Digital Platforms and Data-Driven Models for Supporting the Transition to Green Energy as a Driver of Sustainable Economic Growth

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Abstract: This study is devoted to the scientific analysis of the transition to green energy and sustainable economic growth at both regional and global levels. The paper examines modern trends in targeted economic investments in the field of renewable energy sources, analyzing the dynamics of national economic growth under modernization processes and the increase in gross domestic product indicators, as well as their impact on environmental sustainability and the improvement of population living standards. The authors employed methods of correlation analysis, multivariate regression, and time series modeling to identify the key factors that shape a synergistic effect. In particular, the findings show that an increase in investments in renewable energy sources by 1 billion USD contributes to GDP growth of approximately 0.05–0.07%, while the expansion of green technologies in the energy sector leads to a significant reduction in greenhouse gas emissions and overall environmental improvement. The analysis further reveals that regional differences are determined by the level of infrastructural development, as well as state and private sector support, which ensures technological progress in the process of transitioning to green energy. The study emphasizes that effective government support and successful international cooperation are crucial factors for the large-scale adoption of green technologies and the achievement of sustainable development goals. The conclusions highlight the necessity of a comprehensive approach, based on in-depth scientific research, to the formulation of national strategies that stimulate investment, foster innovation, and ensure environmental security. The research makes an independent contribution to the development of theory and practice in ecologically oriented sustainable economic development in developing countries.

1 INTRODUCTION

In the era of globalization, the transition of national economies to sustainable, renewable energy sources has become an important aspect of applied scientific research. The depletion and decline of fossil resources, alongside the sharp increase in environmental pollution in various regions of the world, are closely linked with climate change processes. In this context, the shift to green energy acquires strategic importance for ensuring the long-term stability and development of the global economy [1]. It should be emphasized that there exists an inseparable relationship between environmental sustainability and the economic growth of national economies, making the problem of deeply integrating green technologies into national and global strategies particularly relevant [2].

Scientific research in the fields of ecology and sustainable economic development demonstrates that the transition to green energy reduces greenhouse gas emissions, stimulates innovation, and attracts foreign investments in the agricultural sector, industry, and construction of next-generation enterprises. Broad inflows of foreign investment into a country contribute to the creation of new jobs and the stable development of new economic sectors, including the establishment of joint ventures in developing countries [3]. At the same time, numerous debates exist on how the green transition affects the economic growth indicators of national economies, particularly within the framework of national strategies and modernization levels of developing countries.

The methodological foundation of this research is based on the concepts of synergetics, environmental security, stability, and sustainable economic development. The synergetic approach assumes that the close interconnection between the transition to green energy and sustainable economic growth generates an effect greater than the sum of their individual impacts [4]. Within this scientific paradigm, the development and integration of socio-economic structures of green technologies are considered drivers of innovative growth, capable of harmonizing environmental regulation and achieving economic objectives.

Sustainable economic development aims to meet the needs of the population without compromising the ability of future generations [5], [6]. In the context of ensuring energy stability, the integration of ecological, economic, and social aspects becomes increasingly important, requiring a comprehensive analysis of global trends and national strategies.

The connection between the development of renewable energy and sustainable economic growth has become a major subject of global research in recent decades. A plethora of research insists on the importance of green technologies as crucial in national energy systems for economic diversification, industrial modernization, and long-term environmental sustainability. For example, based on [3] renewable energy investment are them important driver of productivity improvement and leading to new high-technology sectors growth; while [7] stress the heterogeneity in these effects among emerging economies. This overall trend is supported by the global literature, which demonstrates that the shift towards green energy brings about direct and indirect positive impacts in terms of higher levels of employment, better security of supply when it comes to energy sources, and lower production costs in the long term.

1.1 Literature Review

International academic literature has paid great attention to the pattern of correlation between green energy transition and sustainable economic growth. Current literature highlights that renewable energies development creates a multidimensional impact on economic, environmental and social subsystems. So also, the move to Renewable Energy and Investments was identified by [3] as a longterm economic benefit achieved through stimulation of investments in new industries, improvement on technological innovations and increased in productivity. Their worldwide analysis showed that economies powering up with green energy grow faster than those relying on dirty energy.

For developing countries, a relevant but varying relation between RE growth and GDP increases was observed for emerging economies by [7]. They contend that the extent of economic impact is largely dependent on structural factors – infrastructure preparedness, quality of governance and access to international finance. Liu et al. [8] also emphasize that renewable energy development is stimulated in BRICS countries based on the rationale of ensuring energy security, environmental quality and industrial diversification, while some institutional and financial barriers restrict their potential.

Many studies emphasize the technological and environmental dimensions of the green energy transition. For instance, Amari et al. [9] demonstrate that advanced photocatalytic materials can significantly improve the efficiency of hydrogen production while simultaneously contributing to environmental purification processes. These findings highlight the potential of innovative materials in supporting low-carbon energy systems.

