ENERGY TRANSITION AND ECONOMIC GROWTH: EVIDENCE FROM SOUTH ASIA, SUB-SAHARAN AFRICA, AND OECD ECONOMIES

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ABSTRACT:

This study examines the relationship between energy transition and economic growth across three regional blocs—South Asia, Sub-Saharan Africa (SSA), and OECD economies—between 2000 and 2022. Using a balanced panel dataset of 57 countries, the analysis incorporates multiple dimensions of energy transition, including renewable energy adoption, energy efficiency, fossil fuel dependence, and electricity access, while accounting for the moderating roles of institutional quality and human capital. Employing fixed-effects and dynamic panel estimations with robust standard errors, the results reveal that renewable energy consumption significantly enhances economic growth, whereas fossil fuel dependence and higher energy intensity constrain it. Institutional quality and human capital positively influence growth, though their direct moderating effects on renewables are weaker, suggesting lagged impacts. Regional analyses highlight strong renewable-led growth in South Asia, limited effects in SSA due to infrastructural and governance barriers, and innovation-driven growth in OECD countries. The findings substantiate endogenous growth and institutional economics theories, emphasizing that technological progress, efficiency improvements, and institutional capacity are central to sustainable growth. Policy recommendations underscore the need for region- specific strategies integrating renewable infrastructure, governance reform, and human capital investment to achieve long-term green growth and resilience.

Keywords: Energy transition, renewable energy, institutional quality, human capital, economic growth, panel analysis, cross-regional comparison.

INTRODUCTION

The global economy is completely transforming the ways of living as the different countries are trying to fulfill the dual aims of maintaining economic growth and taking care of the Earth's nature. The transformation is marked by the energy transition where the world is moving away from fossil fuels to renewables and to the efficient energy sources. This transition is not only a change in technology but also a more comprehensive economic and institutional change towards sustainability.

Economic growth has, more or less, always been linked with the consumption of fossil fuels. Starting from the Industrial Revolution, the three most important fossil fuels, namely coal, oil, and gas, have led to industrialization, thereby supplying energy for factories, transport, and agriculture (Stern, 2004). The resulting resources did cause a significant increase in the GDP of nations, but at the same time, they also led to the emission of greenhouse gases, the degradation of ecosystems, and the acceleration of climate change (Shahbaz et al., 2019). In recent decades, environmental concerns have been growing and the progress made in the clean technology field has led the policymakers to adopt energy systems that can provide the necessary support for growth and at the same time prevent heavy ecological damage. Henceforth, the global energy transition is a very important step to have the economy grow without harming the environment (Bildirici & Bakirtas, 2014).

The energy transition is regarded as beneficial universally; the discussions regarding its impacts on the economy, however, continue. The proponents of the renewable energy sector highlight the issues that the sector can turn into a good way for technology innovations, raising the efficiency in all applications and sectors, and creating a lot of new jobs (Apergis & Payne, 2010; Bhattacharya et al., 2016). On the other hand, the critics point out the fact that the transition may bring along short-term costs, especially in the economies that are still developing, due to costly investments needed, problems related to the reliability of the power supply, and poor infrastructure (Ozturk, 2017; Dogan et al., 2021).

This research intends to pull apart the knots by looking at the different ways in which the energy transition motivates economic growth in three geographically and economically distinct regions: South Asia, Sub-Saharan Africa (SSA), and the Organisation for Economic Co- operation and Development (OECD). The research explores through various lenses the energy transition to a cleaner energy mix - making it harder to distinguish which pathway actually leads to economic growth. Therefore, the study yields a more comprehensive picture of how the different stages of development affect the result of the energy transition on economic growth.

BACKGROUND AND RATIONALE

The position of energy is two-fold; it is always needed for production and is also a source of innovation and productivity. The Solow-Swan growth model (Solow, 1956; Swan, 1956) and similar models treated energy as an exogenous input that was largely used in capital and labor productivity. On the contrary, endogenous growth theory (Romer, 1990; Aghion & Howitt, 1992) considers new technology and human talents at the center of the economic development

process over time. In this context, investment in renewables, energy efficiency, and clean technologies is regarded as a type of “green innovation” that not only increases productivity but also leads to knowledge spillovers and creates new markets.

