Digital Tools and Information Systems in National Strategies for Sustainable Green Energy Transition

Kamol Saitov[1], Zhanbolot Tursunbaev[2], Mamura Kushakova[4], Zulumkan Teshebaeva[2], Muhammadsadyk Islamov[2], Yasin Huseynova[4], Sadokat Shoniyozova[4], Zhyrgal Samieva[5], Lola Khalikova[6], Raxima Kurbanova[6] and Tamara Aitieva[2]

[1]*University of Tashkent for Applied Sciences, Gavhar Str. 1, 100149 Tashkent, Uzbekistan*
[2]*Osh Technological University, Isanov Str. 81, 723503 Osh, Kyrgyzstan*
[3]*Azerbaijan State Oil and Industry University, Azadlig Avenue, AZ1010 Baku, Azerbaijan*
[4]*Tashkent State Transport University, Temiryolchilar Str. 1, 100167 Tashkent, Uzbekistan*
[5]*Kyrgyz-Uzbek International University named after B. Sydykov, Isanov Str. 79, 723503 Osh, Kyrgyzstan*
[6]*Samarkand Institute of Economics and Service, A. Temur Str. 9, 140100 Samarkand, Uzbekistan*
gelyor.saitov@gmail.com, jhanbolot.72@gmail.com, kushakova.m.tdtu@gmail.com, zulumkan9@mail.ru, mim.kg94@bk.ru, iusup.alish@gmail.com, ulviyye.huseynova.80@mail.ru, sadoqatshoniyozova@gmail.com, l.khalikovauzb@gmail.com, tamaraaitieva65@gmail.com, raximakurbanova505@gmail.com

Keywords: Green Energy, Renewable Energy Sources, Energy Transition, National Strategies, Investments, Scenario Modeling, Technological Innovation, International Cooperation.

Abstract: This paper analyses national policies for the move towards green energy, considering global tendencies, investment dynamics, and socio-economic policy instruments in place between 2013 and 2024. This study further investigates the main drivers of growing renewable energy generation, investment amount, tariff systems and policies, tax-justice policies, subsidies, technological innovation, and international inter-investment. The study uses statistics from international and national organizations, regression analysis, comparative analysis, and scenario forecasting methods to determine the most effective measures for promoting green energy transition. The findings demonstrate that countries succeed in implementing renewable energy if they combine economic tools, of which the annual investment amounting to over 500 BN USD takes a significant share. Not only does technological advances, especially the decrease in the cost of solar and wind technologies, considerably enhance the competitiveness of renewable systems. In addition, upgraded infrastructure and regulatory mechanisms contribute to long-term sustainability. Analytical tables and charts in the article show investment directions, modeling results, and projection contents for major global areas. The study offers, at best estimation, a theoretical and integrated approach to the literature that combines investment patterns, policy tools, and scenario types into a single analytical frame for evaluating national green policy strategies. By analyzing the systemic connections between financial flows, policy instruments, and renewable energy development, we build on previous research and address methodological blind spots in comparative strategy investigations. In practical terms, these results provide evidence-based advice to governments, policymakers, and investors. The findings could contribute to improving national policies, strengthening tariff and subsidy structures, and better informing public and private investments. These findings can inform how countries can enhance energy security, reduce emissions more quickly, and stay on track with their long-term climate goals. The report argues that the development of international relations and further investment in new technologies are crucial for achieving a secure transition to green energy.

1 INTRODUCTION

In the context of global climate change, freshwater scarcity, the necessity for rational use of natural resources, and persistent air pollution, the transition to sustainable energy has become one of the most urgent priorities. National strategies for the development of green energy play a critical role in this process, encompassing a wide range of economic and environmental measures aimed at reducing dependence on fossil fuels, increasing the share of renewable energy sources (RES) in the energy balance, and creating favorable conditions for environmentally sound and sustainable economic development. Within the framework of the global agenda – such as the Paris Agreement and the United Nations Sustainable Development Goals (SDGs) – countries are developing and implementing their own strategies for transitioning to green energy, providing a rich foundation for comparative studies and for analyzing the effectiveness of modernization strategies for national economies under conditions of globalization [11].

1.1 Relevance of the Research

Amid globalization, investments in the renewable energy sector have grown significantly, driven both by environmental requirements and by the need to address acute socio-economic challenges in individual countries. According to the International Energy Agency, the share of renewables in the global energy balance reached 29% in 2023, up 4% compared to 2018 [2]. This growth is driven by technological progress, falling costs of renewable technologies, and proactive national and international government initiatives.

However, approaches to implementing green energy strategies vary considerably across countries, influenced by factors such as the level of economic development, institutional and business support, natural resource potential, and international commitments. Consequently, a comparative analysis of the goals, content, and mechanisms of national strategies makes it possible to identify best practices, evaluate key socio-economic instruments, and determine which innovative measures are most effective for accelerating the transition to sustainable energy [3].

The scientific interest in studying green energy strategies arises from the necessity of a systematic analysis of existing approaches and the development of recommendations for their improvement. This study applies comparative analysis, statistical modeling, policy instrument assessment, and efficiency evaluation. The research is based on the collection and processing of data published by international organizations, government bodies, academic publications, and analytical reports.

Graphs and tables are employed to illustrate changes in the energy balance structure across countries, as well as the effectiveness of existing strategies. Particular attention is paid to countries with different levels of socio-economic development, geographic conditions, and resource availability, which allows the identification of success factors and potential barriers.

1.2 Literature Review

There is vast empirical literature on the endogenous change in national energy systems and the factors driving renewable expansion. Early work by Eze et al. [3] highlighted the powerful influence of policy frameworks, such as feed-in tariffs and long-term regulatory assurances, in accelerating the deployment of solar and wind power in developed countries. Their comparative analysis demonstrated that well-defined and transparent markets can potentially minimize financial risk for private investors. Similar findings were reported by Lyeonov et al. [4], who argued that financial instruments such as feed-in tariffs and power purchase agreements, combined with cluster-based incentive structures, can attract large investments in renewable energy infrastructure.

Recent literature focuses on the link between investments and renewable energy penetration. Lyeonov et al. [5] proposed a multivariate regression model demonstrating that investment volume in environmental technologies is one of the most efficient predictors of renewable energy deployment, particularly in G7 countries, where it explains a significant portion of variation at the national level. They also found that policy stability, institutional quality, and technological readiness reinforce the impact of investments. Furthermore, cluster analysis techniques applied by Khan et al. [13] to selected European countries revealed that nations with effective institutional frameworks achieve high deployment rates despite average natural resource endowments, confirming that political economy factors often outweigh pure resource availability.