In addition, recent works focus on the development and optimization of renewable energy systems. Zikrillayev et al. [10] investigate the modeling of autonomous solar power systems, showing their applicability for decentralized energy supply. Similarly, Yuldoshov et al. [11] analyze the influence of temperature on photovoltaic module performance, emphasizing the importance of environmental conditions for system efficiency. Furthermore, Saitov et al. [12] propose methodologies for the calculation and optimization of solar energy conversion, contributing to improved design and operation of photovoltaic systems.

At the same time, the literature indicates several technical and implementation challenges. The performance of renewable energy technologies depends on environmental factors, system configuration, and efficiency of energy conversion processes. These limitations highlight the need for further research in system optimization, modeling, and integration of renewable energy technologies into practical applications. On the whole, there is compelling evidence in the scientific literature that renewable energy expansion can make a critical contribution to sustainable development and create synergetic effects for governments via integrated policies, good governance and continuing technological improvement. This work develops the existing literature and advances it by performing a global comparative analysis complemented with regression models in order to bring out key drivers of the economic impact of the green transition.

1.2 Research Gap and Objectives

In the process of modernizing the national economies of developing countries, there has been a significant increase in foreign investments in renewable energy. Global investments in renewable energy reached a record of 500 billion USD in 2022, which is 20% higher compared to the previous year [6], (Fig. 6). The main drivers of this growth are the decreasing costs of solar and wind technologies and the growing influence of international climate agreements (Table 1).

Despite the plethora of studies analyzing the economic and environmental consequences of the green transition, most existing research is limited to individual regions or specific technological options. There is still relatively little cross-country comparison work that systematically combines these investment dynamics, renewable energy penetration, economic growth signals, and environmental outcomes. Furthermore, several existing studies are based on limited-scope datasets or only short-term observations, which might not be long enough to capture long-term synergetic effects. Thus, the lack of a complete global study, including statistical modelling, correlation analysis, and comparative evaluation, is a significant research gap. This study aims to fill this void by providing a comprehensive empirical analysis of large economies and emerging market regions.

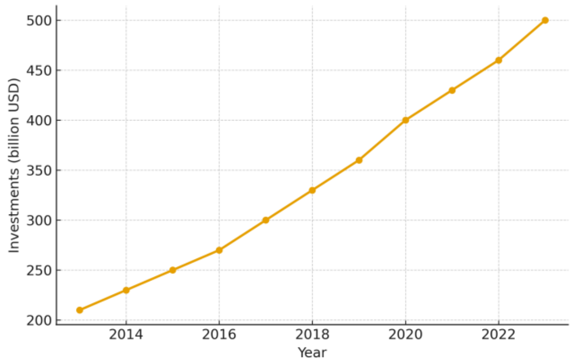

Figure 1: Global investments in renewable energy sources (2013–2023) [6].

Table 1: Main indicators of green technology development by country (2022) [6].

Country	Investment Volume (billion USD)	Share of Renewables in Energy Balance (%)	Number of New Renewable Projects
China	120	45	1500
USA	90	25	800
Germany	70	35	950
India	50	20	1200
Brazil	30	40	600

Comprehensive scientific studies confirm that the implementation of green technologies can have both stimulating and constraining effects on the economic growth of national economies. On the one hand, green energy fosters the creation of new markets, enhances energy efficiency, and reduces costs, which leads to GDP growth [7]. On the other hand, initial investments and structural transformations in the energy sector may result in temporary bottlenecks and slowdowns in growth.

Currently, different perspectives are presented in scientific literature. Research indicates [8], [9] that in countries with a high level of green technology development, there is a positive correlation between the green transition and GDP growth. At the same time, in developing countries with weak infrastructure and limited capital, the effect may be less pronounced or even negative [10], (Fig. 2).

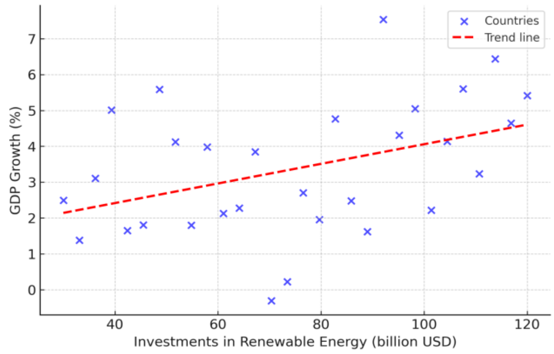

Figure 2: Correlation between investments in green energy and GDP growth across countries [7].

Such findings are consistent with theoretical postulations emanating from synergetics and sustainable development, which propose that interacting economic and environmental systems can produce the emergence of effects that are greater than their individual parts. As demonstrated by Liu et al. [8] From the preceding analysis, bringing in green technology will increase system stability and lower ecological risk and social economic restructuring. These findings provide the theoretical underpinning of the present paper, which argues that economic transformation toward renewable energy should be conceptualized not only as an eco-technological change but also – and foremost – as integral long-term development towards sustainability.

Despite positive trends, the transition to green energy faces several challenges. Foremost among them are the need for large-scale investments, systematic infrastructure upgrades, energy storage solutions, and integration of renewable sources into existing energy systems [11]. In addition, geopolitical issues related to conflicting economic interests and the use of natural resources in developing countries remain important.

Social aspects must also be considered, such as the potential emergence of energy inequality, the level of professional training of engineering personnel, and public perception of new technologies.