The Environmental Kuznets Curve (EKC) hypothesis is another aspect of the debate, suggesting a non-linear relationship between income and environmental quality (Grossman & Krueger, 1995). In the early stages of development economic growth tends to drive the environment to worse conditions; however, once the income level goes beyond a certain limit, cleaner technologies and stricter regulation are factors leading to better environmental conditions. This means the pros and cons of the energy transition differ with the income level: developed countries might reap the benefits of growth while the undeveloped ones might face the drawback of being in transition.

Heterogeneity is evidenced by actual data. In the OECD countries, the adoption of renewable energy has been correlated with an increase in productivity and a decrease in carbon intensity (Marques & Fuinhas, 2012; Pablo-Romero & Sánchez-Braza, 2017). These economies have a well-developed infrastructure, sound institutions, and supportive policies such as carbon pricing and subsidies that ease the transition. However, in the less developed regions, the main obstacles are inadequate financing,

RESEARCH PROBLEM

The main research question that this study revolves around is: What is the impact of the energy transition on economic growth in countries with different levels of development?

Green growth theories support the view that the use of renewable energy and improving energy efficiency lead to sustainable growth, but empirical findings are still inconsistent. For the countries in the development phase, the adoption of non-carbon energy sources might lead to the use of limited resources otherwise meant for industrialization. On the other hand, in developed countries, capital invested in clean energy could act as a new source of innovation and economic growth (Sadorsky, 2009; Payne, 2010).

One of the shortcomings of the current body of research is that it is rather limited. The results are often based on studies that are either geographically very narrow (single country) or a sample that is not very diverse. Additionally, the measurement of the energy transition is often very narrow, as it is mainly limited to the percentage of renewables involved, while other dimensions such as energy efficiency, fossil fuel dependence, and electricity access are disregarded. A thorough knowledge of the situation calls for the amalgamation of these different dimensions within one analytical framework that also considers the moderating effects of governance and human capital.

Thus, the current study is significant as it applies a multi-dimensional, cross-regional approach and looks into the economic consequences of energy transition in three different blocs: South Asia, Sub-Saharan Africa, and the OECD.

SIGNIFICANCE OF THE STUDY

This research brings forth a number of significant contributions to the academic literature and the policy debates of the day.
To begin with, the author has put forward a cross-regional analysis of the world's economies, which are at different stages of development. The comparative study of South Asia, Sub- Saharan Africa, and OECD countries aims to determine whether the regions' differences in institutional strength and policy maturity are the main drivers of the different renewable energy growth impacts.

In the second instance, the research suggests that the transition to renewable energy is not simply a matter of replacing one source with another, but rather it is a multi-dimensional process involving renewable energy adoption, energy efficiency, fossil fuel dependence, and electricity access. The application of this broad framework allows moving beyond the classical models that consider only one variable at a time, thus fostering a more realistic apprehension of structural and institutional dynamics.

Third, the author has identified institutional quality (comprising governance effectiveness, rule of law, regulatory quality, and corruption control) and human capital (measured by education spending and life expectancy) as the main mediators through which the transition to renewable energy can take place. This way, it is acknowledged that the winning transitions are those that are not only driven by technology but also by good governance and social capacity, thus reflecting the tenets of institutional economics (North, 1990; Acemoglu & Robinson, 2012) once again.

The fourth and final contribution consists of the application of advanced econometric techniques to the panel data, such as the ones that deal with fixed effects and the like, in order to get rid of the country's heterogeneity as well as the endogeneity that might occur in the process. The analysis also adopts standardization, outlier management, and robust standard errors to ensure the reliability and validity of the results.

RESEARCH OBJECTIVES

The study is according to five connected objectives:

- To analyze the influence of renewable energy adoption and energy efficiency on the economic growth from the perspective of South Asia, Sub-Saharan Africa, and OECD countries.
- To determine the influence of fossil fuel dependency and carbon emissions on economic performance.
- To find out if the quality of institutions and human capital can amplify or attenuate the impact of energy transition on growth.
- To examine the regional disparities in the effects of energy transition with consideration of development levels, technological maturity, and governance as factors.
- To suggest policy recommendations that are specific for each region and at the same time sustainable for the environment and in line with the long-term economic growth strategies.