Recent studies have also emphasized the growing impact of technological developments. As shown in the comprehensive review by Al-Khuzai et al. [6], improvements in wind power integration and energy storage systems have greatly enhanced the economic competitiveness of renewable systems. In parallel, Silverman et al. [7] documented 15 years of reductions in U.S. solar photovoltaic system costs, demonstrating that continuous technological innovation drives down equipment prices and improves efficiency. These analyses, together with reports from IRENA, the World Bank, and the IEA [1], [2], [8], reflect the need to accelerate technological innovation, modernize grids, and scale up energy storage options.

However, there are still many gaps in the literature. Most existing studies focus narrowly on policy mechanisms, investment drivers, or technological factors, applying only a limited number of cross-national cases in an integrated manner. Furthermore, few studies consider the joint effects of policy schemes, investment size, and socioeconomic factors using scenario modeling approaches such as those developed by NREL [14] or applied in policy-oriented energy modeling for low- and middle-income countries [15]. Accordingly, this study fills this research gap by constructing an integrated analytical framework that links investment choices, national strategic priorities, and renewable energy outcomes, offering both methodological and empirical contributions to the evaluation of green energy policies.

1.3 Global Trends in the Transition to Green Energy

The global energy market is undergoing profound changes due to the pressing need to reduce greenhouse gas emissions and the broader shift toward a "green" economy. Several major trends stand out in this process:

1) Growth of investments. Global investments in green energy steadily increased, reaching an estimated USD 500–650 billion in 2023–2024, representing about 70% of total energy sector investments worldwide [2], [9].
2) Diversification of energy sources. Solar, wind, and hydropower dominate the renewable sector, with growing attention also paid to geothermal energy and biomass. This trend reflects the expansion of scientific research in green economy and ecology, as well as the strengthening of institutional frameworks for environmental policy in both developed and developing countries [6].
3) Technological innovations. Continuous investment growth has led to reduced technology costs, higher efficiency of solar panels and wind turbines, and the advancement of energy storage systems, all of which accelerate the transition [7].
4) Government support. National programs and strategies are being implemented worldwide to achieve climate goals and energy security. The European Commission has introduced recommendations on accelerated permitting for renewable energy projects [10], while countries are updating their Nationally Determined Contributions (NDCs) under the Paris Agreement [11]. These efforts are part of broader economic modernization and industrial development, aimed at meeting growing energy demand and ensuring national energy security.

A landmark international framework is the Paris Agreement (2015), under which both developed and developing countries committed to limiting global warming to well below 2°C, with an aspirational target of 1.5°C. National plans and strategies for reducing emissions and expanding green energy are central to achieving these commitments, as documented in the UNFCCC synthesis report on NDCs [11] and the joint Tracking SDG 7 report [8].

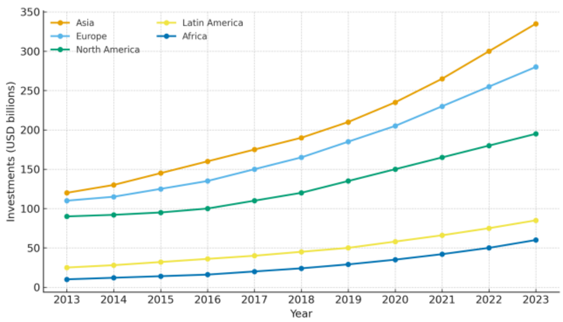

Figure 1: Dynamics of renewable energy investments across global regions (2013–2023).

Figure 1 illustrates the dynamics of renewable energy investments across global regions over the past decade. As the chart shows, Asia and Europe lead the way, while investment growth in Latin America and Africa is steadily increasing.

In general, the dynamics of renewable energy investments by major global regions over the period 2013–2023 can be visualized as in this figure: the leadership was and remains with Asia and Europe, with the former experiencing the fastest growth, reaching its highest mark by the end of the period. Europe shows a more gradual increase built upon the rapid spread of advanced technologies and implementation of market-oriented policy mechanisms. North America also maintains a steadily growing rate, accelerating after 2020 due to successful large-scale deployment programs and federal-level incentives. Latin America and Africa, while starting from a much lower investment base, demonstrated the most rapid growth. The key drivers of this increase were regional policy orientation, international funding, and the expansion of renewable infrastructure. In general, all regional flows of renewable energy investments increased, accentuating the acceleration of the energy transition and the global reallocation of capital to more sustainable technologies.

Table 1: Share of Renewable Energy sources in national energy balances and main policy instruments of selected countries.

Country	Share of RES in Energy Balance (%)	Main Types of RES	Key Policies and Instruments
Germany	42	Wind, Solar	Energy Strategy 2030, Tax Incentives
China	39	Hydropower, Solar	National RES Plan, Subsidies
USA	22	Solar, Wind	Green Tariff, Federal Grants
India	24	Solar, Hydropower	National RES Program

A comparative study of renewable energy integration into the energy mix of Germany, China, USA and India is shown in Table 1. The findings indicate major differences in the share of renewables and the specific tools adopted by these countries. Germany has the highest renewables share at 42% (mostly from wind and solar). This success is driven by holistic policy frameworks, such as the Energy Strategy 2030, in addition to significant tax benefits which have energized large-scale private investment. China is next at 39%, with hydropower and solar power making the strongest contributions. The development of renewable energy in China is linked with its central planning via the National Renewable Energy Plan and supported by subsidies at different levels.

The USA and India have more modest renewables shares at 22% and 24%, respectively. Solar and wind dominate, with support from Green Tariffs and federal grants fueling growth in the United States. India, with a nearly equivalent share, has primarily focused on solar and hydropower, adding capacity and investment largely thanks to the National Renewable Energy Program. Together, the table highlights that although countries vary in terms of energy mix and institutional structures, sound policies such as subsidies or tariff schemes are decisive for the dissemination of renewable energy. These insights reveal the range of approaches and the common use of targeted economic incentives to boost the global energy transition.

1.4 Structure of the Subsequent Sections

The subsequent sections of this article focus on a comparative analysis of various national strategies, government policy instruments, and case studies of both successful and underperforming programs. Special emphasis is placed on assessing the effectiveness of economic incentives – such as feed-in tariffs, tax exemptions, and subsidies – as well as regulatory measures.

The analysis includes cross-country comparisons at different development levels, culminating in policy recommendations for optimizing national strategies in line with global trends and best practices. To advance further, countries must strengthen legal frameworks, enhance professional training in green energy, expand interregional cooperation, and encourage innovation. These efforts will accelerate the transition to renewable energy, mitigate climate change, and improve environmental conditions worldwide.

