

Economic Efficiency and Payback of Renewable Energy Projects

Elyor Saitov¹, Ortikjon Mamasaliev¹, Madina Mirzakhmudova², Urazbay Erniyozov³, Nurzhamal Aldasheva⁴, Xinlei Chen⁴, Gulnara Mamedova⁵, Ainura Khamzaeva⁴ and Dilfuza Umarova³

¹University of Tashkent for Applied Sciences, New Sergeli Road, 700012 Tashkent, Uzbekistan

²National University of Uzbekistan named after Mirzo Ulugbek, Universitet Str. 4, 100174 Tashkent, Uzbekistan

³Tashkent State Transport University, Temiryulchilar Str. 1, 100167 Tashkent, Uzbekistan

⁴Osh Technological University, Isanov Str. 81, 723503 Osh, Kyrgyzstan

⁵Azerbaijan State Oil and Industry University, Azadlig Ave., AZ1010 Baku, Azerbaijan

elyor.saitov@utas.uz, ortiqmamasaliyev@gmail.com, mirzamakhmudovamadina@gmail.com, urazboy68@gmail.com, aldashaeva73.20@mail.ru, ainura.hamzaeva@gmail.com, umarova_dilfuza_3103@mail.ru

Keywords: Renewable Energy, Investments, Economic Efficiency, Risks, Monte Carlo Simulation, NPV, IRR, Scenario Analysis, Risk Management, Environmental Sustainability.

Abstract: This paper investigates the economic efficiency and payback performance of renewable energy investment projects, with a focus on solar and wind power plants. The study aims to provide a comprehensive assessment of investment viability by integrating profitability evaluation with advanced risk analysis techniques. A unified analytical framework is proposed, combining traditional financial indicators—Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period—with modern tools such as sensitivity analysis, scenario modeling, and Monte Carlo simulation. The novelty of the research lies in the integration of probabilistic risk assessment methods and scenario-based modeling into a single framework that captures both technological development and market dynamics. The model incorporates key external factors, including energy price volatility, regulatory changes, and technological innovation, to enhance the accuracy of investment evaluation. The results demonstrate that renewable energy projects are economically viable under baseline conditions, with positive NPV, competitive IRR, and acceptable payback periods. However, project performance is highly sensitive to electricity prices, capital costs, and discount rate assumptions. Monte Carlo simulation confirms a high probability of positive returns, while scenario analysis reveals significant variability in outcomes across optimistic, baseline, and pessimistic conditions. The study emphasizes the importance of flexible investment strategies and effective risk management mechanisms, such as long-term power purchase agreements, insurance instruments, and revenue diversification. Overall, the findings confirm that renewable energy projects offer substantial economic potential when supported by robust analytical evaluation and adaptive risk management approaches, contributing to sustainable energy development.

1 INTRODUCTION

In recent decades, sustainable development and the transition to environmentally friendly energy sources have become critical global priorities. In the context of climate change, fossil fuel depletion, and the urgent need to reduce greenhouse gas emissions, renewable energy (RE) plays a key role in ensuring both environmental and economic stability [1]. Many countries are actively investing in solar, wind, hydro, and biomass energy, highlighting the growing importance of this sector for modern energy policy and economic development [2].

Despite these trends, the economic feasibility of renewable energy projects remains a major challenge. Such projects typically require significant upfront

investments and are characterized by relatively long payback periods. Therefore, comprehensive assessment methods that combine profitability and risk analysis are essential for informed decision-making by investors and policymakers [3].

Existing studies widely apply traditional financial indicators such as Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PBP). At the same time, recent research emphasizes the importance of incorporating uncertainty through scenario analysis and Monte Carlo simulation [5], [7]–[9]. However, there is still a lack of integrated frameworks that simultaneously account for financial performance, risk factors, technological change, and regulatory dynamics.

The aim of this study is to conduct a comprehensive assessment of the economic efficiency of renewable energy projects, with particular emphasis on investment risks and payback performance. To achieve this, the study develops an integrated analytical model combining classical financial evaluation methods with advanced risk modeling techniques. The proposed approach also incorporates external factors such as energy price volatility, technological innovation, and regulatory changes.

The scientific contribution of the paper lies in the development of a unified framework that integrates profitability analysis with probabilistic risk assessment. The practical significance of the research is related to its applicability in investment decision-making and the formulation of risk management strategies for renewable energy projects.

The remainder of the paper is structured as follows. Section 2 presents the methodological framework, Section 3 discusses the results, Section 4 provides a discussion, and the final section concludes the study.