REVIEW OF LITERATURE

Over the last half a century, the interplay of energy demand and economic growth has been analyzed in detail in development and environmental economics. The problem has matured into viewing energy use and production primarily through the application of very intricate models which consider factors like technology, sustainability, and institutional quality among other things. This section discusses the academic progress from initial theoretical contributions to current research on energy transition—accompanied by the discussion of major controversies, empirical results, and voids that characterize this line of inquiry.

THE EARLY THEORETICAL AND EMPIRICAL FOUNDATIONS (1950S–1990S)

The first growth models did not recognize energy as an independent factor in production. In classical economic frameworks such as the Solow–Swan model (Solow, 1956; Swan, 1956) for instance, the growth of the economy was fanned by factors like capital accumulation, labor, and exogenously determined technological progress. In a way, energy was implicitly contained within the total factor productivity, implying that growth could go on indefinitely with increased technological wizardry.

Nevertheless, the 1970s oil crises steered the economists to reconsider their position. The economists of that time started to analyze the interaction of energy consumption and output very closely. Kraft and Kraft (1978) were able to provide the very first empirical evidence of such causation in their case of the United States whereby they found that growth Granger- caused energy demand. Consequently, a flood of studies questioning the direction of causality followed the four hypotheses that were put forward:

- The growth hypothesis that claims energy consumption is the driving force behind economic growth;
- The conservation hypothesis that proposes the opposite;
- The feedback hypothesis that mentions bidirectional causality; and
- The neutrality hypothesis that asserts no relationship at all exists (Yu & Choi, 1985; Erol & Yu, 1987).

Most of the initial researches were bivariate and concentrated on the developed world, giving rise to ambiguous findings. Later on, Stern (1993, 2000) brought the field to a higher level by introducing multivariate models with cointegration methods which took into consideration the contributions of capital, labor, and technology, thereby proving that energy and output are jointly determined. His research was a turning point in the method of applying dynamic modeling to the energy-growth nexus.

Emergence of the Environmental Perspective (1990s–2005)

In the 1990s, environmental worries changed the dialogue around economic growth. The Environmental Kuznets Curve (EKC) hypothesis (Grossman & Krueger, 1995) first proposed that the deterioration of the environment is directly proportional to the rise in income but gradually reverses as societies move towards cleaner technologies. The idea of decoupling which means that economic growth takes place alongside the improvement of the environment, was thus, initiated.

Theoretical and methodological progress made in the evaluation of the energy–environment– growth triad. **Ang (2007)** reported in the case of France that there is a long-run bidirectional causality between energy consumption, carbon emissions, and GDP, thus supporting the feedback hypothesis. **Soytas and Sari (2003)** also stated that energy consumption has a considerable influence on income in developing countries, at the same time, warning that the adoption of energy conservation measures could lead to a slowdown in growth.

While this period saw the introduction of renewable energy into academic discussions, limited data was a major factor restricting empirical research. Still, early debates **(Cleveland et al., 2000)** conceded that the switching over to renewable energy sources was a key condition for the coexistence of economic and ecological stability, thus providing a foundation for further studies.

Transition to Renewable Energy and Panel Data Applications (2006–2015)

The global ascent of renewable energy technologies, climate agreements (such as the Kyoto Protocol, 1997; Paris Agreement, 2015), and the access to extended time-series data during the mid-2000s, were the factors that changed the scene. The econometrics also advanced, and simultaneous with the researchers' use of panel data methods that took into account heterogeneity and dynamic adjustment processes across countries, the econometric techniques got evolved.

Sadorsky (2009) was one of the pioneers in employing panel cointegration techniques to study the interactions between renewable energy consumption and income in emerging economies. According to his findings, GDP and renewable energy had a bidirectional relationship, which means that investments in clean energy can lead to growth and environmental improvement at the same time. Much the same, **Apergis and Payne (2010)** analyzed the situation in OECD countries and confirmed the existence of a long-run equilibrium between the use of renewable energy and economic growth, thus supporting the feedback hypothesis in advanced economies.

Sadorsky (2011) applied the same methodology to G7 countries and found that while renewable energy contributes positively to the output, non-renewable energy sources still have the upper hand in the short run. Likewise, **Menegaki (2011)** carried out a study on 27 European countries and found neutrality — meaning that renewable energy policies did not have a significant impact on GDP, because of high costs and early-stage technology adoption, as was the case. It is really the mixed results that brought to the fore the context-dependent aspect of the energy–growth relationship.

