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Exploring Investment Dynamics in Renewable Energy for Low-Carbon Economies through a Global Comparative Analysis

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Abstract
This study examines factors influencing investment in renewable energy across low-carbon and high-carbon economies. A dynamic panel analysis was conducted on 29 countries to assess renewable investment trends. The findings reveal similar investment dynamics in both economic panels, influenced by nuclear power generation, GDP, and technological efficiency. The results highlight a collective effort among nations to reduce CO2 intensity, reflecting a strategic transition toward sustainable energy sources. This shift aligns with global sustainability goals, emphasizing a commitment to cleaner energy. The analysis suggests that energy sustainability depends on the strategic utilization of renewable resources, which can complement nuclear technology. A balanced energy portfolio integrating renewables and nuclear power offers synergistic benefits, surpassing the limitations of individual sources. Policymakers should focus on fostering an environment conducive to renewable energy investment by enhancing technological advancements, financial incentives, and regulatory frameworks. Strengthening international collaborations can accelerate the transition toward a low-carbon economy. Economic growth and energy security must align with environmental sustainability for long-term success. Investments in renewable energy can drive innovation, create employment opportunities, and reduce dependency on fossil fuels. Diversification of energy sources is crucial to mitigate risks associated with overreliance on a single energy type. Government policies should support infrastructure development, research, and incentives for renewable energy projects. Technological advancements in storage and efficiency can further enhance the viability of renewables. The study underscores the importance of integrating renewable energy into mainstream energy systems. Strategic planning and sustained investment can facilitate a smoother transition to a sustainable energy future.
Keywords: renewable energy, low-carbon economies, investment dynamics
JEL Codes: P18, P28

1. INTRODUCTION

There is a global consensus that anthropogenic greenhouse gas (GHG) emissions are a pivotal factor contributing to the persistent global warming trend, a concern also connected to broader macroeconomic and financial vulnerabilities highlighted in studies on economic instability and social progress (Ali, 2015; Ali & Rehman, 2015). The overarching reliance on traditional fossil fuels, notably a resurgence in the extensive use of coal, within the framework of overall economic growth has been identified as a primary source of heightened CO_2 emissions originating from the energy sector (Jaccard et al., 2003). This increased carbon dioxide output from the energy sector is acknowledged as a significant contributor to climate change on a substantial scale, which also aligns with earlier discussions on economic structures and financial dynamics in Pakistan and other emerging nations (Hussain, 2018; Manzoor & Agha, 2018). The Kyoto Protocol, recognized by some as an initial step in the global commitment to combat climate change, sought to curtail the aggregate emission of carbon dioxide and other greenhouse gases. Primarily directed at industrialized nations, the agreement acknowledged the historical contributions of these nations to emissions while recognizing the imperative for more substantial efforts in mitigating climate change. Nevertheless, criticisms arose, asserting that the prescribed measures were insufficient to address the magnitude of the environmental challenge. Similar concerns regarding policy inadequacy have also been echoed in the financial and economic literature, where macroeconomic volatility and structural disparities have impeded long-term development trajectories (Ali & Bibi, 2017; Sajid & Ali, 2018). Notably, industrialized countries, some of which were in the process of overcoming prior conditions of underdevelopment, grappled with the dual challenge of economic growth and emissions reduction, contributing to ongoing debates about equity and responsibility in the context of climate action. In more recent times, international agreements have underscored the imperative of technology transfer to developing countries, emphasizing the urgency of constraining CO_2 emissions to cap the global temperature rise within the confines of a 2°C limit. These accords have also delineated specific measures aimed at the preservation and sustainable management of forests, recognizing their pivotal role in climate change mitigation.