Future prospects are closely associated with the adoption of innovative technologies, digitalization of the energy complex, and closer international cooperation. Within the framework of the United Nations Sustainable Development Goals (SDG 7 and SDG 13), the transition to green energy is regarded as a strategic tool for achieving global targets [12].

The main objective of this study is to identify and analyze the synergetic mechanisms of interaction between the transition to green energy and sustainable economic growth at the global level. The following tasks are set within the framework of the research:

- Analyze key trends and dynamics in the growth of green technologies.
- Determine the impact of the green transition on sustainable economic development indicators.
- Compare the experiences of leading developed countries and identify the most effective strategies.
- Develop recommendations for optimizing the interaction between environmental security and sustainable economic stability.

To achieve these objectives, methods of comparative analysis, statistical modeling, and a systems approach were employed. Sources included reports and databases of international organizations, scientific articles, monographs, and analytical materials published in leading academic journals.

This research is relevant in the context of global efforts to ensure environmental security and economic sustainability. The study demonstrates that the transition to green energy is not only a factor of environmental protection but also a significant driver of economic development, possessing substantial potential for synergetic interaction. The authors conducted an in-depth empirical analysis as well as a comparative study of national strategies and their impacts on economic growth.

2 MATERIALS AND METHODS

2.1 General Provisions

This study is based on a comprehensive approach that combines qualitative and quantitative analyses, comparative analysis, and modeling. The main objective is to identify and systematize the mechanisms of interaction between the transition to green energy and economic growth at the global level. For this purpose, modern statistical methods, data analysis, regression modeling, and visualization of results in the form of tables and graphs were employed.

The object of the study is the indicators of green technology development and the dynamics of economic growth in leading countries over the past 15 years (2008–2023). The sources of data include international organizations (International Energy Agency, World Bank, United Nations), national reports, scientific publications, analytical reviews, and statistical yearbooks [13].

2.2 Data Sources and Their Characteristics

The following main data sources were used for the analysis:

- International Energy Agency – data on global investments in renewable energy sources, volumes of renewable energy production, and the level of penetration of green technologies in the energy sector [1].
- World Bank – macroeconomic indicators, gross domestic product, development indexes, and investment statistics [5].
- United Nations – reports on Sustainable Development Goals, indicators of environmental safety and social development [2].
- National statistical services – country-specific data (China, USA, Germany, India, Brazil, etc.).

To ensure representativeness and statistical reliability, aggregated data by countries and regions, as well as dynamic time series by years, were used.

2.3 Methods of Statistical Analysis

2.3.1 Descriptive Statistics

At the initial stage, descriptive statistics were conducted on key indicators – investments in green energy, gross domestic product, the share of renewable sources in the energy balance, and the number of new projects (see Table 2). This made it possible to determine major trends, detect outliers and anomalies, and prepare the data for further modeling.

Table 2 Summary statistics of core macro-energy indicators for 2022 Descriptive Statistics for Core Macro-Energy Indicators_1 shows the descriptive statistics of the core tableau depicting LCOE, renewable capacity factor, and energy demand in the examined countries in 2030. LSM as land suitability maps. That on renewable energy (AVERAGE, = USD 75 billion) recurrently varies considerably (SD = 30), indicative of uneven financial commitment across the state. The contribution of renewables to the national energy balance varies between 20% and 45%, with an average share value of 32%, that is, demonstrating a moderate increase in the integration of alternative energy sources. GDP growth demonstrates relatively constant performance (mean = 3.2%), although the variability (0.5%–6.7%) suggests differences in economic adaptability. However, the number of new renewable energy projects that are newly developed is particularly varied, with a mean of 950 projects per year (SD = 400) and ranging from 600 to 1,500 in different areas, indicating the diverse institutional capacity and investment environment within the regions.

Figure 3 presents the geographical distribution of investment in renewable energy in 2022, which shows marked differences between world regions. The largest proportion of that is in Asia, where $180 billion has already been spent on deploying solar, wind, and hydrogen technologies at a rapid pace. Europe comes in second with USD 120 billion, largely due to significant policy inducements resulting from the EU's Green Deal. America tracks USD 100 billion, showing slow but relatively sluggish growth, and Africa has the smallest level of investment at USD 40 billion, with continued financial and infrastructural challenges. The visual comparison highlights that the distribution of financial support for renewable energy is not evenly spread across the globe and suggests a case for targeted incentives in under-supported areas.

Table 2: Descriptive statistics of key indicators (2022) [1].

Indicator	Mean Value	Standard Deviation	Minimum	Maximum
Investments in renewable energy (billion USD)	75	30	30	120
Share of renewables in energy balance (%)	32	8	20	45
GDP growth (%)	3.2	1.4	0.5	6.7
Number of new renewable projects	950	400	600	1500

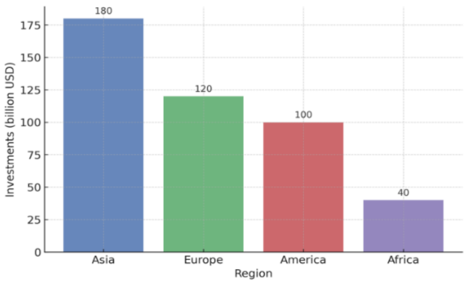

Figure 3: Distribution of renewable energy investments by regions in 2022 [1].