In the case of underdeveloped areas, **Ozturk and Acaravci (2013)** observed one-way causation from energy to GDP for low-income countries, which implies that such countries are heavily dependent on energy availability. **Odhiambo (2014)**, focusing on Sub-Saharan Africa, demonstrated that energy dependence and CO_2 emissions exert negative effects on growth, highlighting the challenges of transitioning to renewables in energy-deficient contexts. **Bhattacharya et al. (2016)** advanced this literature by analyzing the top 38 renewable energy-consuming countries from 1991–2012, concluding that renewable energy consumption promotes economic growth in both developed and developing economies, though more strongly in the former.

Integration of Institutional and Technological Factors (2016–2020)

Towards the end of the 2010s, the research community started to point out the importance of the quality of the institutions, the level of innovation, and the governance as the intermediaries in the relationship between energy and growth. Referring to the institutional economics approach **(North, 1990)**, authors claimed that the success of the renewable energy policy mainly depends on the governance and regulatory framework in place.

Bildirici and Bakirtas (2014) focused their study on rapidly developing countries and disclosed that institutional criteria and the ability to innovate determine the share of renewable energy in economic performance. Similarly, **Marques and Fuinhas (2012)** argued that the existence of government support mechanisms and R&D investment are the two main factors influencing the conversion of renewable deployment into productivity gains.

Al-Mulali et al. (2016) took the debate further by adding trade liberalization, urbanization, and financial growth into the European countries' renewable–growth–environment model. The author's results showed that renewable energy is a pollution mitigator, but its impact on GDP is reliant on the presence of complementary economic and institutional factors.

Pablo-Romero and Sánchez-Braza (2017) did a cross-country comparison between the rich and the poor ones, highlighting that renewables in the case of high-income economies are the more significant contributors to growth owing to better innovation systems and market integration, while in the case of developing countries with infrastructural deficits the effect is just the opposite and weaker. Conversely, **Shahbaz et al. (2019)** with the help of the global panel of 157 countries from 1990 to 2014 confirmed that renewable energy not only contributes to growth but also plays a major role in reducing the carbon footprint, thereby giving support to the "green growth" hypothesis.

Contemporary Studies and Regional Divergence (2020–Present)

Recent years have seen intensified interest in the energy transition, focusing on regional disparities and structural heterogeneity. **Dogan et al. (2021)** found that renewable energy enhances growth in high-income economies but shows weaker effects in middle-income ones, highlighting the role of institutions and innovation capacity.

In Africa, **Adebayo and Kirikkaleli (2021)** and **Appiah (2022)** affirmed that renewable energy can only encourage growth if supported by good governance and skilled labor. In Asia, **Khan et al. (2022)** and **Rahman and Vu (2023)** found that the combination of renewable energy and digitalization is a factor of the sustainable growth of which R&D investment and institutional quality are important support pillars. In the case of the developed countries, **Mele and Lisi (2023)** as well as **Li and Zhang (2024)** acknowledged that renewable technology uptake contributes to productivity gains, and the impacts are more pronounced in the countries with carbon pricing and consistent regulatory environments.

Synthesis and Research Gap

The evolution of the literature reveals a few consistent themes and unresolved issues:

- The causality direction between energy transition and growth remains debated, May depend on country's income level and methods used
- Although beneficial, the empirical evidence on renewable energy suggests that significant contextual considerations such as governance, technology and human capital are determinants
- Most of the studies are context specific or use global samples as homogeneous comparisons and overlook potential cross-region differences that would allow structural asymmetries to be detected
- Only a few studies implemented a multi-dimensional concept of energy transition that encompasses renewable energy, energy efficiency, reduced fossil fuels use, and access to electricity
- Finally, while the effect of institutional quality is becoming more recognized in the field, the interactive effects of institutional quality together with energy transition remain under-studied

To address these issues, a comprehensive cross-region panel analysis is undertaken (2000- 2022). The analysis includes renewable energy consumption, energy efficiency, fossil fuel dependence together with institutional quality across South Asia, Sub-Saharan Africa, and

OECD economies.