With regard to electricity production, it is noteworthy that all employed technologies exert some degree of impact on the environment. Consequently, beyond the conventional economic considerations of reliability and safety, there exists a distinctive ethical responsibility towards future generations. This ethical imperative resonates with earlier scholarly insights stressing the relationship between economic development, energy consumption, and human well-being (Ali & Audi, 2016; Marc & Ali, 2017). These concerns underscore the importance of conducting comprehensive footprint analyses of the plant environment, ensuring a conscientious evaluation of the long-term environmental consequences associated with various electricity generation technologies. Hence, a substantial reduction in the adverse environmental effects of the energy sector can be achieved through a greater proportion of renewable energy sources in the overall electricity generation. However, it is crucial to acknowledge that the implementation of renewable energy strategies generally entails three significant technological shifts: foremost, energy conservation measures on the demand side (Blok, 2005; Lund, 1999); secondly, enhancements in the efficiency of energy production (Lior, 1997; 2002); and thirdly, the substitution of fossil fuels with diverse forms of renewable energy (Afgan & Carvalho, 2002; 2004). These interrelated changes collectively contribute to a more sustainable and environmentally responsible energy paradigm. Similar shifts have been noted in analyses of total factor productivity and energy intensity in large economies (Kumar, 2018), as well as in country-specific studies focusing on the nexus of electricity use and economic performance (Iqbal, 2018; Okurut & Mbulawa, 2018).

When contemplating large-scale renewable energy implementation plans, a country must integrate renewable sources into a new energy system guided by energy savings and efficiency measures (Li, 2005; Ghanadan & Koomey, 2005). However, it is important to note that these measures, while essential in the current state of the art, are not independently adequate to achieve sustainability goals and maintain manageability of climate change. Additional, comprehensive strategies and multi-faceted approaches are imperative to address the complexity of transitioning to a sustainable and climate-resilient energy landscape. These requirements are consistent with structural insights from financial and macroeconomic analyses indicating that fragmented policy efforts seldom yield sustainable long-term outcomes (Ali & Naeem, 2017; Ali, 2011; Ali, 2018).

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In a recent development, the International Energy Agency (IEA) has identified a potential solution to enhance energy efficiency and diminish CO_2 emissions. Acknowledging the protracted timelines associated with the development of new technologies and considering the distinctive attributes of renewable sources, the IEA advocates for the adoption of extensive nuclear facilities and technologies for carbon capture and storage as a pragmatic approach. This recommendation aligns with earlier research emphasizing the value of diversified energy structures and the role of nuclear energy in mitigating environmental pressure (Matsui et al., 2008; Marc & Ali, 2017). A crucial concern pertains to the CO_2 emissions per GDP, commonly referred to as the CO_2 intensity of GDP, arising from fossil fuel combustion. This metric is notably sensitive to meteorological conditions and the overarching demand for power, reflecting the intricate interplay of various factors influencing the carbon footprint associated with economic activities. While energy efficiency undoubtedly contributes to the carbon intensity equation, it is essential to emphasize that the predominant factor influencing carbon intensity is the composition of the energy structure. In essence, carbon intensity poses a central challenge related to energy quality, specifically concerning the ratio of clean energy sources within the broader energy framework. These insights parallel earlier findings on economic growth, financial market performance, and structural adjustments in both emerging and developed economies (Ali et al., 2016; Arshad & Ali, 2016; Ahmad, 2018). The intricate relationship between energy structure and carbon emissions per unit of economic output underscores the importance of transitioning towards cleaner energy alternatives to effectively mitigate environmental impact and foster sustainable economic development.

Certain developed nations have successfully curtailed their CO_2 footprint through the strategic deployment of nuclear power plants. In contrast, other countries are focusing on alternative approaches to diminish their environmental impact. This includes initiatives aimed at enhancing energy efficiency or adopting a paradigm shift in their energy structure, marked by substantial investments in renewable energy sources. These diverse strategies underscore the global commitment to address climate change by exploring a spectrum of solutions tailored to each nation's unique circumstances and priorities. This complexity mirrors the diversity of economic and financial conditions explored in empirical investigations across regions such as Pakistan, India, Japan, Malaysia, and Lebanon (Maurya, 2018; Yen, 2018; Ahmad, 2018; Muhieddine, 2018). Both nuclear and renewable energy technologies stand out for their environmentally friendly characteristics, as they do not produce polluting gases. A burgeoning body of scientific literature is dedicated to renewable energy sources and their intersection with the sustainability of economic growth over the medium to long term. Numerous authors, including Sary and Soytas (2004) and Bradley et al. (2007), have delved into the causal relationship between renewable energy consumption and economic growth, particularly in countries with diverse characteristics, yielding inconclusive results. Contemporary evidence similarly shows mixed results regarding the relationship between electricity consumption and economic performance across countries (Zhang, 2018; Wiafe, 2018; Gorus & Groeneveld, 2018). This underscores the complexity of the interplay between renewable energy dynamics and economic development, necessitating further research and nuanced analyses for a comprehensive understanding.

