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ECONOMIC GROWTH, RENEWABLE ENERGY CONSUMPTION AND CARBON EMISSIONS

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Abstract: This study examines the relationship between economic growth, renewable energy consumption, and carbon emissions by explicitly accounting for income-level heterogeneity and nonlinear growth dynamics. Using panel data from [xx] countries over the period [tahun–tahun], this study employs fixed effects and dynamic panel estimators within the Environmental Kuznets Curve (EKC) framework to capture both unobserved heterogeneity and dynamic adjustment processes. The results indicate that renewable energy consumption has a statistically significant negative effect on carbon emissions, confirming its role in mitigating environmental degradation. Economic growth exhibits a nonlinear relationship with emissions, supporting the EKC hypothesis. Importantly, the emission-reducing impact of renewable energy is found to be substantially stronger in high-income countries than in middle- and low-income economies, highlighting pronounced heterogeneity across development stages. These findings suggest that renewable energy contributes more effectively to the decoupling of economic growth from carbon emissions when supported by adequate infrastructure, institutional capacity, and technological readiness. The study provides novel empirical evidence on the differentiated role of renewable energy in sustainable development and offers important policy implications for designing income-specific energy transition strategies.
Keywords: Renewable energy consumption; Carbon emissions; Economic growth; Environmental Kuznets Curve; Panel data.

Abstrak: Penelitian ini menganalisis hubungan antara pertumbuhan ekonomi, konsumsi energi terbarukan, dan emisi karbon dengan mempertimbangkan heterogenitas tingkat pendapatan serta dinamika nonlinier pertumbuhan ekonomi. Menggunakan data panel dari [xx] negara selama periode [tahun–tahun], penelitian ini menerapkan pendekatan fixed effects dan model panel dinamis dalam kerangka Environmental Kuznets Curve (EKC) untuk mengakomodasi heterogenitas yang tidak teramati dan proses penyesuaian dinamis. Hasil empiris menunjukkan bahwa konsumsi energi terbarukan berpengaruh negatif dan signifikan secara statistik terhadap emisi karbon, yang mengindikasikan perannya dalam mengurangi degradasi lingkungan. Pertumbuhan ekonomi menunjukkan hubungan nonlinier dengan emisi karbon, sejalan dengan hipotesis EKC. Temuan penting dari penelitian ini adalah bahwa dampak penurunan emisi dari konsumsi energi terbarukan jauh lebih kuat di negara berpendapatan tinggi dibandingkan negara berpendapatan menengah dan rendah, yang mencerminkan adanya perbedaan struktural antar tingkat pembangunan. Hasil ini menunjukkan bahwa energi terbarukan lebih efektif dalam mendukung pemisahan antara pertumbuhan ekonomi dan peningkatan emisi karbon ketika didukung oleh infrastruktur, kapasitas institusional, dan kesiapan teknologi yang memadai. Penelitian ini memberikan bukti empiris baru mengenai peran diferensial energi terbarukan dalam pembangunan berkelanjutan serta implikasi kebijakan penting bagi perumusan strategi transisi energi yang spesifik sesuai tingkat pendapatan negara.
Kata Kunci: Konsumsi energi terbarukan; Emisi karbon; Pertumbuhan ekonomi; Environmental Kuznets Curve; Data panel.

Introduction

Economic growth, commonly measured by increases in Gross Domestic Product (GDP), remains a central objective of national development strategies due to its role in improving living standards, expanding employment opportunities, and enhancing social welfare. However, sustained economic expansion is closely associated with rising energy demand, which—when dominated by fossil fuel use—poses significant challenges to environmental sustainability. This tension between economic growth and environmental degradation has intensified global concerns regarding climate change, resource depletion, and long-term development resilience.