Hypotheses

Based on the underlying theory and previous studies, the researchers put forward the following hypotheses:

- H1: It is hypothesized that the use of renewable energy will have a cumulative and significant effect on the economic growth of all regions.
- H2: Energy efficiency in the form of lower energy consumption will lead to the growth of the economy.
- H3: Fossil fuels will be a barrier to the growth of the economy.
- H4: Energy transition will have a more significant impact on growth in the countries/regions with better institutional quality.
- H5: The role of human capital in the economic growth resulting from renewable energy will be positive and strong.
- H6: The regional differences in development, technology, and institutions are responsible for the variation in effects' size and direction.

Subsequently, the hypotheses were subjected to fixed-effects and dynamic panel models testing, thereby allowing the reception of insights from both the cross-sectional and time-series perspectives.

METHODOLOGY

The method section specifies the data sources, definitions of variables, and econometric techniques applied to the assessment of the relation between energy transition and economic growth in South Asia, Sub-Saharan Africa, and OECD countries during the period from 2000 to 2022.

Data Sources and Sample Selection

The World Bank's World Development Indicators (WDI), IMF macroeconomic databases, and Worldwide Governance Indicators (WGI) are the key sources of information for the analysis and energy statistics from the Global Energy Observatory and Our World in Data are included. The total number of countries in the dataset is 57 with the following arrangement:

South Asia: India, Bangladesh, Pakistan, Sri Lanka, Nepal, Bhutan

Sub-Saharan Africa: 24 representative countries including Nigeria, Kenya, Ghana, South Africa, and Ethiopia

OECD: 27 advanced economies such as the United States, Japan, Germany, the United Kingdom, and France

The final balanced panel covers the period 2000–2022. Data were merged, cleaned, and converted into panel-long format using **Python** and **Stata**, ensuring consistency and comparability across indicators.

VARIABLE DEFINITIONS

- **Dependent Variable:**
  - **Economic Growth (GDPG):** Annual percentage growth rate of GDP (constant 2015 US$) — the measure of economic performance.
- **Independent Variables (Energy Transition Indicators):**
  - **Renewable Energy Share (RENEW):** % of renewables in total final energy consumption.
  - **Energy Intensity (EINT):** Energy

use per unit of GDP (MJ per $2017 PPP GDP), inverse measure of efficiency.

- **Fossil Fuel Consumption (FOSSIL):** % of fossil fuels in total energy consumption.
- **Electricity Access (ELEC):** % of population with access to electricity.

- **Moderating Variables:**

- **Institutional Quality (INST):** Composite index combining four WGI indicators — government effectiveness, regulatory quality, rule of law, and control of corruption (−2.5 to +2.5 scale).
- **Human Capital (HC):** Represented by education expenditure (% of government spending) and life expectancy (years).

- **Control Variables:**

- **CO_2 Emissions (CO2):** Metric tons per capita.
- **Internet Use (INT):** % of population using the internet (proxy for technological diffusion).
- **Population Density (POP):** People per km^2 of land area.

Variables were standardized and transformed where necessary; missing data were interpolated linearly, and skewed distributions (e.g., energy intensity) were log-transformed.

Results and Analysis

The current section shares the empirical evidence regarding the energy transition economic growth influence in South Asia, Sub-Saharan Africa (SSA), and OECD economies during the period of 2000 to 2022. The data was analyzed through different models starting from baseline estimation, followed by regional regressions, interaction models, dynamic specifications, and robustness checks. Robust standard errors or cluster-robust standard errors were used in all the models. Also, the coefficients were interpreted as elasticities or semi-elasticities.

Descriptive Overview

The global average GDP growth rate from 2000 to 2022 was about 3.4% each year. The most rapid growth was in South Asia (average 5.8%) and moderate in Sub-Saharan Africa (3.9%), although OECD economies still had a stable but lower average of 2.1% growth.

Renewable energy consumption was almost one-quarter of the total global energy consumption (around 23%), however, the consumption was not uniform across the globe with the different regions consuming different proportions, i.e. approximately 45% in SSA (where hydro and biomass are the main sources), 27% in South Asia, and 15% in the OECD countries. The energy intensity experienced a significant drop from 6.8 MJ/$GDP in 2000 to 4.9 MJ/$GDP in 2022, which is due to the efficiency gain in the sector.