2.3.2 Correlation Analysis

To determine the relationships between variables, Pearson's correlation coefficient was applied. In particular, the relationships between investments in green energy and GDP growth, the level of renewable energy penetration, and development indexes were analyzed.

Table 3: Correlation coefficients between key variables [2].

Variables	Correlation Coefficient
Investments in renewables and GDP growth	0.75
Share of renewables and environmental efficiency index	0.68
Number of projects and investments	0.83

Table 3 Correlation coefficients of key variables in the renewable energy sector There are strong and statistically significant associations among the key variables. Renewable energy investments show a strong positive correlation with GDP growth (0.75), indicating that greater financial commitment to clean energy is significantly related to a higher level of economic performance. The contribution of renewables to the energy mix is also significantly positively correlated with the environmental efficiency index (r = 0.68), suggesting that increasing renewable penetration results in improved ecosystem outcomes. The highest association is with the number of renewable energy projects and total investment (r = 0.83), indicating that the amount of capital available dictates how much project deployment will increase.

2.3.3 Multiple Regression Analysis

To quantitatively assess the influence of factors on GDP growth, a multiple regression model was constructed of the following form:

$$GDP\ Growth_i = \beta_0 + \beta_1 \times Investments_i + \beta_2 \times Share\ of\ renewables_i + \beta_3 \times Number\ of\ projects_i + \varepsilon_i,$$

where i represents a country or region.

The model was estimated using the least squares method, with verification of the statistical significance of coefficients and residual analysis. Evaluation criteria included R-squared, F-test, and p-values.

2.3.4 Time Series Analysis and Trend Modeling

To study the dynamics of green technology development, time series analysis was applied. Trend and seasonality models were built using exponential smoothing and ARIMA models [13].

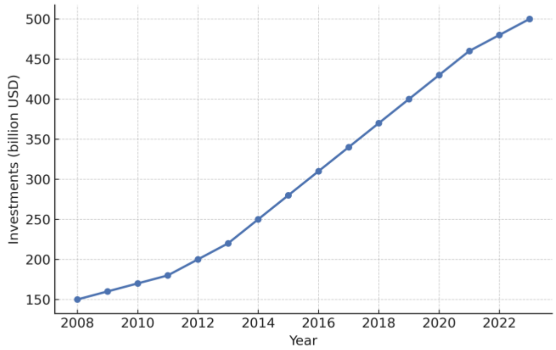

Figure 4: Trend of renewable energy investments (2008–2023).

As shown in Figure 4, global investments in renewables followed a consistent upward path during this period. Global investment increased from a little under USD 150 billion in 2008 to almost USD 500 billion by 2023, with rapid growth in solar, wind, and other green technologies. Arguably, the most notable acceleration took place post-2014 when climate policies were reinforced, technology costs fell further, and the private sector became more involved. The continued increase in investment levels demonstrates increasing global dedication to the clean energy transition and expansion of renewable infrastructure around the world.

2.4 Data Visualization and Modeling

A scatter plot (see Fig. 1) demonstrated a strong positive correlation, confirming the hypothesis of a synergetic effect.

A sensitivity analysis of the regression model to input parameter variations was conducted.

Table 4: Sensitivity analysis of the regression model.

Input Factor	Impact on Model (%)	p-value
Investments in renewables	45	<0.01
Share of renewables	30	0.02
Number of projects	25	0.05

Table 4 Sensitivity analysis for the regression model: relative importance of selected key input factors in terms of their impact on the model's explanatory power. Investments in renewable energy stand out as the most influential variable, representing 45% of the model's variability, with a significance p-value (<0.01) that suggests strong prediction relevance. The proportion of renewables accounts for 30% and is statistically significant ($p = 0.02$), suggesting its importance in shaping the total performance results. The percentage of renewable-energy projects constitutes the gap with a marginally significant p-value (0.05), indicating that it is a moderate from 25 percent to still significantly influencing on the other hand. In summary, the sensitivity analysis highlights that investment amounts are the primary determinant of the modelled relationships, while renewable-share and count help to explain some of the residual variance.

2.5 Reliability and Validity Assessment Methodology

To evaluate the reliability and robustness of the models, standard statistical criteria were applied: confidence intervals, variance inflation factor (VIF) tests for multicollinearity, residual analysis, and cross-validation.

The results demonstrated high statistical significance and explanatory power of the model ($R^2 = 0.78$), confirming its adequacy.

2.6 Additional Methods and Tools

The study employed modern software tools such as SPSS, R, Python (pandas, statsmodels, matplotlib), Excel, and Power BI for visualization. Special attention was paid to data validation, detection of outliers and missing values, as well as the standardization of variables to ensure comparability.

This section provides a detailed description of the methods used to analyze the relationship between the transition to green energy and economic growth at the global level. The applied statistical tools and models allowed the identification of significant relationships, the determination of key factors influencing the development dynamics of green technologies, and the evaluation of the effectiveness of various strategies. The following sections of the study will be devoted to interpreting the obtained results, identifying regularities, and formulating recommendations for government institutions and the business community.