Several studies have explored the normative perspective and factors influencing the adoption of energy from renewable sources. Works by Bird et al. (2005) and Menz & Vachon (2006) have delved into these aspects. Additionally, Matsui et al. (2008) have specifically examined the role and potentials of nuclear energy systems within the context of a sustainable development framework. Parallel investigations into financial behavior and socio-economic systems further highlight how institutional structures shape adoption and transition pathways in energy and economic sectors (Asif & Simsek, 2018; Iqbal, 2018; Ali & Ahmad, 2014). These studies contribute to a broader understanding of the normative considerations and determinants that shape the trajectory of renewable and nuclear energy pathways in the pursuit of sustainability. Their argument underscores a commitment to sustainable development through a policy emphasizing energy conservation, while concurrently emphasizing the pivotal role that nuclear power plants play in safeguarding the environment. The contention highlights the intricate relationship between strategic energy policies, conservation efforts, and the unique contribution of nuclear energy in achieving broader environmental sustainability objectives—an idea also echoed in literature on economic resilience, credit markets, and financial reforms in developing regions (Wali, 2018; Khan & Ahmad, 2018; Ali et al., 2015). The objective of this study is to examine the determinants influencing investments in renewable energy sources within two distinct panels of countries: one characterized by low CO_2 intensity and another comprising nations with high CO_2 per GDP. This dual-panel approach enables a comprehensive analysis of the driving forces behind investments in renewable energy, taking into account the contrasting environmental contexts of these country sets. Similar cross-sectional and comparative approaches have been widely applied in economic and financial research focusing on market behavior, growth determinants, and structural change (Haider & Ali, 2015; Khan & Ali, 2018; Ali & Zulfiqar, 2018).

The countries constituting the former panel are distinguished by their remarkable efficiency in production processes, manifesting as a low carbon dioxide emission per unit of GDP. These nations, recognized as low carbon economies, stand out for their commitment to integrating a substantial share of CO_2-free technologies into their electricity production portfolios. Notably, this includes a robust utilization of nuclear and renewable energy sources, reflecting a strategic emphasis on environmentally sustainable practices in their energy sector. Such long-term structural efficiency is consistent with earlier findings on macroeconomic stability, financial sector reform, and policy-driven productivity improvements (Ali, 2018; Ali et al., 2016; Ali & Audi, 2018). In contrast, the countries constituting the latter panel exhibit a discernibly high environmental footprint, characterized by an elevated production of CO_2 per unit of GDP. Within this group, our investigation centers on discerning the divergences among these nations by honing in on two key metrics: energy efficiency and the magnitude of nuclear electricity consumption within their production portfolios. This analytical approach provides a comprehensive understanding of the distinct energy dynamics at play, shedding light on the factors contributing to the heightened environmental impact observed in countries with a substantial CO_2 output relative to their GDP. The obtained results provide valuable insights for strategic planning in the establishment of new power plants. Moreover, they contribute to a comprehensive understanding of the evolving energy policies adopted by countries, particularly in these dynamic years marked by a shifting environmental sensibility. This knowledge is instrumental in shaping informed decisions for future energy infrastructure development, aligning with the global imperative of fostering sustainable and environmentally conscious practices in the evolving landscape of energy production (Ali, 2018; Zahid, 2018; Ali et al., 2016).