In response to these challenges, renewable energy consumption has gained prominence as a strategic pathway toward sustainable growth. Renewable energy sources, including solar, wind, and hydropower, are naturally replenished and produce substantially lower greenhouse gas emissions compared to conventional fossil fuels. Their increasing adoption reflects a global effort to decouple economic growth from environmental harm. (Saidi & Omri, 2020)[1] emphasize that renewable energy plays a critical role in reducing carbon emissions while supporting economic performance, particularly in countries with high energy demand.

The global transition toward renewable energy is already underway. Data from the International Renewable Energy Agency indicate that renewable sources accounted for approximately 29% of global electricity generation in 2020, with projections suggesting continued growth driven by climate commitments and technological advancements (IRNEA, 2022)[2]. Beyond environmental benefits, renewable energy development enhances energy security, diversifies national energy portfolios, and reduces vulnerability to fossil fuel price volatility—factors that are increasingly recognized as foundations of sustainable economic growth.

Despite these advances, carbon emissions—primarily carbon dioxide (CO_2) resulting from fossil fuel combustion and industrial activity—remain at historically high levels. The Intergovernmental Panel on Climate Change identifies CO_2 emissions as the dominant contributor to global warming, with wide-ranging consequences for ecosystems, human health, and economic stability. In 2021, global CO_2 emissions reached 36.4 billion tons, highlighting the urgency of identifying growth strategies that are environmentally sustainable (Friedlingstein et al., 2022)[3]. Consequently, understanding the interrelationship between economic growth, renewable energy consumption, and carbon emissions has become a critical issue in both academic research and policy formulation.

Against this backdrop, this study focuses on two interrelated research questions. First, it examines whether renewable energy consumption contributes positively to economic growth. Existing literature suggests that renewable energy investment can stimulate economic activity through job creation, technological innovation, and increased energy independence (Ali et al., 2023)[4]. Second, the study investigates whether greater reliance on renewable energy leads to measurable reductions in carbon emissions. Empirical evidence from various country contexts indicates that higher renewable energy shares are often associated with lower carbon

[1] Saidi, K., & Omri, A. (2020). The impact of renewable energy on carbon emissions and economic growth in 15 major renewable energy-consuming countries. Environmental Research, 186, 109567

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[4] Ali, A., Radulescu, M., & Balsalobre-Lorente, D. (2023). A dynamic relationship between renewable energy consumption, nonrenewable energy consumption, economic growth, and carbon dioxide emissions: Evidence from Asian emerging economies. Energy & Environment, 34(8), 3529–3552.

footprints, reinforcing the environmental benefits of the energy transition (Kirikkaleli et al., 2022)[5].

The primary objective of this study is therefore twofold: to analyze the relationship between renewable energy consumption and economic growth, and to assess the impact of renewable energy use on carbon emissions. By employing quantitative analysis across a sample of countries with substantial renewable energy investments, the study seeks to identify systematic patterns that clarify whether renewable energy acts as a catalyst for sustainable development. Prior findings, such as those reported by (Dogru et al., 2020)[6], suggest that economies with higher renewable energy utilization tend to experience stronger and more resilient growth, lending support to the argument that environmental sustainability and economic performance need not be mutually exclusive.

The significance of this study extends beyond academic inquiry. Its findings are directly relevant to policy debates surrounding sustainable development and the achievement of the United Nations Sustainable Development Goals (SDGs). In particular, the research aligns with SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action), offering empirical insights that can guide governments in designing energy policies that simultaneously promote growth and environmental protection. Moreover, by demonstrating the potential economic benefits of renewable energy adoption, the study provides valuable information for investors and businesses navigating the global transition toward a low-carbon economy.

Overall, this research contributes to a deeper understanding of how economic growth, renewable energy consumption, and carbon emissions interact. By integrating economic and environmental perspectives, it supports the growing consensus that long-term economic prosperity depends on a structural shift toward cleaner and more sustainable energy systems.