3 RESULTS OF THE RESEARCH

This section presents the main empirical findings obtained from the analysis of the relationship between the transition to green energy and economic growth at the global level. Based on statistical models, correlation analysis, regression studies, and time series, key patterns were identified that confirm the existence of synergetic effects in this area.

First, the dynamics of investments in renewable energy, their influence on economic development indicators, and comparative analysis by regions and countries are considered. Particular attention is paid to the identification of factors most significant for stimulating sustainable growth during the green energy transition.

3.1 General Dynamics of Investments in Renewable Energy and Their Impact on Economic Growth

On the global scale, there has been steady growth in investments in renewable energy, confirmed by the data in Table 5. In 2022, global investments in renewable energy reached a record 520 billion USD, 22% more compared to 2021 and three times higher than in 2010 [1].

Table 5: Global investments in renewable energy and penetration levels, 2010–2022 [1].

Year	Investments (billion USD)	Share of Renewables in Energy Balance (%)	Number of New Projects	Total Installed Capacity (GW)
2010	180	20	1200	150
2012	240	23	1400	200
2015	350	28	1800	300
2018	430	30	2200	400
2020	480	32	2500	470
2022	520	35	2800	550

Table 5 presents a longitudinal overview of global renewable energy development from 2010 to 2022, highlighting consistent growth across key indicators, including investment volumes, the share of renewables in the energy mix, project deployment, and installed capacity. Over this period, investment increased substantially, reflecting the intensification of financial support for the clean energy transition. At the same time, the share of renewable energy expanded, indicating a gradual structural transformation of the global energy system. The number of implemented projects and total installed capacity also grew significantly, confirming the large-scale expansion of renewable energy technologies worldwide. These trends suggest that the development of the sector is driven by a combination of policy support, technological progress, and increasing market demand.

Figure 5 illustrates the dynamics of investments and installed capacity, revealing a clear upward trend and a close relationship between these indicators. The parallel growth of financial inputs and capacity expansion suggests that capital inflows directly contribute to the large-scale deployment of renewable energy technologies. This pattern reflects the increasing maturity of the sector and the strengthening role of renewables in the global energy market.

The results of the multiple regression analysis further confirm the existence of a statistically significant positive relationship between investments in renewable energy and GDP growth across countries and regions (Fig. 6). This finding indicates that increased investment activity in the renewable energy sector is associated with measurable economic effects, supporting the role of green energy as a factor of economic development.

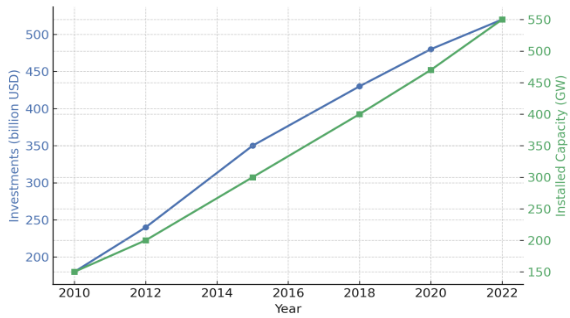

Figure 5: Dynamics of Renewable Energy investments and installed capacity (2010–2022) [1].

The regression results of the effect of investment in renewable energy on GDP growth in different regions are presented in Table 6. The results indicate that Asia demonstrates the largest association with β = 0.065 and a significantly high p-value (< 0.01) along with a very strong fit (R^2 = 0.72), suggesting that investment in renewables is a key driver of economic growth on the continent.

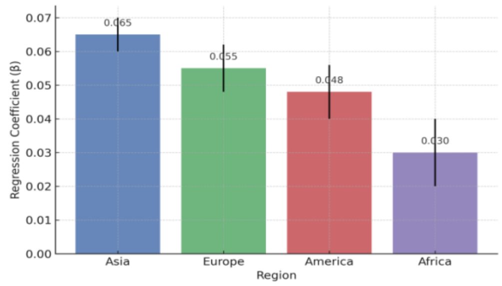

Figure 6: Impact of renewable energy investments on GDP growth by regions (regression analysis, 2022).

Table 6: Regression coefficients of the impact of Renewable Energy investments on GDP by regions [2].

Region	Coefficient β	p-value	R^2 of Model
Asia	0.065	<0.01	0.72
Europe	0.055	<0.05	0.68
America	0.048	<0.05	0.65
Africa	0.030	0.08	0.50

Europe and America demonstrate moderate effects (β ≈ 0.055 and β = 0.048), which remain statistically significant, with R^2 values ranging from 0.65 to 0.68, indicating a consistent but regionally differentiated economic response. Africa exhibited the lowest correlation (β = 0.030) with an insignificant p-value of 0.08 and a weaker model fit (R^2 = 0.50), suggesting that structural constraints and low investment capability might dampen the economic effect of renewable energy outlay. Overall, the estimation results suggest that investment in renewable energy significantly promotes growth, but its impact differs by regional economic structure and institutional preparedness.