This paper tackles these complex issues through the application of a dynamic panel analysis, focusing on investments in renewable sources across a diverse sample of 29 countries. These nations exhibit distinct economic and social structures, coupled with varying levels of economic development. The dynamic panel analysis serves as a robust methodological approach to unravel the nuanced dynamics influencing investment patterns in renewable energy within this heterogeneous group of countries.

2. VARIABLES SELECTION AND DATA SOURCES

The dataset employed in this study spans an annual time series encompassing the years 1980 to 2008. The data sources are derived from the U.S. Energy Information Administration (EIA) and cover key variables, including Total Renewable Electricity Net Generation (REN), Gross Domestic Product adjusted for $2000 constant prices (GDP), Energy Intensity (EI), CO2 emissions, and Nuclear Electricity Net Consumption (Nuc). This comprehensive dataset allows for a detailed exploration of the interrelationships among renewable energy investments, economic indicators, energy intensity, carbon emissions, and nuclear electricity consumption over the specified period. The literature offers various approaches for assessing the progress of renewable energy sources. One method involves measuring the displacement of traditional energy sources within the overall energy supply. Alternatively, another approach entails quantifying the total volume of renewable energy produced, as outlined by Bird et al. (2005). These distinct methodologies provide complementary perspectives, allowing for a comprehensive evaluation of the advancements in the utilization and production of renewable energy. In our paper, the investment in renewable energy sources (ShREN) is elucidated as the ratio between renewable generation and the variance between Total Net Electricity Generation and Net Electricity Imports. This formulation provides a specific metric to quantify the proportion of renewable energy investment in the overall electricity generation landscape, taking into account both domestically generated electricity and net imports.

In the context of nuclear energy, our approach involves the utilization of the ratio of Nuclear Electricity Net Consumption (ShNUC) to the variance between Total Net Electricity Generation and Net Electricity Imports. This methodology ensures a comprehensive consideration of the entire electricity generation portfolio. The unaccounted portion, not explicitly incorporated into the model, is attributed to fossil fuel sources. This method allows for a nuanced assessment of nuclear energy's contribution in relation to the overall electricity generation mix. The proportion of Renewable Electricity Net Generation serves as a viable proxy for assessing investments in renewable energy sources. Simultaneously, Energy Intensity, defined as the total primary energy consumption per unit of GDP (expressed in Btu per Year 2005 U.S. $), functions as a proxy for technological efficiency. These chosen proxies provide meaningful indicators to evaluate the extent of reliance on renewable energy and the efficiency of technology deployment within the energy sector. To mitigate variability, the variables Gross Domestic Product (GDP), Energy Intensity (EI), and CO2 emissions have been logarithmically transformed. This transformation helps stabilize the distribution of these variables, making the statistical analyses more robust and facilitating a more reliable exploration of the relationships within the model. Panel dataset of OECD countries and developing countries (Brazil, China and India) is used in order to limit the effect of the small time span of the aggregated data. There are three main issues that can be solved using a panel dataset.

To distinguish investment decisions in countries with varying CO2 per GDP ratios, we employ the median of the distribution of each country's mean CO2 intensity. Countries with mean CO2 intensity below the median are categorized as low carbon economies, while those exceeding the median are deemed high carbon economies. Subsequently, the sample is bifurcated into two distinct subsamples: one comprising low carbon countries and the other encompassing the remaining nations characterized by higher carbon intensity. This segmentation allows for a targeted analysis of investment dynamics within each subset, providing insights into the nuanced considerations associated with renewable energy investments in different environmental contexts. Certainly, the categorization of low carbon economies is inherently intricate, as it encompasses a multifaceted concept that involves the implementation of comprehensive, long-term policy plans. These plans span various critical domains, including but not limited to transport, energy, and climate change. The classification of economies as low carbon reflects a commitment to a holistic approach, indicating concerted efforts to address and mitigate environmental impact across diverse sectors with a focus on sustainability and reduced carbon emissions. Recently, the European Commission has been actively exploring cost-efficient strategies to enhance the climate-friendliness and energy efficiency of the European economy. In pursuit of these goals, the Commission has proposed a comprehensive roadmap, outlining a strategic path forward to address environmental concerns while promoting sustainable and resource-efficient practices across various sectors of the economy. This initiative aligns with the broader global imperative to transition towards a more environmentally conscious and resilient economic framework.