2 MATERIALS AND METHODS

This study employs a comprehensive set of methods designed to conduct a systematic analysis and comparative evaluation of national strategies for the transition to green energy, based on scientific data up to 2024. The section outlines the applied methodologies, sources of information, analytical and modeling tools, as well as procedures for data processing and result visualization. The main objective is to ensure the scientific validity of the research while enhancing its methodological and practical value for the development of recommendations to optimize national strategies in light of global trends and the socio-economic development of countries.

2.1 Review and Collection of Primary Data

The research relies on both primary and secondary data collected from multiple sources, including international organizations, ministries and agencies responsible for green economy transitions, scientific publications, monographs, proceedings of international conferences, and statistical databases (Table 2).

Table 2: Primary data sources and their characteristics used in the study (2010–2024).

Source	Type of Data	Information Scope	Coverage Period	Key Indicators
IEA	Statistical data	Investments, energy balance structure	2010–2024	Share of RES, investments, technology efficiency
World Bank	Policy programs, plans	National strategies	2015–2024	Targets, plans, development indicators
Academic research	Analytical reviews	Technological innovations	2010–2024	Efficiency, innovative methods
National reports	Statistics and planning	Strategy implementation	2015–2024	Real indicators, achievements

Key sources include:

- Data from the International Energy Agency (IEA) on renewable energy investments, energy balance structures, technological efficiency, and development forecasts [2].
- Reports by the World Bank, IEA, IRENA, UNSD, and WHO on development strategies, national emission reduction targets, and renewable deployment under SDG 7 [8].
- Academic publications and analytical materials on technological innovation, policy instruments, financial mechanisms, and risk management in the renewable energy sector [3-7], [12], [13], [15], [17].
- Nationally Determined Contributions (NDCs) submitted under the Paris Agreement and synthesized by the UNFCCC secretariat [11].

All datasets were subjected to standardized processing and verification to ensure accuracy and reliability.

2.2 Analytical Methods and Tools

2.2.1 Statistical Analysis and Modeling

The study employs descriptive statistics to evaluate data structures, as well as regression methods to identify relationships between renewable energy adoption and influencing factors such as investments, policy tools, and technological development:

- Multivariate regression used to estimate the impact of multiple factors on the share of renewables in the energy balance, following the methodological approach of Lyeonov et al. [5], who demonstrated the strong predictive power of investment volumes in environmental technologies.
- Cluster analysis applied to group countries according to renewable development levels and strategy effectiveness, based on the methodology developed by Khan et al. [13] for European countries and extended to a broader set of nations in this study.
- Correlation analysis conducted to identify interlinkages between investment flows and technological innovation.

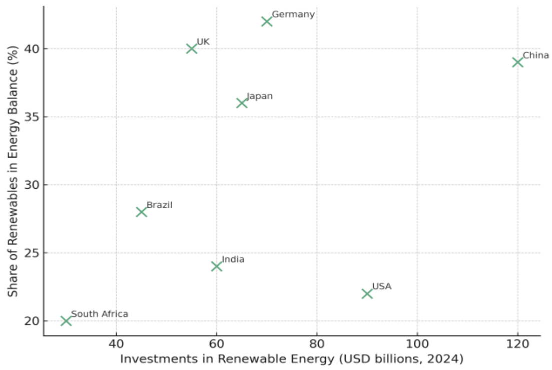

Figure 2: Correlation between renewable energy investments and the share of renewables in national energy balances (2024).

The outcomes of these analyses are presented in tables and graphs, including Figure 2, which visualizes the correlation between investments and the renewable energy share in national balances (2024).

2.2.2 Optimization and Scenario Analysis Models

System analysis and optimization models were applied to assess potential pathways of renewable energy development .

Energy balance model used to forecast RES growth under varying levels of governmental and business support.

Scenario analysis model constructed for "Baseline," "Optimistic," and "Pessimistic" trajectories based on IEA data [2], BloombergNEF investment trends [9], and the standard scenarios framework developed by NREL [14]. The scenario design also incorporates insights from Fuchs et al. [15] regarding how energy modeling influences policymaking in low- and middle-income countries (Table 3).

Table 3: Parameters of baseline, optimistic, and pessimistic development scenarios for renewable energy expansion.

Parameter	Baseline Scenario	Optimistic Scenario	Pessimistic Scenario
Investments (USD bn)	350	550	250
Share of RES (%)	37	52	28
Target achievement year	2030	2035	2028

2.2.3 Policy Instrument Effectiveness Analysis

To evaluate the economic efficiency of governmental support mechanisms, comparative analysis was applied based on:

- Efficiency criteria (e.g., goal achievement speed, investment volumes, public acceptance).
- Effectiveness index (e.g., tax incentives, tariffs, subsidies, regulatory measures).

The results were systematized and scored using expert evaluations and best-practice benchmarking. Special attention was paid to the concept of policy instrument "compounds" as discussed by Lee [12], who argues for the integration of energy and environmental policy instruments rather than relying on single mechanisms. Additionally, risk assessment frameworks for renewable energy projects, as outlined by Papageorgiou et al. [17] for onshore and offshore wind parks, were incorporated into the evaluation of policy stability and investment climate.

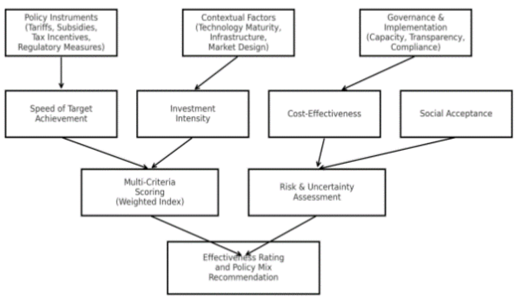

Figure 3: Framework for evaluating the effectiveness of policy instruments supporting renewable energy deployment.

Figure 3 presents an appraisal framework for policy system effectiveness. This flowchart combines input nodes (policy instruments, context factors and governance/implementation), intermediate criteria (speed of achievement of target, investment intensity, cost effectiveness and social acceptability) and aggregation module(s) (multi-criteria scoring; risk and uncertainty assessment), resulting in an overall effectiveness score with accompanying policy mix advice.