On a −2.5 to +2.5 scale, the institutional quality rounded up to zero (average) but the OECD countries were scored +1.1, while South Asia and SSA were scored −0.4 and −0.6 respectively. The pairwise correlations demonstrated the predicted trends: the share of renewable energy has a direct correlation with GDP growth ($r \approx 0.29$), while the opposite is true for fossil fuel dependence and CO_2 emissions ($r \approx$

−0.31 and −0.34, respectively). The quality of institutions and spending on education were positively correlated with renewable energy adoption (r ≈ 0.42), which implies that good governance and skilled human resources transition the energy. Baseline Regression Results

The **Fixed Effects (FE)** model with time dummies explained about 22% of within-country variations in GDP growth (R^2 = 0.223). The results were as follows:
All variables were statistically significant at the 5% level, except education expenditure (p ≈ 0.11). These results confirm **H1**, **H2**, and **H3**: renewable energy boosts growth, while inefficiency and fossil dependence reduce it.

Regional Results

To capture developmental heterogeneity, region-specific regressions were estimated:

These findings confirm **H6**, showing that the energy–growth nexus differs markedly by development stage. In South Asia, renewable expansion has strong pro-growth effects, while in SSA, structural and institutional bottlenecks dampen outcomes. OECD economies experience modest yet positive innovation-led gains.

Interaction Effects: Institutional Quality and Human Capital

The inclusion of interaction terms revealed how governance and human capital shape the renewable–growth link:

These results only **partially support H4 and H5**, suggesting that while institutions and education enhance overall growth, their immediate moderating influence on renewables is limited—possibly due to lag effects.

Dynamic Panel Results

To capture persistence, a dynamic model with lagged GDP growth and renewable energy was estimated:

Table 1

Variable	Coefficient	Sign	Interpretation
Renewable Energy Share (RENEW)	+0.0136	Positive	A 1% increase in renewables raises GDP growth by 0.0136 points.
Energy Intensity (EINT)	−0.0214	Negative	Higher inefficiency lowers growth.
Fossil Fuel Consumption (FOSSIL)	−0.0092	Negative	Fossil dependence constrains growth.
Electricity Access (ELEC)	+0.0171	Positive	Electrification supports growth, especially in SSA and South Asia.
CO_2 Emissions (CO2)	−0.0156	Negative	Environmental degradation curtails long-term output.
Institutional Quality (INST)	+0.0248	Positive	Good governance enhances productivity and investment.
Education Expenditure (EDU)	+0.0075	Positive	Human capital contributes to growth but less strongly.

Table 2

Region	Renewable Energy Coefficient	Significance	Interpretation
South Asia	+0.3881	$p < 0.05$	Renewables drive growth through industrial expansion.
Sub-Saharan Africa	−0.0023	Not significant	Weak effect due to infrastructure and policy constraints.
OECD	+0.0191	$p < 0.05$	Renewables sustain moderate, innovation-led growth.

Table 3

Variable	Coefficient	Interpretation
RENEW	−0.0227	The direct within-country effect weakens once interactions are introduced.
RENEW × INST	−0.0173	Strong institutions may initially impose compliance costs but improve long-run sustainability.
RENEW × EDU	−0.0048	Education’s moderating effect is small and delayed.

Table 4

Variable	Coefficient	Significance	Interpretation
Lagged GDP Growth	+0.2917	$p < 0.01$	Strong persistence: past growth predicts current growth.
Lagged Renewable Energy	+0.1638	$p < 0.05$	Renewables have delayed but lasting positive effects.
Energy Intensity	−0.0204	$p < 0.05$	Efficiency remains critical.
Fossil Dependence	−0.0087	$p < 0.10$	Gradual decline consistent with decarbonization trends.

These findings align with **endogenous growth theory**—renewable energy investments yield dynamic, long-term productivity effects.

Robustness Checks

Three robustness specifications were tested: standardized (z-scores), outlier-trimmed, and cluster-robust models. Across all, the renewable–growth relationship remained **positive and statistically significant**, confirming model stability.

Additional diagnostics showed no major violations of assumptions:

- **VIF:** between 1.8 and 4.2 (no multicollinearity).
- **Durbin–Watson ≈ 2.1:** minimal serial correlation.
- **Breusch–Pagan test ($p = 0.078$):** mild heteroskedasticity addressed with robust SEs.
- **Residual normality and Cook's D:** no influential outliers.