In our paper, our analysis extends to the production of goods and services, employing a criterion where countries categorized as low carbon economies are those that demonstrate a higher level of output while concurrently minimizing their environmental impact. This approach aligns with the notion that efficiency in production processes, coupled with a reduced environmental footprint, characterizes economies making substantial progress toward achieving sustainability goals. The consideration of production efficiency and environmental impact provides a nuanced perspective on the complex interplay between economic activities and ecological responsibility. The decision to split the sample using the median, rather than quartiles, is driven by the imperative to maintain a relevant sample dimension while still adhering to the principle of granularity in our analysis. While using quartiles might provide additional granularity, it could potentially lead to smaller sample sizes in each subgroup, which may compromise the statistical robustness of the analysis. Therefore, opting for the median ensures a balance between granularity and sample size, allowing for meaningful insights into the investment decisions of low and high carbon economies while maintaining statistical reliability. The first subsample, including Austria, Brazil, Denmark, Finland, France, Ireland, Israel, Italy, Japan, Norway, Portugal, Sweden, Switzerland and United Kingdom is made up of the low carbon economies. The second subsample comprising the countries with high CO_2 per GDP: Australia, Belgium, Canada, Chile, China, Greece, India, South Korea, Luxemburg, Mexico, Netherlands, New Zealand, Spain, Turkey and USA. Given the lack of data, countries excluded by the OECD panel are: Czech Republic, Poland, Slovak Republic, Slovenia and Germany (which is not included because of difficulty in time series reconstruction until 1989). Accession candidate countries and enhanced engagement ones are also not considered. All the countries included in dataset are categorized as high income by World Bank. Only Brazil, Mexico, Chile and Turkey are categorized as upper middle income while China and India are in the lower middle-income group.

Prior to delving into the dynamics of the country panel, we initiate our analysis with an exploratory examination. This preliminary analysis aims to elucidate the evolving trends in the energy policy choices of these countries. By conducting this exploratory phase, we seek to uncover patterns, trends, and shifts in the energy policy landscape, providing valuable context for the subsequent in-depth investigation into the panel dynamics. To achieve this objective, factor analysis is employed, utilizing the identical variables identified for the general model of the moments proposed by Arellano and Bond (1991), which will be utilized in subsequent analyses. This method is chosen with the primary motivation of establishing a comprehensive framework to assess the performance of countries over the 29-year period from 1980 to 2008. The application of factor analysis provides a structured approach to distill essential patterns and underlying factors that contribute to the evolution of energy policy choices during this timeframe. The stability of factor loadings over time is notable, contributing to a consistent distribution of variables on the primary axes. This distribution enables the identification of a meaningful physical interpretation for the two principal axes, which collectively explain approximately 70% of the total variability. This level of explanatory power proves adequate for discerning key features in the evolution of energy choices made by various countries. The robustness of the factor loadings allows for reliable insights into the overarching patterns and trends characterizing the energy policy landscape across the considered nations.

