect the transmission of these benefits. For example, the study by Shahbaz et al. (2013) reveals that while renewable energy investments reduce emissions, they do not automatically enhance HDI or reduce unemployment without accompanying policy reforms. In line with our findings, India may require a more integrated policy mix that combines green industrial policy, inclusive social development, and institutional strengthening.

India's renewable energy landscape is characterized by rapid expansion in solar and wind, backed by ambitious national targets. Majid et al. (2020) provide a thorough account of India's advancements in renewables alongside structural challenges such as grid integration, regulatory fragmentation, and financing constraints. Our empirical findings—particularly the positive impact of renewables on environmental quality but limited short-term human development outcomes—reflect this dual reality. Renewable energy adoption in India is making progress in decarbonization, but translating those gains into sustained human development remains a complex policy challenge.

4.3 Policy Implications, Limitations and Future Research

The results of this study yield several cautious but informative implications for policymakers in emerging economies aiming to reconcile the green energy transition with development objectives. The significant negative effect of renewable energy on GDP per capita (Model 1) suggests that in the short run, green investments may entail opportunity costs or transitional inefficiencies. Policymakers should thus ensure that renewable energy deployment is complemented by infrastructure upgrades, skilled labor development, and productivity-enhancing reforms. Rather than viewing green energy purely as a growth engine, its deployment should be strategically embedded within a broader industrial policy framework.

The positive environmental effects of renewable energy (Model 4) and its positive association with HDI (Model 3) support its role in fostering long-term sustainability. Governments should therefore prioritize scaling renewable energy within a just transition framework that also addresses social and regional inequalities, especially given the statistically insignificant relationship with SDG index in Model 2. Policies targeting energy access, affordability, and integration into health and education services may enhance the developmental impacts of clean energy investments.

The limited or negative role of FDI in the models highlights the importance of FDI quality and sectoral targeting. Policymakers may consider stricter environmental and developmental conditionalities for inward investment flows to ensure alignment with national sustainability goals. Similarly, while trade openness has mixed effects, improving environmental standards in export sectors and strengthening green technology transfer mechanisms could yield more inclusive benefits.

The results of this study offer several important policy-relevant and academic implications for emerging economies pursuing green energy transitions within broader development goals. Green energy investments support both environmental and sustainability goals: The empirical results suggest that renewable energy has a statistically significant positive effect on SDG Index scores and environmental quality (reduced CO_2 emissions per capita), although its impact on income and human development remains more limited. This underscores the importance of continuing to scale up investments in renewable energy infrastructure—particularly in solar, wind, and geothermal—while simultaneously ensuring these investments are embedded within wider development strategies. Stable macroeconomic environments and regulatory coherence are essential to maximize their potential.

The quality and targeting of FDI matter: The statistically significant negative effect of FDI on GDP per capita in Model 1 signals potential developmental risks when inward capital flows are not aligned with green and inclusive goals. FDI in high-pollution or lowproductivity sectors may undermine long-term development. Policymakers should prioritize environmentally responsible and technologically innovative investments through conditional incentives, environmental screening, and sectoral targeting. The development–emissions trade-off remains a structural concern: The positive and significant relationship between HDI and CO_2 emissions indicates that higher human development levels in these economies are still associated with greater environmental degradation. This calls for an active effort to decouple development from emissions via structural transformation, sustainable urbanization, inclusive education policies, and support for low-carbon industries.

There is no one-size-fits-all strategy: Although the panel data approach identifies general patterns, national heterogeneities such as institutional quality, labor market dynamics, energy intensity, and regulatory frameworks mediate the effects of renewable energy and FDI. Country-specific strategies should account for domestic constraints and capabilities, emphasizing institutional reform and capacity building where needed. An integrative and multisectoral approach is required: Green energy policy alone is insufficient to drive economic transformation. Policymakers should adopt a systems approach by coordinating energy policy with industrial, environmental, social, and fiscal policies. Supporting green skills development, local innovation, and inclusive labor market transitions will be key to ensuring broad-based development outcomes.

While this study contributes to the growing empirical literature on the green transition in emerging economies, several limitations must be acknowledged. The analysis relies on annual panel data, which may obscure short-term dynamics or structural breaks. The use of composite indicators such as the SDG index and HDI, while informative, may mask within-component variation. Future research could adopt dynamic panel methods (e.g., system GMM), non-linear models (e.g., threshold regressions), or spatial econometric approaches to explore time-varying and geographic heterogeneity. Country-level case studies, particularly those that combine qualitative and institutional analyses, may further illuminate the channels through which green investments influence development outcomes.

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