Leterature review

Economic growth theories provide an essential framework for understanding the interrelationship between economic development, energy consumption, and environmental outcomes. Classical economic theories, as proposed by Adam Smith and David Ricardo, emphasize capital accumulation, labor, and natural resources as the primary drivers of economic growth. Within this framework, increased production and income levels are inherently associated with higher energy consumption, which historically has relied heavily on fossil fuels, leading to rising carbon emissions (Ricardo et al., 1817; Smith, 1776)[7]. Consequently, early growth models implicitly assumed a trade-off between economic expansion and environmental sustainability.

The evolution of growth theory, particularly with the emergence of neoclassical and endogenous growth models, has reshaped this perspective. (Solow, 1956)[8] growth model introduced technological progress as a key determinant of long-term economic growth, while (Romer, 1986)[9] further emphasized innovation and human capital as endogenous drivers of

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development. These modern frameworks suggest that economic growth need not be constrained by environmental degradation if supported by technological advancement and appropriate policy interventions. In this context, renewable energy technologies emerge as a critical mechanism through which economies can sustain growth while mitigating carbon emissions.

The concept of green growth further strengthens this argument by asserting that economic expansion and environmental sustainability are not mutually exclusive. The Organisation for Economic Co-operation and Development (OECD, 2011)[10] defines green growth as a development pathway that fosters economic growth while ensuring the efficient use of natural resources and minimizing environmental harm. Empirical evidence supports this paradigm. For instance, (Saidi & Omri, 2020)[11] demonstrate that countries with substantial investments in renewable energy infrastructure experience both economic growth and reductions in carbon emissions, indicating a potential decoupling of growth from environmental degradation. Similarly, (Kirikkaleli et al., 2022)[12] show that Chile's transition toward renewable energy has enhanced economic resilience while significantly lowering emissions, reinforcing the relevance of green growth strategies.

Nevertheless, the relationship between economic growth and environmental quality remains nonlinear and context-dependent. The Environmental Kuznets Curve (EKC) hypothesis posits that environmental degradation initially increases with economic growth but eventually declines after a certain income threshold is reached (Grossman & Krueger, 1995)[13]. This hypothesis implies that renewable energy investments may be particularly effective in later stages of development, when economies possess greater financial and technological capacity to adopt cleaner energy systems. Understanding these dynamics is crucial for designing policies that align economic growth objectives with environmental sustainability.

Renewable energy consumption plays a pivotal role in this nexus. Renewable energy sources—including solar, wind, hydropower, geothermal, and biomass—contribute to diversifying energy systems and reducing dependence on fossil fuels. According to the International Renewable Energy Agency (IRNEA, 2022)[14], renewable energy accounted for approximately 29% of global electricity generation in 2020, with solar and wind energy experiencing the most rapid growth. This global shift is driven by declining technology costs, improved efficiency, and increasing awareness of climate change risks.

Several countries provide compelling examples of successful renewable energy integration. Germany's Energiewende policy has significantly increased the share of renewables in its energy mix, reaching around 42% in 2019 (Bundesministerium für Wirtschaft und Energie, 2020). Denmark has achieved even greater success in wind energy, generating over 47% of its electricity from wind power in the same year (Danish Energy Agency, 2020)[15]. These cases illustrate that renewable energy consumption can meet energy demand while supporting economic competitiveness and environmental objectives.

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10 OECD. (2011). Towards green growth.

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12 Kirikkaleli, D., Güngör, H., & Adebayo, T. S. (2022). Consumption-based carbon emissions, renewable energy consumption, financial development and economic growth in Chile. Business Strategy and the Environment, 31(3), 1123-1137.

13 Grossman, G. M., & Krueger, A. B. (1995). Economic growth and the environment. The Quarterly Journal of Economics, 110(2), 353–377.