The first principal axis exhibits a contrast between variables related to production scale (LnGDP), pollution levels (LnCO2), and high energy intensity (LnEI) against the share of renewable sources (ShREN) relative to total energy production. On the other hand, the second principal axis contrasts variables associated with CO2 emissions and energy intensity against the shares of renewable and nuclear energy production (ShNUC), emphasizing low-pollution alternatives. Consequently, countries characterized by high production achieved through conventional pollutants and exhibiting energy inefficiency would be positioned in the first quadrant of this analysis. This quadrant serves as an indicative space where nations with certain undesirable energy characteristics are identified based on the interplay of these principal axes. In the analysis, countries falling into the second quadrant are those with a less substantial production, primarily realized through conventional production processes. On the other hand, the third quadrant accommodates countries where a significant level of production is not attained, despite a notable application of renewable energy sources. These distinctions in the quadrants provide a nuanced understanding of countries' energy dynamics, considering both the scale of production and the nature of the energy sources utilized. The fourth quadrant is designated for countries characterized by a high production level achieved with a substantial proportion of nuclear energy, resulting in a correspondingly low level of CO2 emissions. This quadrant identifies nations that have strategically integrated nuclear energy into their energy portfolios, demonstrating a commitment to reducing carbon emissions while maintaining a robust production output. The distinct placement of countries within each quadrant serves as a visual representation of their unique energy profiles, considering both production scale and the environmental impact of their energy choices. The distribution of the countries considered in the analysis demonstrates a considerable stability over time, with a few noteworthy exceptions that will be discussed shortly. This overall stability underscores the persistence of certain patterns and trends in the energy choices made by these countries, providing a foundation for understanding the evolution of their energy policies throughout the analyzed period.

3. RESULTS AND DISCUSSION

The regression results provided in Table 1 offer an empirical lens into the investment behaviors and structural dynamics associated with renewable electricity generation across economies of varying carbon intensities. Drawing on a time series dataset from 1980 to 2008 that includes renewable electricity generation, gross domestic product, energy intensity, carbon dioxide emissions, and nuclear electricity consumption, the model disaggregates findings into three categories: low-carbon economies, high-carbon economies, and the full global sample. This classification allows for an enriched understanding of how different types of economies respond to economic and environmental drivers in shaping their renewable energy trajectories. In low-carbon economies, the lagged value of renewable electricity generation (REN-1) shows a strong and positive coefficient of 0.36, significant at the one percent level. This implies a path dependency in renewable investment—countries already committed to renewables tend to maintain or scale up their production in subsequent periods. The importance of historical capacity is well-supported in the literature, which finds that early movers in the renewable energy sector build institutional frameworks, technical expertise, and policy environments that reinforce continued expansion (Johnstone et al., 2010). The robustness of this autoregressive behavior underscores the self-reinforcing nature of clean energy development, where infrastructural and policy momentum drive sustained investment.

Energy intensity (EI) is another major determinant of renewable energy generation in low-carbon economies, with a coefficient of 0.6. This high elasticity indicates that energy efficiency improvements are closely tied to renewable investment in cleaner economies. Such economies typically prioritize both supply-side decarbonization and demand-side efficiency, leveraging renewables to meet increasingly efficient energy service demands. This observation aligns with findings that countries with strong regulatory mechanisms and efficiency goals are better positioned to integrate renewables without overburdening the grid or economic system (Sadorsky, 2009). The substantial impact of energy intensity suggests that managing demand and enhancing productivity are vital components in shaping the renewable energy investment landscape in these nations. Conversely, carbon dioxide emissions (CO_2) exhibit a negative coefficient of −0.67 in low-carbon countries, implying that higher emissions are associated with lower renewable electricity output. This inverse relationship may appear counterintuitive at first, but it likely reflects the composition of the energy mix in these economies. Because low-carbon countries already rely heavily on renewables and have lower overall emissions, any increase in emissions may stem from temporary reliance on fossil fuels, thus suppressing renewable generation relative to the historical baseline. This dynamic has been observed in advanced economies undergoing energy transitions, where short-term carbon spikes sometimes accompany structural shifts in energy systems (Marques & Fuinhas, 2012).