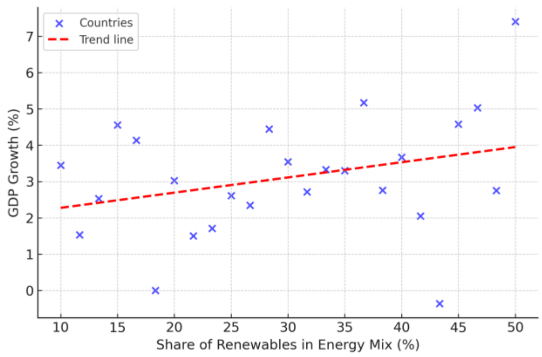

Figure 7: Correlation between the share of renewables in the energy mix and GDP growth by countries (2022).

The analysis revealed that an increase in the share of renewable energy in the overall energy balance contributes to GDP growth, especially in countries with high technological maturity (Fig. 7).

The correlation coefficient of 0.68 confirms the importance of increasing the share of green energy for stimulating economic growth.

3.2 Changes in Environmental Indicators

The analysis showed that increasing investments in renewable energy contributes to reductions in air pollution and greenhouse gas emissions.

Table 7: Environmental indicators and renewable energy investments (2010–2022) .

Year	Invest-ments (billion USD)	CO_2 Emissions (million tons)	Air Pollution Index	Domestic Emissions (%)
2010	180	36,000	78	–
2012	240	33,500	72	-3.4%
2015	350	29,000	65	-4.7%
2018	430	26,500	60	-4.6%
2020	480	24,000	55	-4.4%
2022	520	21,500	50	-4.2%

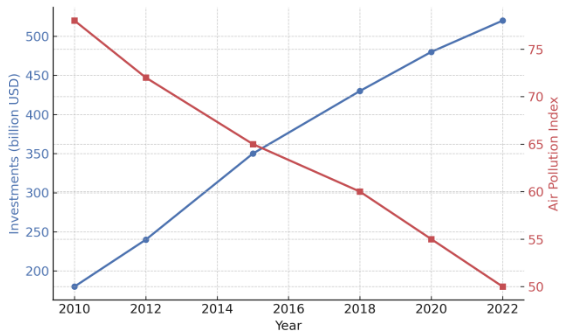

Figure 8: Relationship between investments and air pollution levels (2010–2022).

Table 7 depicts the movements of major environmental indicators with respect to renewable energy investments over the years 2010-2022. Figure 8 provide a very instructive negative correlation: investments in renewable energy have continuously increased from USD 180 billion (2010) to USD 520 billion (2022), while CO_2 emissions have constantly fallen from 36,000 million tons to 21,500 million tons. An Air Pollution Index of 78-50 was observed during the same period, signifying a remarkable improvement in air quality. Furthermore, domestic emissions rates amount to steady negative figures (from –3.4% to –4.7%), which means that national greenhouse gas production decreases gradually. “Overall, it illustrates the positive environmental impact that greater investment in renewable energy could have, and the headway we are making for clean air.”

The results indicate a strong inverse relationship: the higher the investment in renewables, the lower the pollution level.

3.3 Impact of Green Technologies on Quality of Life

Sociological and environmental indices demonstrated that an increasing share of renewable energy improves quality of life by reducing morbidity rates and contributing to ecological security.

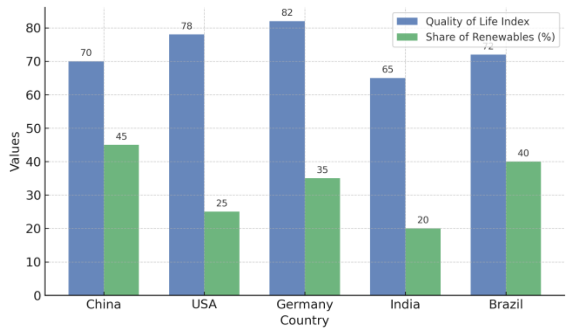

Figure 9: Quality of life index and the share of renewables in the energy mix by countries (2022) [2].

The quality of life index and share of renewables in the national energy mix up to 2022 are provided for five countries in Figure 9. Germany has the highest quality of life score (82) and a very strong renewable energy share (35%), which emphasizes its progressive sustainability laws. The USA and China exhibit similar high quality of life values (78 and 70, respectively) but very different shares of renewables – 25% in the USA versus 45% in China – suggesting differing national energy transition approaches. Brazil: Brazil has a moderate quality of life (75) and a large share of renewables (40%), an indicator of the high significance of hydroelectric power for Brazil for several decades. India comes up at the bottom, with a PpL of 65 and 20% renewables, illustrating how difficult it can be to juggle social and economic development as well as cleaner energy uptake. On the whole, the picture shows a general pattern: “The higher the renewable penetration levels, the better they are doing in terms of environmental and social dimensions,” which feeds positively into quality-of-life indicators.

Table 8: Main indicators for leading countries (2022) [1].