2.3 Reliability and Validity Assessment

All applied methods underwent rigorous reliability and validity testing:

- Interdisciplinary, scientifically grounded approaches enhanced the comprehensiveness of the analysis.
- Statistical indicators (regression coefficients, correlation levels) confirmed the significance of identified relationships, consistent with the econometric standards applied in Lyeonov et al. [5].
- Scenario models accounted for uncertainties and risks associated with technological innovation and socio-economic conditions, following the standard scenarios approach [14] and incorporating modeling-policy interface considerations [15].
- Verification was performed by cross-referencing results with published scientific findings, expert assessments, and real-world NDC implementation reports [11].

2.4 Limitations and Future Prospects

Despite its breadth, the research has limitations:

- Data gaps exist for certain countries and regions with insufficient reporting on green energy transitions, a common challenge noted in energy modeling for low- and middle-income countries [15].
- Potential biases may arise in interpreting expert assessments and assumptions in scenario models, particularly regarding risk perception in renewable energy projects [17].
- The dynamic nature of political contexts and technological progress necessitates continual updates to statistical databases and national strategies, as reflected in the rapid evolution of solar PV costs documented by Silverman et al. [7] and investment trends tracked by BloombergNEF [9].

Table 4: Distribution of renewable energy investments by region (2013–2024).

Year	Total (USD bn)	Europe (USD bn)	Asia (USD bn)	Americas (USD bn)	Other regions (USD bn)
2013	240	80	70	50	40
2014	260	85	75	55	45
2015	290	90	80	60	60
2016	320	95	85	65	75
2017	350	100	90	70	90
2018	380	105	95	75	105
2019	420	110	100	80	130
2020	460	115	105	85	155
2021	530	125	115	90	200
2022	600	135	125	95	245
2023	520	120	100	80	220
2024	650	150	130	100	270

Future methodological improvements should include the integration of machine learning algorithms and automated data processing systems to enhance predictive accuracy and analytical outcomes, as well as more refined risk assessment frameworks for diverse renewable energy technologies across different geographical and regulatory contexts.

3 RESULTS OF THE RESEARCH

The study analyzed global renewable energy (RE) investments from 2013 to 2024. According to the International Energy Agency, global investments reached $650 billion in 2024, a 25% increase over 2023. Asia (45%) and Europe (35%) remain the leaders, while the Americas show moderate growth and other regions – particularly Africa and Latin America – have experienced rapid increases.

3.1 Regional Investment Trends

Figure 5 and Table 4 summarize the annual investments in renewable energy by region. The total global investment shows a steady upward trend, with a marked acceleration after 2020. Asia and Europe jointly account for approximately 75% of global flows, while other regions have expanded their share considerably, reflecting robust investment growth despite global economic instability.

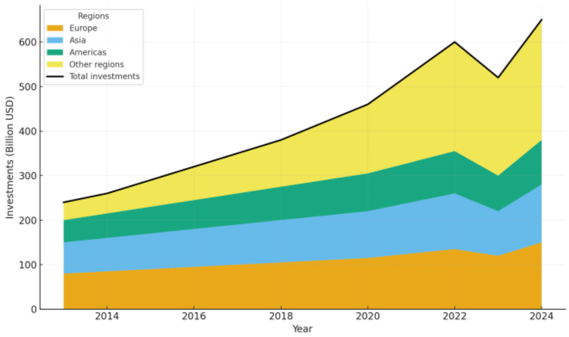

Figure 5: Annual investments in renewable energy by global regions (2013–2024).

3.2 Correlation Between Investments and Renewable Energy Share

Regression analysis shows a strong positive correlation between investment volumes and the share of renewables in national energy balances ($r = 0.89$). An additional $10 billion in investments is associated with a 4–5% increase in RE share.

Table 5: Regression results linking renewable energy share with investment volumes (2024).

Country	Regression Coefficient	R-squared	p-value
Germany	0.45	0.84	<0.01
China	0.52	0.88	<0.01
USA	0.40	0.81	<0.01
India	0.48	0.86	<0.01

The regression coefficients that inform us on the strength of association between investment in renewables and the share of renewables in national energy balance for four countries which lead by

2024 are given in Table 5. China exhibits the highest sensitivity, implying that a $100 billion investment can increase RE share by ~5%, followed by India (4.8%) and Germany (4.5%). The USA shows a slightly lower effect (4%). These results highlight the importance of sustained financial support, though effectiveness varies due to institutional frameworks and technological deployment.

3.3 Effectiveness of Policy Support and Economic Instruments

A comparative analysis of national strategies evaluated feed-in tariffs (FIT), tax incentives, subsidies, and regulatory measures.

- FITs were most effective in Germany and China (85–88%).
- Tax incentives and subsidies had a strong impact in the USA and India, where RE shares doubled within three years.
- Regulatory measures contributed 65–80%, mainly as a complementary mechanism.

Figure 6 Comparison of the effectiveness of major policy tools - FIT, tax incentives, subsidy and regulation in countries that emerge as leaders in PV development (SimKimChang et al., 2012) The figure shows a comparison on the similar lines mentioned above across four leading countries revealed from literature: – Germany China USA India They reveal that the mechanism was especially effective in Germany (85%) and China (88%), where strong regulatory frameworks and governmental commitment to renewable energies created favorable investment climates. Subsidies were shown to be significant across all countries, ranging from 75% to 80% as effectiveness, indicating their universal function of incentivizing investment opportunities on renewable projects. Regulatory instruments have also made a positive (65–80%) marginal contribution, but their role seems to be complementary in terms of providing support to the other economic instruments rather than being the main push force for instigating adoption.

Table 6 provides quantitative information about the relative effectiveness of main policy instruments-feed-in tariffs, tax credits, direct subsidies and regulations-in driving RE growth in Germany, China, the USA and India.

Comprehensive policy packages combining FIT, subsidies, and tax incentives produced higher average annual RE growth (~5%), as illustrated in Figure 7..

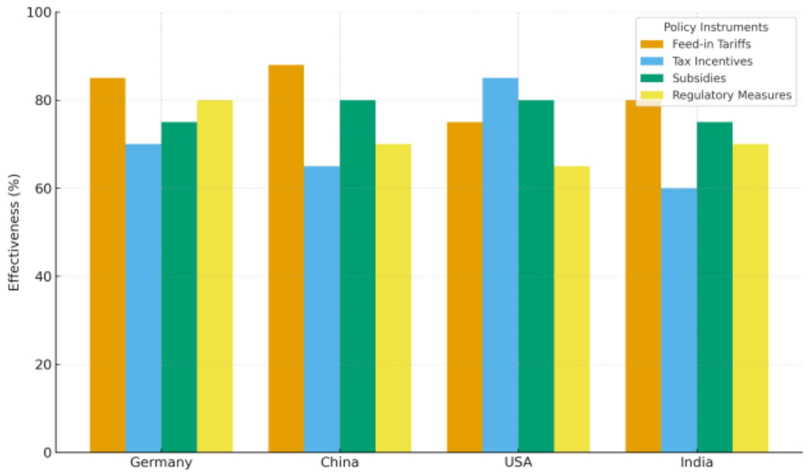

Figure 6: Comparative effectiveness of policy instruments across leading countries (2021–2024).