Gross domestic product (GDP), measured in constant 2000 dollars, exerts a strong positive effect (0.66) on renewable energy generation in low-carbon economies. This confirms the foundational role of economic growth in enabling capital-intensive investments in renewables. Wealthier nations are more capable of financing renewable projects, subsidizing technologies, and developing enabling infrastructure. Economic growth thus acts as a critical enabler of the energy transition, particularly in states with pre-existing commitments to sustainability (Balsalobre-Lorente et al., 2016). Interestingly, nuclear electricity consumption (NUC) is negatively associated with renewable generation in low-carbon economies, with a coefficient of −0.24. This suggests a substitutive rather than complementary relationship between nuclear and renewables in these contexts. Despite being low in carbon emissions, nuclear energy may compete with renewables for investment and policy attention due to budget constraints or political preferences. The trade-off underscores a broader debate in clean energy policy over the optimal mix of low-carbon technologies, especially in countries striving to balance risk, cost, and environmental impact (Koengkan et al., 2020). Shifting to high-carbon economies, the dynamics differ in notable ways. The autoregressive term for renewables (REN-1) is even higher at 0.71, indicating that once initiated, renewable programs in these countries are highly persistent. This could reflect the catch-up behavior of high-carbon economies attempting to decarbonize, where past installations significantly influence future growth due to technological learning and policy commitments. However, the relationship is likely also influenced by external pressures, including global agreements and climate finance incentives that encourage sustained investment in renewables once a baseline is established (Lee & Zhong, 2015).

Energy intensity in high-carbon economies still has a positive effect (0.27) but is less pronounced than in low-carbon economies. This reflects a more complex and less efficient energy system, where improvements in intensity are harder to achieve or do not translate directly into renewable capacity growth. In such settings, legacy infrastructure and entrenched fossil fuel interests may blunt the responsiveness of renewable investment to changes in energy productivity (Apergis & Payne, 2010). The CO_2 coefficient in high-carbon economies is also negative, albeit less so at −0.31. This again reinforces the view that higher emissions are inversely related to renewable generation, possibly indicating slow substitution of fossil fuels or the dominance of incumbent carbon-intensive industries. Although high emissions often spur calls for reform, their presence does not always guarantee swift renewable adoption without supportive institutional frameworks (Pao & Fu, 2013). GDP remains a significant driver at 0.47 in high-carbon economies, affirming the economic basis of renewable investment even in countries where sustainability may not be the primary policy goal. Here, growth facilitates modernization and infrastructure development that can indirectly support renewables. The positive role of income reinforces the hypothesis that financial capacity is a necessary, though not sufficient, condition for transitioning to cleaner energy sources (Narayan & Smyth, 2009). Nuclear energy's effect in high-carbon economies remains negative and statistically significant (−0.25), consistent with the low-carbon group. This recurring pattern across both classifications further supports the substitution thesis, indicating that countries tend to pursue either a nuclear or renewable pathway rather than integrating both simultaneously within their energy strategies (Cervantes et al., 2019). For the full global sample, the model estimates remain directionally consistent with the subgroup analyses. The lagged renewable generation variable (0.29), energy intensity (0.45), and GDP (0.68) all exhibit positive and significant relationships with renewable output. Carbon emissions remain negatively related at −0.4, and nuclear electricity continues to demonstrate a negative impact at −0.01, though this final effect is smaller than in subgroup models. These results suggest a convergence in the global energy investment behavior, where certain structural relationships persist across diverse economic contexts but may vary in strength depending on national characteristics. The regression outcomes emphasize that while economic growth and energy productivity are universal drivers of renewable energy investment, the carbon intensity of an economy significantly shapes the interaction of these drivers with legacy energy systems, institutional capabilities, and technology choices.

Table 1: Regression Results

Variables (Low Carbon)	Estimates (Low Carbon)	Variables (High Carbon)	Estimates (High Carbon)	Variables (Full Sample)	Estimates (Full Sample)
REN-1	0.36***	REN-1	0.71***	REN-1	0.29***
EI	0.6***	EI	0.27***	EI	0.45***
CO2	-0.67***	CO2	-0.31***	CO2	-0.4***
GDP	0.66***	GDP	0.47***	GDP	0.68***
NUC	-0.24***	NUC	-0.25***	NUC	-0.01***
Constant	-16.77***	C	-8.69***	C	-14.77***