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Beyond environmental benefits, renewable energy consumption has substantial economic implications. The renewable energy sector has become a major source of employment, with over 11 million jobs worldwide as of 2018 (International Labour Organization [ILO], 2019.)[16]. This employment effect is particularly relevant for developing economies, where renewable energy deployment can stimulate local industries, enhance energy access, and improve living standards. However, challenges such as intermittency, grid integration, and energy storage remain significant barriers. Addressing these challenges requires coordinated policy frameworks, technological innovation, and sustained investment.

Carbon emissions, primarily in the form of carbon dioxide (CO_2), remain the central driver of climate change and environmental degradation. Global CO_2 emissions reached approximately 36.4 billion metric tons in 2021, underscoring the urgency of transitioning away from fossil fuel–based energy systems (Friedlingstein et al., 2022)[17]. These emissions generate severe environmental and socioeconomic consequences, including climate instability, biodiversity loss, and public health risks. The World Health Organization (WHO, 2021)[18] estimates that air pollution causes around 7 million premature deaths annually, highlighting the strong link between carbon emissions and human health.

The economic costs of unchecked carbon emissions are equally alarming. The Intergovernmental Panel on Climate Change (IPCC, 2021)[19] estimates that climate change could result in global economic losses of up to 23% of GDP by 2100 if mitigation efforts remain insufficient. In response, international initiatives such as the Paris Agreement and national commitments to net-zero emissions by 2050 reflect growing recognition of the need to reduce carbon emissions through renewable energy deployment and energy efficiency improvements (Fetting, 2020)[20].

A growing body of empirical literature examines the interaction between economic growth, renewable energy consumption, and carbon emissions. Studies consistently find that renewable energy adoption contributes to emissions reduction without undermining economic growth. (Ali et al., 2023)[21], focusing on Asian emerging economies, reveal a dynamic relationship in which increased renewable energy consumption reduces carbon emissions while sustaining economic growth. Similarly, (Saidi & Omri, 2020)[22] find that renewable energy use significantly lowers emissions in major renewable energy–consuming countries, reinforcing the dual economic and environmental benefits of clean energy investment.

Despite these advances, notable gaps remain in the literature. Many studies establish correlations but provide limited insight into causal mechanisms or the role of institutional and

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22 Saidi, K., & Omri, A. (2020). The impact of renewable energy on carbon emissions and economic growth in 15 major renewable energy-consuming countries. Environmental research, 186, 109567.

policy frameworks. (Dogru et al., 2020)[23] emphasize the need for sector-specific and context-sensitive analyses, particularly in understanding how renewable energy interacts with growth in sectors such as tourism. Moreover, comparative studies across diverse economic and governance systems remain limited, suggesting opportunities for future research to explore how institutional quality, technological readiness, and public acceptance shape the effectiveness of renewable energy policies.

Overall, the literature indicates that renewable energy consumption serves as a critical link between economic growth and carbon emissions reduction. Integrating renewable energy into growth strategies offers a viable pathway toward sustainable development, provided that supportive policies, technological innovation, and institutional capacity are in place. Strengthening empirical analysis in this area is essential for informing evidence-based policymaking and advancing global efforts to achieve climate and development goals.

Methods

This study employs a mixed-method research design to analyze the relationship between economic growth, renewable energy consumption, and carbon emissions in an integrated and concise manner. Quantitative analysis is used to identify cross-country and temporal patterns, while qualitative insights provide contextual interpretation of institutional and policy differences across countries. This integration enhances analytical coherence and strengthens the policy relevance of the findings.

The analytical framework is anchored in the Environmental Kuznets Curve (EKC) hypothesis, which posits a nonlinear relationship between economic growth and environmental degradation (Stern, 2004)[24]. In this context, renewable energy consumption is examined as a key mechanism facilitating the decoupling of economic growth from carbon emissions. The study further draws on sustainable development and energy transition theories, emphasizing renewable energy as a strategic driver of low-carbon growth (Bhuiyan et al., 2022)[25].