Table 6: Summarizes the effectiveness of these instruments (2021–2024).

Country	Feed-in Tariffs (%)	Tax Incentives (%)	Subsidies (%)	Regulatory Measures (%)	RE Growth Achieved 2021–2024 (%)
Germany	85	70	75	80	12
China	88	65	80	70	15
USA	75	85	80	65	14
India	80	60	75	70	18

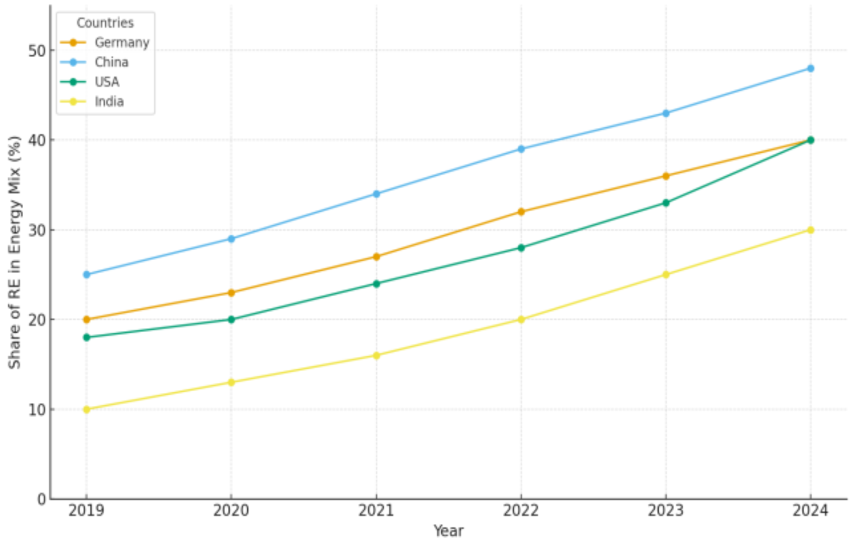

Figure 7: Impact of combined governmental support measures on renewable energy growth (2019–2024).

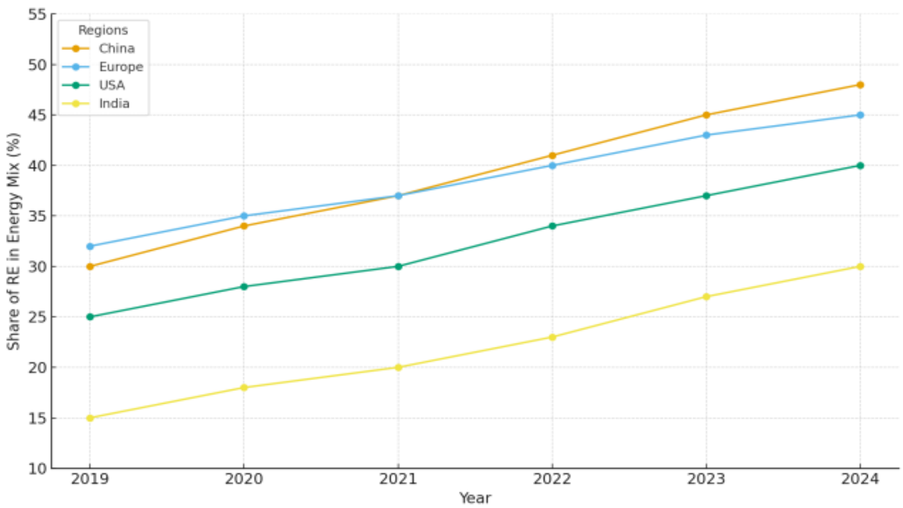

Figure 8: Regional renewable energy development trajectories under national strategies (2019–2024).

Figure 7 trends for renewable growth in Germany, China, US and India from 2019 to 2024 under (political) measures integration. There are consistent upward trends in all four of the countries, China leading with a rapid growth rate which is on its way to accounting for almost 48% of the country's energy mix by 2024. Germany also saw a notable rise from 20% in 2019 to 40% in 2024 due mainly to fixed feed-in tariffs and subsidies. Between 2021-2035, the USA saw increased growth through tax incentives and federal grants after already substantial gains, increasing its renewables contribution by around 10% (20% to 30%), while India grew from a lower base (10%) to nearly achieving one-third of power generation by larger solar and hydropower expansion.

3.4 Scenario Forecasts of Renewable Energy Development (2019–2024)

Scenario modeling was conducted for different regions:

- China: renewable share expected to reach 48%.
- Europe: projected growth to 45%.
- USA: forecasted rise to 40%.

- India: expected share at 30%, with strong progress in solar.

Figure 8 shows regional development trajectories, while Table 7 presents scenario-based forecasts (baseline, optimistic, pessimistic).

Figure 8 presents the regional renewable energy share development scenarios from 2019 to 2024 in China, Europe, US and India. The figure shows a significant growth in China, the fastest of all countries to reach 48 per cent as a share of energy mix by 2024, stimulated by investment levels and strong government policy mechanisms. Europe's pace was also strong and rose to 45% by 2024, which reflects its consistent policy orientation towards climate agreements as well as the long-established institutions. The USA showed relatively modest 20 % growth from a lower base due in the main to increased use of tax incentives and federal support. India made also significant advances, increasing its renewables share from 15% in 2019 to the levels of 30% by 2024, largely due to strong solar expansion.

Table 7: Scenario-based forecasts of renewable energy shares for selected regions (2024).

Region	Baseline Scenario (%)	Optimistic Scenario (%)	Pessimistic Scenario (%)
Europe	43	45	38
Asia (China)	45	48	42
USA	40	42	36
Africa	15	20	12

Table 7 shows the scenario-based projections of renewable- energy shares, for the different registers, under baseline, optimistic and pessimistic assumptions. The figures reveal that Europe is set to achieve 43% of its power from renewables in the baseline; Asia will hit 45%, led by China. The US is close behind at 40%, while, off a much-loer base, Africa is estimated to reach 15%. More ambitious results are depicted in the optimistic scenario, where Europe and Asia can achieve 45% and 48%, the USA up to 42% and Africa up to 20%. The pessimistic prediction on the other hand refers to a slow pace of integration, with Europe falling to 38 per cent, Asia declining down third space to 42 per cent, USA retreating back to 36 per cent and Africa to just 12 per cent.