4. CONCLUSION

In this paper, we undertake an analysis of the determinants driving investments in renewable energy sources, examining three distinct samples. The first sample encompasses low carbon countries, characterized by a low CO2 per GDP ratio. These nations utilize a diverse portfolio for electricity generation, incorporating fossil fuel, renewable, and nuclear sources. The second sample consists of countries that emit a higher amount of carbon dioxide per unit of GDP during electricity production. Third sample analyzes all countries considered in this paper. The coexistence of nuclear power plants seems to exert a suppressing influence on the inclination to invest in renewable energy. This suggests a dynamic where the availability of nuclear energy may mitigate the emphasis on, or urgency for, expanding investments in renewable sources. The relationship between these energy sources, characterized by a certain interdependence, prompts a nuanced examination of how the presence of nuclear power infrastructure can shape the trajectory of renewable energy investments in the broader context of sustainable energy development. This phenomenon is accentuated in our analysis, where a significant factor contributing to this dynamic is the presence of economically advanced countries that bolster their electricity generation share from nuclear power. The advanced economic status of these nations appears to correlate with a greater reliance on nuclear energy, potentially influencing the investment landscape for renewable sources. This intricate interplay between economic development, energy mix, and investment decisions underscores the multifaceted nature of energy policies in the context of advanced economies. Moreover, the imperative to diminish environmental impact incentivizes high carbon economies to augment their investments in renewable sources. This reflects a recognition of the pressing need to transition toward cleaner and more sustainable energy alternatives in order to mitigate the adverse environmental effects associated with higher carbon intensity. The observed increase in renewable investments among high carbon economies underscores a crucial shift towards more environmentally conscious energy practices in response to global sustainability imperatives. Certainly, the endeavor to diminish carbon intensity is inherently tied to a two-fold strategy: amplifying the utilization of clean energy sources and curtailing coal consumption per unit of GDP. This dual approach aligns with global efforts to transition towards a low-carbon future, emphasizing the pivotal role of clean energy adoption and the gradual phasing out of coal-dependent practices in achieving a more sustainable and environmentally responsible energy landscape. Indeed, when a country aspires to attain a specific carbon intensity goal, it faces the strategic choice between enhancing energy efficiency and reshaping its energy structure. This involves considering options like investing in wind power, solar power, or other renewable sources. The decision-making process hinges on finding a balanced and effective approach that aligns with the nation's unique circumstances, resources, and environmental objectives. Whether through optimizing efficiency or transitioning to cleaner energy sources, these decisions play a crucial role in shaping the trajectory of carbon intensity reduction initiatives. Optimizing returns in the pursuit of clean energy goals necessitates a delicate balance, achieved when the marginal gains from improving energy efficiency align with the benefits derived from investing in clean energy sources. This equilibrium provides the central government with a spectrum of alternatives for formulating an effective clean energy strategic plan. By implementing robust policies and concerted efforts, substantial improvements in energy efficiency can be realized, with the potential to capture and utilize various forms of "energy wastage," such as heat. This approach offers a promising avenue to significantly enhance useful energy outputs without resorting to increased reliance on fossil fuels. The strategic significance of the energy sector demands concerted attention from countries, especially considering the escalating demand for electrical power, which is only partially met by renewable energy sources. Presently, renewable energy sources fall short in ensuring continuous power supply during peak hours. As alternatives, countries often resort to fossil fuel-based power plants, which, as anticipated, have a considerable environmental impact and contribute to increased CO2 emissions. Another option is the establishment of new nuclear power plants, which can curtail environmental footprint but necessitate meticulous planning and substantial investments. The challenge lies in finding a balanced and sustainable approach that meets energy demands while minimizing adverse environmental effects. Achieving energy sustainability necessitates a path that involves the utilization of renewable resources, which can act in tandem with nuclear technology under the condition that both surpass their inherent limitations. Future research endeavors may focus on incorporating additional socioeconomic variables and investigating the impact of subsidies on investments in renewable sources. This expanded scope of inquiry aims to provide a more comprehensive understanding of the interplay between various factors influencing energy sustainability and the efficacy of policies aimed at fostering renewable energy development.

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