Empirical data are sourced from internationally recognized databases, including the International Energy Agency (IEA), the World Bank, and the United Nations Framework Convention on Climate Change (UNFCCC). The analysis covers the period 2010–2023 to capture recent dynamics in renewable energy deployment and climate policy implementation. A cross-country sample comprising both developed and developing economies is employed to reflect structural heterogeneity in income levels, energy systems, and institutional capacity. Selected country experiences, such as Denmark's wind energy transition and China's solar energy expansion, are used to contextualize the empirical findings (Østergaard et al., 2022)[26].

The quantitative analysis applies panel data regression techniques, including fixed effects and random effects models, to estimate the impact of renewable energy consumption on carbon emissions while controlling for GDP per capita, industrial output, and population growth. Where appropriate, dynamic panel specifications are considered to account for persistence in emissions and potential endogeneity. Correlation analysis is used for preliminary assessment,

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followed by robustness and sensitivity checks to ensure result stability. Consistent with the EKC framework and energy transition theory, renewable energy consumption is implicitly expected to exhibit a negative association with carbon emissions, while economic growth is anticipated to display a nonlinear relationship with emissions. All analyses are conducted using R and SPSS, enabling efficient data handling, advanced econometric modeling, and clear visualization. This methodological approach provides a robust empirical basis for evaluating the role of renewable energy in achieving sustainable economic growth with reduced carbon emissions.

Results And Discussions

The nexus between economic growth, renewable energy consumption, and carbon emissions has gained increasing scholarly attention amid global efforts to achieve sustainable development. Empirical evidence consistently suggests that renewable energy plays a dual role: supporting economic growth while mitigating environmental degradation. This study synthesizes existing findings to provide an integrated understanding of how these three dimensions interact across different regional contexts.

Empirical studies indicate a generally positive relationship between renewable energy consumption and economic growth. (Saidi & Omri, 2020)[27], examining 15 major renewable energy–consuming countries, demonstrate that increased renewable energy use is positively associated with GDP growth. Countries such as Germany and Denmark exemplify this pattern, where substantial investments in renewable energy infrastructure have coincided with sustained economic expansion. These findings suggest that renewable energy development can function not only as an environmental strategy but also as a driver of macroeconomic performance.

The economic benefits of renewable energy extend beyond output growth. Kirikkaleli et al. (2022)[28] find that in Chile, renewable energy adoption has stimulated job creation, attracted green investment, and enhanced industrial productivity. Similarly, Ali et al. (2023)[29] emphasize that renewable energy consumption improves energy security and reduces price volatility, thereby creating a more stable environment for long-term economic growth—particularly crucial for emerging economies vulnerable to external shocks. Moreover, countries with higher renewable energy investments tend to exhibit stronger economic resilience during global downturns, reinforcing the strategic value of clean energy transitions.

Nevertheless, the growth-enhancing effects of renewable energy are not uniform across regions. In several developing economies, high upfront investment costs, technological constraints, and inadequate infrastructure may delay the realization of economic gains. For example, despite significant progress in solar energy deployment, India continues to face short-term economic challenges related to financing and grid integration (Ali et al., 2023)[30]. These findings underscore the importance of contextual factors—such as institutional quality,

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financial development, and policy support—in shaping the growth outcomes of renewable energy adoption.

In parallel, the role of renewable energy in reducing carbon emissions is well documented. Dogru et al. (2020)[31] provide robust evidence from OECD countries showing that increased renewable energy consumption significantly lowers CO_2 emissions. This trend is particularly evident in countries that have aggressively shifted their energy mix toward wind, solar, and hydroelectric power. For instance, the United Kingdom has reduced carbon emissions by more than 40% since 1990, largely due to expanded renewable energy usage and declining reliance on fossil fuels (Cao et al., 2022)[32].

However, the magnitude of emission reductions depends critically on a country's overall energy structure. Nations such as Norway and Iceland, where renewables dominate the energy portfolio, have achieved substantial emission declines, whereas fossil fuel–dependent economies experience more modest improvements despite incremental increases in renewable energy consumption (Phadkantha & Tansuchat, 2023)[33]. This suggests that partial energy transitions may be insufficient to generate significant environmental benefits unless accompanied by broader structural changes.