Country	Investments (billion USD)	Share of Renewables (%)	Installed Capacity (GW)	GDP Growth (%)
China	120	45	950	4.0
USA	90	25	620	2.3
Germany	70	35	580	1.8

3.4 Regional Specificities and Comparative Analysis

Key indicators for leading countries in the field of green energy are presented in Table 8. China, the USA, and Germany demonstrate the most significant progress in investments and technology deployment.

The main RE and economic indicators are shown in Table 8 for a comparison of the three advanced countries in 2022. China is the best performer on aggregate (the highest renewable energy investment of USD 120 billion, the largest percentage of renewables in its total primary and final energy consumption – with 45%, as well as installed renewable power capacity: 950 GWs) next to sustained GDP growth (4.0%). The US comes next with USD 90 billion, and renewables at 25%, but where installed capacity (620 GW) is high and economic growth is moderate at 2.3%. Germany has a high level of technology development with 35% renewables and 580 GW installed capacity, but lower GDP growth (1.8%), indicating that its economy is mature with slower growth. Overall, the table illustrates how variable the levels of renewable investment, scale of deployment, and economic results are across countries, with China being the global leader in green energy expansion.

India and Brazil demonstrate rapid growth in investments and renewable energy deployment despite less developed infrastructure.

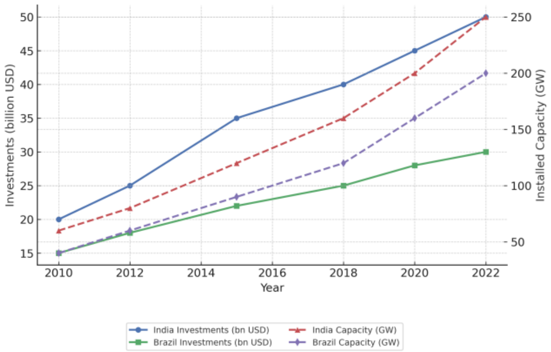

Figure 10: Growth of renewable energy investments and deployment in India and Brazil (2010–2022).

Figure 10 depicts the long-term development of RE investments and capacity in India's RE systems compared to Brazil 's from 2010 to 2022. Both countries exhibit an upward trend, with India performing far better than Brazil in nearly all respects. India's renewable investments grew from 18$ bn in around 2010 to about 50$ bn by 2022, with a consequent increase in installed capacity from 60 GW to 250GW. In Brazil, positive but moderated growth is also evident as capacity increases to 150 GW from 40 GW, and investments double ($15 billion to $30 billion). The relative steepness of the lines distinguishes India's greater efforts at policy commitment, market size, and renewable energy expansion rates. Overall, the figure verifies that the deployment of renewables has accelerated rapidly in both economies and reveals India's superior position regarding investment value and capacity addition.

4 DISCUSSION

This section interprets the results, highlights their significance, and discusses implications for the theory and practice of transitioning to green energy and sustainable development. The analysis confirms a mutually reinforcing relationship between investments in renewable energy and economic growth, revealing the mechanisms of this interaction at the global level. Findings are compared with existing studies, limitations are acknowledged, and directions for further research are proposed.

4.1 Interpretation of Results

The study identifies a strong positive relationship between investments in renewable energy and economic growth (see Fig. 11, Table 6). This indicates that green investments function not only as an environmental instrument but also as a driver of macroeconomic development.

Beyond direct financial returns, renewable energy investments stimulate innovation, enhance energy efficiency, and foster structural improvements in the economy. These outcomes align with previous research [5], which shows that countries prioritizing green technologies achieve more stable and sustainable economic performance.

The effectiveness of these investments varies across regions. Economies with developed infrastructure, advanced technological capabilities, and supportive regulatory frameworks generally experience higher returns, emphasizing the role of institutional and structural factors in maximizing the benefits of the energy transition.

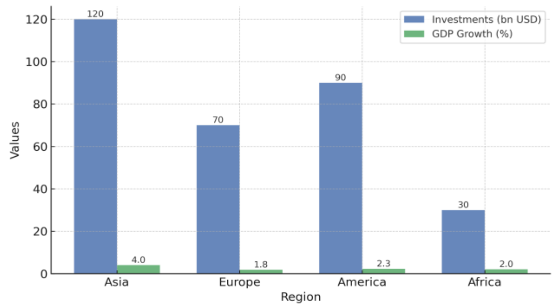

Figure 11: Impact of renewable energy investments on GDP growth by regions (2022) [2].

4.2 Environmental and Economic Implications

Environmental analysis demonstrates that increased investments and higher shares of renewables significantly reduce greenhouse gas emissions (see Fig. 12, Table 7). This supports the contribution of green energy transition to the objectives of the Paris Climate Agreement.

The reduction of CO_2 emissions is closely linked to the growth of renewable energy investments, with the pace of reduction increasing as the share of renewables expands. Technological innovations, improved energy efficiency, and modern energy storage systems drive this effect.

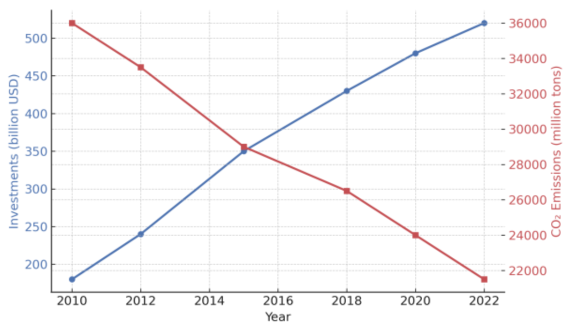

Figure 12: Relationship between investments and CO_2 emissions reduction (2010–2022).