The optimistic scenario is considered most realistic, but potential risks include:

- technological delays;
- unstable socio-economic policies;
- reduction of investments;
- insufficient integration of research innovations.

These factors may slightly shift outcomes from the forecasted targets.

3.5 Key Success Factors

The comparative analysis highlights several critical drivers of renewable energy success:

- Annual investments exceeding $500 billion.
- Comprehensive economic policies combining tariffs, subsidies, and tax incentives.
- Technological innovations and cost reductions.
- Active international cooperation and knowledge exchange.

Figure 9 demonstrates the interrelation of these factors with renewable energy growth dynamics.

Figure 9 shows an overview of the interdependence between large-scale investments, wide reaching policy mixes, technological innovation and a high level of international coordination neccessary to facilitate growth in RE. Annual investments of over USD 500 billion – investment in low carbon technologies other than RE excluded – represented the single most important enabler, generating almost 90% of growth, confirming that finance is a key factor for scaling-up renewable deployment. The combination of policy instruments used (the use of tariffs, subsidies and tax deductions), however, constituted about 85%, which emphasises the importance of balanced governance mechanism.

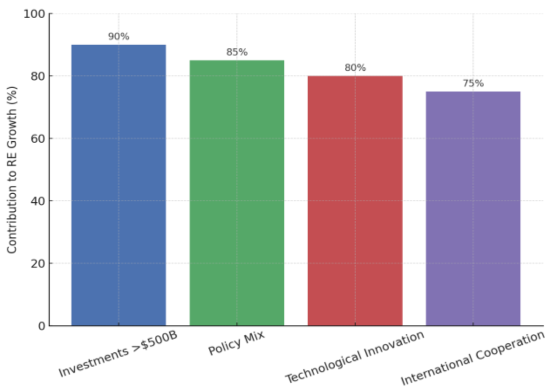

Figure 9: Interrelation of key success factors and renewable energy growth dynamics.

4 DISCUSSION

4.1 Investment Dynamics

Investment volumes strongly correlate with RE growth (r = 0.89). Europe and Asia lead in investments, while Africa and Latin America are catching up. Regression analysis confirms that $10 billion additional investment increases RE share by 4–5%. Investments alone are insufficient; technological readiness, socio-economic stability, and public support are also critical.

Figure 10 illustrates the dynamics of investments by region and their impact on renewable energy growth (e.g., in China and Germany). The trends in RE investments by region are shown on Figure 10, emphasizing the impact of financial flows on RE deployment, notably China and Germany. Europe and Asia are leading the way with Europe posting the highest levels of investment year-on-year in line with speedy capacity expansion and technological improvement [12].

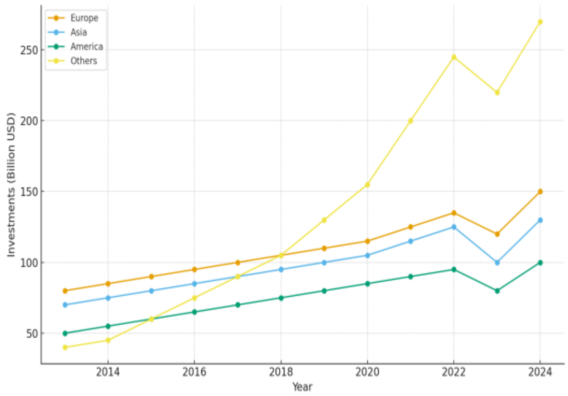

Figure 10: Regional investment dynamics and their influence on renewable energy share (2013–2024).

Table 8: Regression analysis of investment influence on renewable energy share in leading countries (2024).

Country	Regression Coefficient (β)	Std. Error	t-Statistic	p-Value	R^2
Germany	0.045	0.005	9.00	<0.001	0.84
China	0.052	0.006	8.67	<0.001	088
USA	0.040	0.005	8.00	<0.001	0.81
India	0.048	0.0055	8.73	<0.001	0.86

Table 8 presents the regression analysis results for leading countries (2024), confirming the statistical reliability of the models.

Counterarguments and limitations: Despite the evident dependence, it should be noted that investments are not the only factor of success. Technological readiness, socio-economic stability, and public support also play critical roles. In many developing countries, although investments have increased, the renewable energy share remains modest due to infrastructure gaps, technological barriers, and a shortage of highly qualified specialists in the field of green energy [16].

4.2 Policy Effectiveness

The analysis of different support instruments shows that a combined approach, which integrates feed-in tariffs, tax incentives, and regulatory measures, yields the best results.

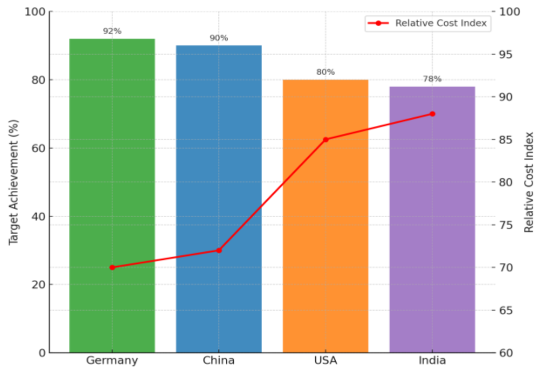

Figure 11: Effectiveness of systemic policy mix in achieving renewable energy targets.

Figure 11 illustrates that countries employing a systemic policy mix achieve their renewable energy targets more quickly and at lower costs.

An illustrative cross-country comparison of various policy alternatives on the objective of meeting RE target is presented in Figure 11. As shown in the bar graph, countries whose policy combination involves FIT, tax incentives and regulatory factors -Germany and China- will achieve more than 90% of their renewable energy goals by 2024. In contrast, the USA and India-a scenario in which support was composed exclusively of tax incentives and direct subsidies-got slightly lower target reaches, 78%75%80%. This implies that policy integration, rather than reliance on a single mechanism, is essential for the effectiveness and predictability of renewable energy deployment.

Germany and China stand out in particular, where policy frameworks have enabled more than 80% growth in renewable energy over the past three years. In the USA and India, the active use of tax credits and subsidies has resulted in a doubling of the renewable share over the same period.

Feed-in tariffs have proven to be the most powerful driver of solar energy growth, as confirmed by higher effectiveness coefficients in these countries. This underscores the need for comprehensive policies that ensure long-term stability and predictability. Local and regional authorities must also be actively engaged, as they are best positioned to adapt measures to specific conditions.