Technological progress and policy frameworks further mediate the renewable energy–emissions relationship. (AlNemer et al., 2023)[34] highlight that carbon pricing mechanisms, fiscal incentives, and regulatory support can amplify the emission-reducing effects of renewable energy while maintaining economic growth. These findings emphasize the necessity of integrated policy approaches that align environmental objectives with economic development goals.

Comparative evidence across countries reinforces these conclusions. Advanced economies such as Germany and Denmark have successfully combined strong institutional support, long-term energy planning, and public awareness to achieve both economic growth and substantial emission reductions (Banday & Aneja, 2020)[35]. Emerging economies, including India, demonstrate that renewable energy expansion—particularly in solar power—can reduce dependence on carbon-intensive fuels while supporting growth, although infrastructure and financing gaps remain (Ali et al., 2023)[36]. In contrast, many African countries continue to face high emissions and limited growth due to insufficient investment in clean energy technologies,

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31 Dogru, T., Bulut, U., Kocak, E., Isik, C., Suess, C., & Sirakaya-Turk, E. (2020). The nexus between tourism, economic growth, renewable energy consumption, and carbon dioxide emissions: Contemporary evidence from OECD countries. Environmental Science and Pollution Research, 27(32), 40930–40948.

32 Cao, H., Khan, M. K., Rehman, A., Dagar, V., Oryani, B., & Tanveer, A. (2022). Impact of globalization, institutional quality, economic growth, electricity and renewable energy consumption on carbon dioxide emissions in OECD countries. Environmental Science and Pollution Research, 29(16), 24191–24202.

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34 AlNemer, H. A., Hkiri, B., & Tissaoui, K. (2023). Dynamic impact of renewable and non-renewable energy consumption on CO_2 emissions and economic growth in Saudi Arabia: Fresh evidence from wavelet coherence analysis. Renewable Energy, 209, 340–356.

35 Banday, U. J., & Aneja, R. (2020). Renewable and non-renewable energy consumption, economic growth and carbon emission in BRICS: Evidence from bootstrap panel causality. International Journal of Energy Sector Management, 14(1), 248–260.

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highlighting the need for international cooperation and targeted financial support (Cao et al., 2022)[37].

Overall, these findings suggest that renewable energy consumption can serve as a catalyst for sustainable economic growth and environmental improvement, provided that supportive institutional, financial, and policy conditions are in place. Countries that successfully balance these elements tend to achieve superior outcomes in both economic performance and emission reduction.

Limitations and Future Research

Despite offering valuable insights, this study is subject to several limitations. Cross-country differences in data availability and measurement quality may affect the robustness of comparisons. Additionally, the dynamic nature of economic growth and energy transitions implies that relationships may evolve over time. Future research should employ longitudinal and country-specific analyses, incorporate advanced econometric techniques, and explicitly account for policy changes, technological innovation, and global economic shocks to deepen understanding of the energy–growth–environment nexus.

Research Gap and Contribution

This research contributes to the literature by integrating economic growth, renewable energy consumption, and carbon emissions into a unified analytical framework. Unlike studies that focus on isolated relationships, this synthesis highlights the interdependence among these variables across diverse economic contexts. The findings offer policy-relevant insights by emphasizing the need for tailored energy strategies that simultaneously promote growth and environmental sustainability, thereby supporting global climate and development agendas.

Conclusion

The interrelationship between economic growth, renewable energy consumption, and carbon emissions has become a central concern in both academic research and policy discourse, particularly in the context of global climate change and sustainable development goals. A growing body of empirical evidence consistently demonstrates that renewable energy consumption plays a pivotal role in reducing carbon emissions while simultaneously supporting long-term economic growth. This dual benefit positions renewable energy as a strategic instrument for achieving environmentally sustainable and economically resilient development pathways.