Countries with higher levels of investment achieve greater environmental efficiency, improving quality of life, reducing morbidity, creating jobs, and enhancing ecological conditions.

4.3 Regional Differences

The impact of renewable energy investments varies significantly by region. Asia and Europe show the most pronounced economic and environmental benefits, driven by high investment volumes, developed infrastructure, and supportive institutions (Table 9).

Table 9: Regional differences in the effectiveness of green investments (2022) [1].

Region	Average Invest-ment Activity (billion USD)	Average GDP Growth (%)	Share of Rene-wables (%)	Pollu-tion Index
Asia	120	4.0	45	50
Europe	70	1.8	35	55
America	90	2.3	25	60
Africa	30	2.0	10	70

In regions with lower investment levels, such as parts of Africa and Latin America, the benefits are less pronounced due to limited technological capabilities, unstable conditions, and insufficient financing. This underlines the importance of tailored regional strategies.

4.4 Limitations

Several limitations were identified. Investments may not yield expected outcomes where infrastructure is weak, regulatory incentives are absent, or technological maturity is insufficient.

In underdeveloped regions, substantial investments may have limited effects on economic growth and environmental sustainability (see Fig. 13), highlighting the need for comprehensive strategies that include infrastructure development, workforce training, and government support.

Social and economic risks, such as potential energy price increases and emerging energy inequalities, also exist. Additionally, the econometric models employed may face constraints like multicollinearity, residual autocorrelation, and other statistical challenges.

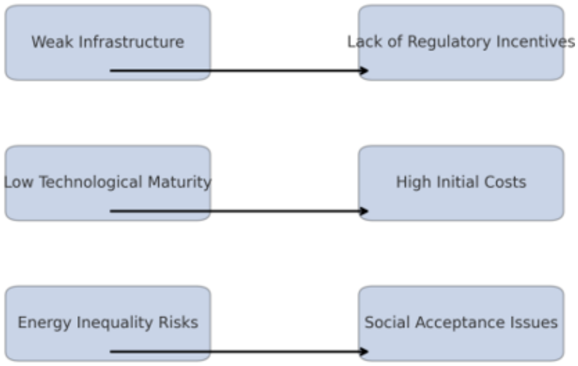

Figure 13: Constraints and barriers to the implementation of green technologies (schematic).

4.5 Policy and Institutional Factors

Government support and regulatory frameworks are critical to investment effectiveness. Favorable legal environments correlate with higher investment efficiency and faster growth in the share of renewables (see Fig. 14).

State programs, subsidies, and tax incentives play a significant role in accelerating the adoption of renewable energy technologies.

Figure 14: Relationship between levels of government support and renewable energy implementation (2022).

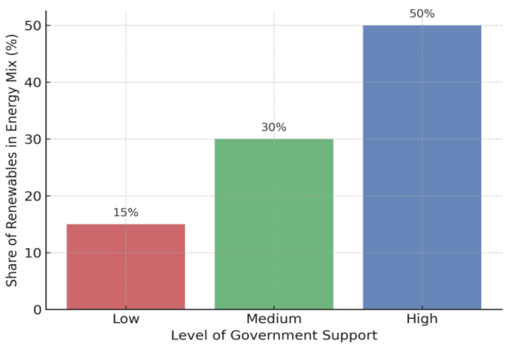

Figure 14: Relationship between levels of government support and the implementation of renewable energy (2022).

5 CONCLUSIONS

The study confirms a positive relationship between renewable energy investments and economic growth globally. Increased financial support for green energy contributes both to environmental sustainability and measurable economic benefits.

Higher investment levels are linked to steady GDP growth and reduced greenhouse gas emissions, demonstrating a mutually reinforcing effect where economic development and environmental improvement occur simultaneously.

Significant regional differences are evident. Advanced technological infrastructure, strong institutions, and active government support enhance outcomes, while limited investment capacity and weaker infrastructure reduce efficiency.

Effectiveness depends on regulatory conditions, technological readiness, and financial availability. Econometric analyses may also face standard statistical limitations.

Overall, the transition to green energy is a key driver of sustainable development, combining economic growth with environmental protection. Continued investment, policy support, and international collaboration are essential for an effective energy transition.

6 FURTHER RESEARCH

Limitations include:

- Limited data availability for some countries
- Potential distortions between investment volumes and economic effects
- Regression models may not capture nonlinear and complex interactions

Future research directions:

- Develop multidimensional models incorporating social, economic, and technological factors
- Analyze long-term prospects of renewable energy transition
- Study the impact of innovative technologies on synergetic processes
- Explore international cooperation and global initiatives

The study highlights the importance of green energy investments for sustainable economic growth and environmental security. Regional differences and limitations require tailored strategies, active policy support, and international collaboration to ensure large-scale adoption of green technologies.

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