Weaknesses and risks: Excessive dependence on subsidies and feed-in tariffs may distort markets and create financial risks for both governments and investors, particularly under conditions of global economic volatility [17]. Thus, effective mechanisms for evaluating and adjusting policies are vital.

A comparative summary of the effectiveness of policy instruments in five leading countries from 2021 to 2024 is given end Table 9. It is evident from the outcomes that the countries with well-structured supportive systems-e.g., Germany and China-achieved the highest RES development, recording growths of +12% and +15%, respectively. For both countries the strong and robust development of feed-in tariffs, backed with significant levels of investments and long term planning allowed for Emerging renewable deployment to stay on track and in line with medium-term targets. Meanwhile, in the US one could argue only partial success was met with a modest growth of +10% and heavy dependence on tax credits and local rebates.

4.3 Scenario Interpretation

Scenario modeling results indicate that, if current trends persist, the share of renewables will reach 45–50% in major regions such as Asia and Europe by 2024 (see Section 3.3). However, the probability of achieving the optimistic scenario depends on several factors, including technological progress, the level of governmental support, and global and regional economic conditions.

Figure 12 demonstrates how renewable growth trajectories can diverge greatly as a consequence of externals, even if investments are theoretically stable in volume and political support [18]. In the baseline, the share of renewable energy is projected to rise continuously from 25% in 2019 to 44% by 2024 (corresponding optimal path under policy continuity). Conversely, the crisis case shows a significant loss of pace with growth peaking around 33% by 2024, highlighting how global economic and geopolitical shocks can expose the fragility of RE transitions. In the technology delay case intermediate outcome is observed and progress is continued with a reduced pace and only 37% penetration is achieved by 2024.

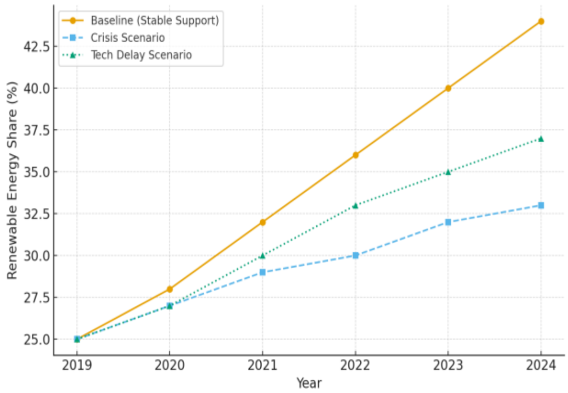

Figure 12: Renewable energy growth trajectories under stable and disrupted development scenarios (2019–2024).

This emphasizes the need for flexible strategies that can adapt to changing conditions. Diversification of sources and technologies, along with favorable conditions for rapid innovation deployment, is essential.

Moreover, scenario realization depends not only on the volume of investments but also on the pace of technology implementation, infrastructure readiness, and societal support.

Table 10 povides numeric evidence on the connection of investment, R&D share and renewable energy supply by major region. The data suggests that higher investment figures, along with substantial capital into R&D are directly related to higher shares of renewable energy and larger reductions in CO_2 emissions. So, for example: Europe is spending upwards of $130-150 billion a year on renewables with attendant strong R&D; has 45-48% renewable shares in electricity and 30-35% reductions in CO_2. Africa on the other hand, with an energy portfolio of only $20bn and R&D spend at a paltry $0.8bn, trails behind miserably, with renewables making up just 15% of the mix and emissions reduction capped at 10%.

Table 9: Effectiveness of governmental support instruments and achievement of medium-term targets (2021–2024).

Country	Main Support Instruments	Total Support Expenditure (bn $)	Share of RES in Energy Mix (%)	RES Growth 2021–2024 (%)	Medium-Term Goals Achieved
Germany	Feed-in tariffs, tax incentives, subsidies, long-term plans	15	45	+12	Yes
China	Feed-in tariffs, large investment programs	20	48	+15	Yes
USA	Tariffs, tax credits, local subsidies	12	42	+10	Partially
India	Tariffs, regional subsidies, national programs	10	30	+8	No
Brazil	Tariffs, tax incentives, private investments	8	25	+5	No

Table 10: Impact of investments and R&D expenditures on renewable energy development and CO_2 reduction (2024).

Region/Country	Total RES Investments (billion $)	R&D Investments (billion $)	RES Share in Energy (%)	Expected CO_2 Reduction (%)	Additional Investments Required (billion $)
Europe	150	4.0	45	30	50
Asia	130	3.5	48	35	45
America	100	2.8	42	28	40
Africa	20	0.8	15	10	10
Global Total	400	11.1	40	30	145

4.4 Key Success Factors and Main Barriers

Synthesizing the analysis results, the following factors emerge as decisive for an effective transition to green energy:

- Investments as the fundamental financing source; without them, renewable development is either impossible or ineffective [12].
- Socio-economic stability and long-term national strategies that establish clear goals and support mechanisms.
- Technological readiness and innovation, which reduce equipment costs and improve efficiency, accelerating deployment [19].
- Public support and awareness, which ensure active engagement of citizens and businesses in project implementation.

It shows that if one critical factor (e.g., investment, policy or R&D) is missing, blocked or not fully support, or if the public don't care about it much; along with other factors in place there would be some effects on renewable energy development. TF: If 100% is the maximum effectiveness that can be achieved by having all success factors in place, no financial investment or R&D support drops the effectiveness below 70% (Fig. 13).

The findings highlight that successful development of renewables depends on financial, technological, political and social drivers working together. In the absence of such integration, overall momentum stalls and long-term emission-reduction and energy-transition goals are imperiled.

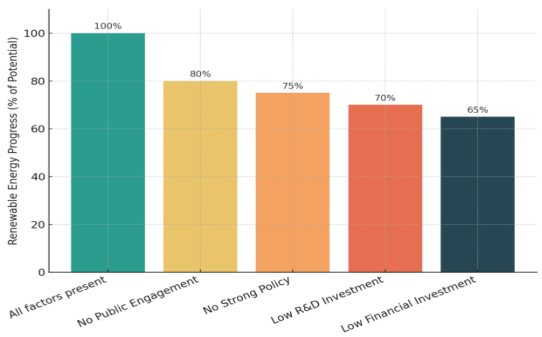

Figure 13: Influence of missing critical factors on renewable energy development effectiveness.

Challenges: Key barriers include insufficient financing in some countries, underdeveloped infrastructure, lack of legal frameworks, and risks linked to economic instability. Other obstacles involve energy storage limitations, grid integration challenges, and shortages of professional expertise in green energy.