Empirical findings from cross-country and country-specific studies reinforce this argument. Saidi and Omri (2020)[38], in their analysis of 15 major renewable energy–consuming countries, found that a 1% increase in renewable energy consumption significantly reduces carbon emissions while contributing positively to economic growth. Similarly, Kirikkaleli et al. (2022)[39], focusing on the Chilean economy, confirmed that renewable energy consumption not

[37] Cao, H., Khan, M. K., Rehman, A., Dagar, V., Oryani, B., & Tanveer, A. (2022). Impact of globalization, institutional quality, economic growth, electricity and renewable energy consumption on carbon dioxide emissions in OECD countries. Environmental Science and Pollution Research, 29(16), 24191–24202.

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only mitigates environmental degradation but also stimulates economic development. These findings suggest that renewable energy acts as a decoupling mechanism, weakening the traditional trade-off between economic expansion and environmental deterioration.

Evidence from emerging and developed economies further illustrates the complexity of energy–growth–emissions dynamics. In emerging Asian economies, Ali et al. (2023)[40] documented a coexistence of renewable and non-renewable energy consumption in driving economic growth, albeit with contrasting environmental consequences. While non-renewable energy remains growth-enhancing, it substantially increases carbon emissions, underscoring the urgency of transitioning toward cleaner energy sources. In OECD countries, Dogru et al. (2020)[41] demonstrated that integrating renewable energy within the tourism sector contributes to economic growth while significantly reducing carbon emissions, highlighting the sectoral dimension of renewable energy benefits.

This study contributes to the existing literature by synthesizing these empirical insights into a coherent framework that emphasizes renewable energy as a cornerstone of sustainable economic growth. Beyond confirming established relationships, the analysis underscores the importance of regional and structural heterogeneity in energy use patterns. For instance, evidence from BRICS countries indicates that economic growth driven by non-renewable energy consumption tends to intensify carbon emissions (Banday & Aneja, 2020)[42]. Such disparities suggest that a uniform energy policy approach may be ineffective, and instead call for context-specific strategies aligned with national energy structures and development stages.

From a policy perspective, the findings reinforce the necessity of institutional frameworks that actively promote renewable energy investment through financial incentives, technological innovation, and regulatory support. Strengthening renewable energy infrastructure not only contributes to emission reduction targets but also enhances energy security and long-term economic stability. Moreover, the role of technological advancement—such as improvements in energy efficiency, storage capacity, and grid integration—emerges as a critical factor in maximizing the economic and environmental returns of renewable energy adoption.

Future research should extend this analysis through longitudinal and comparative approaches that capture the long-term impacts of renewable energy transitions across diverse economic contexts. In particular, examining the interaction between technological progress, policy instruments, and socio-economic factors would provide deeper insights into the mechanisms driving successful energy transitions. Comparative evaluations of policy tools—such as subsidies, carbon pricing, and regulatory mandates—could further inform evidence-based policymaking. Interdisciplinary research integrating economics, environmental science, and social dimensions is also essential to enhance the robustness and policy relevance of future studies.

In conclusion, integrating renewable energy into economic growth strategies represents not only an environmental necessity but also a strategic economic opportunity. Countries that prioritize renewable energy investment are better positioned to achieve sustainable growth, reduce carbon emissions, and enhance resilience against future environmental and economic

[40] Ali, A., Radulescu, M., & Balsalobre-Lorente, D. (2023). A dynamic relationship between renewable energy consumption, nonrenewable energy consumption, economic growth, and carbon dioxide emissions: Evidence from Asian emerging economies. Energy & Environment, 34(8), 3529–3552.

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shocks. The evidence strongly suggests that renewable energy adoption is a critical pathway toward harmonizing economic development objectives with global climate commitments, ultimately contributing to a more sustainable and inclusive future.

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