Discussion

Energy Transition and Growth

The outcomes confirm that renewable energy is a factor in long-term economic growth, which is in line with the endogenous growth theory (Romer, 1990; Aghion & Howitt, 1992). The remarkable renewable coefficient, mainly in South Asia ($\beta = 0.388$), points to the fact that clean energy investment leads to the development of new technologies, the growth of industries, and the creation of new jobs. The delayed positive impact is also indicative of the gradual benefits that new technologies bring to the renewable projects since the latter are time-consuming and the former happen through technological learning.

The negative coefficient on energy intensity validates that unprofitable energy use erodes productivity while dependence on fossil fuels limits diversification—thus confirming the energy efficiency–growth and decarbonization–growth hypotheses.

Institutional and Human Capital Dynamics

The quality of institutions had a very strong positive effect on the growth of the economy and a very weak interaction with renewable energy, which implies that good governance in the economy at large produces broadly, but the moderating benefits on renewables might take a while to materialize. This result is in line with the findings of Al-Mulali et al. (2016) and Dogan et al. (2021), who mentioned that institutional reform necessitates compliance costs at first before allowing the efficiency gains to take place.

In the same way, the influence of human capital was direct and positive but limited. This is in consistency with the view that education and health are key to the absorption of technology and its diffusion, but the benefits from such investments are often realized slowly.

Regional Divergence

The analysis highlights stark regional contrasts:

- **South Asia** benefits most from renewable expansion, as clean energy complements rapid industrialization.
- **Sub-Saharan Africa** shows limited impact due to underdeveloped infrastructure, financing gaps, and dependence on biomass.
- **OECD economies** exhibit steady, innovation-driven growth supported by mature governance and advanced technologies.

This heterogeneity mirrors the **Environmental Kuznets Curve**, where the benefits of decoupling emerge only once economies reach sufficient institutional and technological maturity.

Policy Implications For South Asia

- **Expand renewable infrastructure** through targeted fiscal incentives and public– private partnerships.
- **Improve efficiency** via energy audits, industrial retrofitting, and demand-side management.
- **Enhance governance** to ensure stable regulatory frameworks and attract foreign investment.
- **Invest in human capital**, particularly in technical and vocational education for green sectors.

For Sub-Saharan Africa

- **Modernize energy infrastructure**, emphasizing grid reliability and storage systems.
- **Bridge energy poverty** through decentralized off-grid and mini-grid renewable projects.
- **Build institutional capacity** for transparent, accountable energy governance.
- **Promote regional cooperation** via cross-border electricity trade and shared resource management.

For OECD Economies

- **Sustain innovation leadership** in hydrogen, carbon capture, and storage technologies.
- **Advance decarbonization** through circular economy initiatives and sectoral emission targets.
- **Support developing regions** through technology transfer, climate finance, and knowledge-sharing.

Cross-Regional Recommendations

- Strengthen institutional frameworks to ensure policy stability.
- Develop **green finance instruments** such as green bonds and carbon markets.
- Integrate energy transition with **education, R&D, and industrial policy** to foster inclusive, innovation-led growth.
- Establish **regional monitoring systems** for tracking renewable adoption and efficiency performance.

CONCLUSION

This investigation illustrates very convincingly and with much data that the worldwide energy change is a factor that the economy growth can rely upon but the effect depends on different the development stage and institutional capacity. Switching to renewable energy, working with more efficient technologies, and lessening the use of fossil fuels together increase the stable growth outlooks.

The findings affirm four hypotheses (H1, H2, H3, and H6) and partly support H4 and H5 highlighting that although the renewables are the main drivers of growth their outcome is conditioned by the presence of good governance and the investment in human capital. The use of dynamic models indicates that renewable energy is a source of benefits over a long term period because the effects are continuous and delayed.

On a theoretical level, the results reconcile the concepts of endogenous growth theory, the Environmental Kuznets Curve, and institutional economics, providing a common understanding of how technology, policy, and governance interact in the process of sustainable growth.

In the end, this paper gives a very clear message:

The energy transition should not be considered just an eco-friendly step but rather an economic move for making the economy more resilient, innovative, and inclusive.

To frontline this, countries need to unbind growth from carbon which would mean strengthening institutions and keeping human capital up as these are the pillars of a sustainable worldwide economy.

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