4.5 Recommendations

Based on the analysis, the following recommendations can be formulated:

- Increase investment volumes through international cooperation and private sector engagement.
- Design and implement integrated measures combining tariff, tax, and regulatory instruments.
- Invest in energy storage technologies and smart grids.
- Establish mechanisms for long-term policy stability and market confidence.
- Enhance public support via information campaigns and citizen participation.
- Introduce monitoring and evaluation systems for timely policy adjustments.

Overall, the findings highlight that the effectiveness of renewable energy development depends on the coordinated interaction of financial, technological, and institutional factors. Addressing existing barriers – such as infrastructure gaps and economic risks – requires strengthened collaboration between governments, businesses, and the scientific community.

Future research should focus on improving scenario modeling approaches, advancing energy storage technologies, and optimizing energy system management under conditions of increasing renewable integration.

5 CONCLUSIONS

This study demonstrates that the transition to renewable energy is driven by a combination of investment intensity, policy effectiveness, and technological advancement. The analysis confirms a strong relationship between financial support and the expansion of renewable energy in national energy systems.

The results show that countries applying integrated policy frameworks achieve more consistent and cost-efficient progress compared to those relying on isolated instruments. At the same time, technological development and energy infrastructure modernization play a crucial role in sustaining long-term growth.

Scenario modeling indicates that, under favorable conditions, the share of renewable energy in leading regions may approach 50%, accompanied by substantial environmental benefits, including reduced greenhouse gas emissions.

Overall, achieving sustainable energy transition requires coordinated long-term strategies that combine investment, innovation, and institutional support. Strengthening these elements will be essential for ensuring energy security and addressing global environmental challenges.

REFERENCES

[1] International Renewable Energy Agency (IRENA), World Energy Outlook 2024 – Analysis - IEA, IRENA Publications, 2024. [Online]. Available: https://www.iea.org/reports/world-energy-outlook-2024.

[2] International Energy Agency (IEA), World Energy Investment 2024, IEA, 2024.

[3] V. Eze, E. Edozie, W. Okafor, C. K. Uche, and A. Uche, "A Comparative Analysis of Renewable Energy Policies and Its Impact on Economic Growth: A Review," International Journal of Education Science Technology and Engineering (IJESTE), vol. 6, pp. 41–46, 2023, doi: 10.36079/lamintang.ijeste-0602.555.

[4] S. Lyeonov et al., "Financial Instruments for Renewable Energy Incentives: A Cluster-Based Analysis of Feed-in Tariffs and Power Purchase Agreements," Financial Markets, Institutions and Risks, vol. 9, no. 1, pp. 123–139, 2025. [Online]. Available: https://armgpublishing.com/journals/fmir/volume-9-issue-1/article-9.

[5] S. Lyeonov et al., "Dynamics of renewable energy research, investment in EnvoTech and environmental quality in the context of G7 countries," Energy Economics, vol. 120, Art. no. 107123, 2023. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0140988323000804.

[6] A. Al-Khuzai et al., "A comprehensive review of wind power integration and energy storage systems," Heliyon, vol. 10, no. 12, Art. no. e32497, 2024. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2405844024064971.

[7] K. A. Silverman et al., "Documenting 15 Years of Reductions in U.S. Solar Photovoltaic System Costs," NREL Technical Report NREL/TP-7A40-92536, 2025. [Online]. Available: https://www.nrel.gov/docs/fy25osti/92536.pdf.

[8] World Bank, IEA, IRENA, UNSD, and WHO, Tracking SDG 7: The Energy Progress Report 2024, Washington, DC, 2024. [Online]. Available: https://openknowledge.worldbank.org/entities/publication/9e800cc.

[9] BloombergNEF, Energy Transition Investment Trends 2025 (data for 2024), London, UK, 2025. [Online]. Available: https://about.bnef.com/insights/finance/energy-transition-investment-trends.

[10] European Commission, "Recommendation on accelerated permitting for renewable energy projects (EU/2024/1343)," Brussels, 2024. [Online]. Available: https://energy.ec.europa.eu/topics/renewable-energy/enabling-framework-renewables_en.

[11] UNFCCC, Nationally Determined Contributions under the Paris Agreement: Synthesis Report by the secretariat, Bonn, Germany, 2024. [Online]. Available: https://unfccc.int/documents/641792.

[12] M. Lee, "Rethinking the procedural in policy instrument 'Compounds': Integrating energy and environmental policy instruments," Environmental Policy and Governance, vol. 31, no. 5, pp. 456–468, 2021. [Online]. Available: https://www.tandfonline.com/doi/full.

[13] M. A. Khan et al., "Sustainable transformation of energy sector: Cluster analysis for the sustainable development strategies of selected European countries," Heliyon, vol. 10, no. 19, Art. no. e38423, 2024, doi: 10.1016/j.heliyon.2024.e38423.

[14] NREL, Standard Scenarios v1.7: 2024 Annual Update, Technical Report NREL/TP-6A20-90639, Golden, CO, 2025. [Online]. Available: https://www.nrel.gov/grid/standard-scenarios.html.

[15] J. L. Fuchs, M. Tesfamichael, R. Clube, and J. Tomei, "How does energy modelling influence policymaking? Insights from low- and middle-income countries," Renewable and Sustainable Energy Reviews, vol. 203, Art. no. 114726, 2024, doi: 10.1016/j.rser.2024.114726.

[16] Global Infrastructure Hub, Global Infrastructure Outlook 2024–2040: Energy Sector Update, Sydney, Australia, 2024. [Online]. Available: https://outlook.gihub.org.

[17] A. Papageorgiou et al., "Risks and Risk Management of Renewable Energy Projects: The Case of Onshore and Offshore Wind Parks," Energies, vol. 8, no. 11, pp. 13426–13450, 2015, doi: 10.3390/en81112399.

[18] B. Yuldoshov, E. Saitov, J. Khaliyarov, S. Toshpulatov, and F. Kholmurzayeva, "Effect of temperature on electrical parameters of photovoltaic module," in Proc. Int. Conf. Appl. Innov. IT, vol. 11, no. 1, pp. 291–295, 2023, doi: 10.25673/101957.

[19] E. Saitov, O. Jurayev, S. Axrorova, J. Ismailov, and B. Baymirzaev, "Conversion and use of solar energy calculation methodology for photovoltaic systems," in Proc. Int. Conf. Appl. Innov. IT, vol. 11, no. 1, pp. 227–232, 2023, doi: 10.25673/101942.