2 METHODS

2.1 General Framework and Conceptual Basis

To conduct a comprehensive analysis of the investment attractiveness and associated risks of renewable energy (RE) projects, a systemic approach was developed based on the use of modern methods of economic analysis, risk modeling, and profitability evaluation [6]. The research methodology integrates both classical and innovative approaches, enabling the consideration of project-specific technological features, market conditions, and external factors.

The primary goal of these methods is to obtain objective, reproducible, and representative results that enable the comparison of projects in terms of investment appeal and the identification of effective risk mitigation strategies. In accordance with this objective, the methods applied in the study are classified into the following categories:

- Analytical methods (for economic efficiency evaluation);
- Modeling methods (for risk and scenario simulation);
- Statistical methods (for sensitivity and probability analysis);
- Expert-based methods (for qualitative assessment and validation).

2.2 Analytical Methods for Evaluating the Efficiency of Renewable Energy Projects

2.2.1 Net Present Value (NPV) Method

The most widely used indicator for evaluating investment efficiency is the Net Present Value (NPV), which reflects the difference between the present value of cash inflows and the present value of cash outflows over the project's lifecycle. It is calculated using the following formula:

$$NPV = \sum_{t=1}^n \frac{C_t}{(1+r)^t} - C_0 \quad (1)$$

Where (1):

- R_t - project revenues in year t ;
- C_t - project costs in year t ;
- r - discount rate;
- n - project duration (in years).

A positive NPV indicates that the project is economically viable and capable of generating value above its cost of capital, while a negative NPV suggests financial inefficiency or excessive risk exposure.

This method makes it possible to account for the time value of money and determine how profitable a project is, taking into consideration all future cash flows [6].

2.2.2 Internal Rate of Return (IRR)

The Internal Rate of Return (IRR) is the discount rate at which the Net Present Value (NPV) of a project equals zero. It can be expressed by the following equation:

$$0 = \sum_{t=1}^n \frac{C_t}{(1+IRR)^t} - C_0 \quad (2)$$

This indicator makes it possible to determine the project's rate of return and compare it with alternative investment opportunities. If the IRR exceeds the minimum required rate of return (for example, the benchmark rate for comparable projects or the inflation rate), the project is considered financially attractive [11].

2.2.3 Payback Period (PBP)

The Payback Period (PBP) represents the time span required for cumulative net cash inflows to offset the initial investment cost. It is defined as the minimum period (t_i) during which the sum of discounted cash flows becomes equal to or exceeds the initial outlay [3].

These indicators - NPV, IRR, and PBP - provide a preliminary evaluation of project efficiency; however, they do not take into account the influence of risk factors or alternative development scenarios, which are critical in the dynamic renewable energy market.

2.3 Risk and Uncertainty Modeling

To assess the risks associated with renewable energy investments, a combination of scenario modeling, sensitivity analysis, and statistical simulation methods, including Monte Carlo modeling, was employed. These methods make it possible to capture the probabilistic nature of uncertainties that affect the performance and financial viability of renewable energy projects.

2.3.1 Scenario Analysis

Scenario analysis involves constructing three distinct development scenarios-optimistic, baseline, and pessimistic-to estimate the range of possible project outcomes and their probabilities. Within this method, the main variables influencing project efficiency-such as electricity price, equipment cost, and discount rate-are systematically varied to analyze their impact on performance metrics like NPV and IRR [12].

This approach enables decision-makers to visualize potential risks and benefits under changing external conditions and to prepare adaptive investment strategies for each scenario.

2.3.2 Sensitivity Analysis

The sensitivity analysis method involves varying key project parameters within a predefined range and evaluating how these changes affect the project's efficiency indicators. This technique identifies the most sensitive or vulnerable variables, such as capital cost, energy price, or operational expenses, and helps determine priority areas for risk mitigation [13].

By quantifying parameter elasticity, sensitivity analysis supports the design of robust financial models and provides a deeper understanding of which factors most significantly influence the investment outcome.

2.3.3 Monte Carlo Simulation

The Monte Carlo simulation method allows the simultaneous consideration of multiple uncertainties by generating a large number of simulated scenarios based on random parameter distributions. Through

iterative computation, the model produces probabilistic estimations of key financial metrics such as NPV and IRR, enabling the determination of the likelihood of achieving specific profitability targets [14].

Figure 1 presents a schematic representation of the Monte Carlo simulation process applied for evaluating renewable energy projects. The procedure includes the following stages:

- 1) Definition of input variables and their probability distributions;
- 2) Generation of random values for each variable;
- 3) Repeated simulation of project outcomes;
- 4) Construction of output probability distributions for NPV and IRR;
- 5) Assessment of investment risk and decision-making under uncertainty.

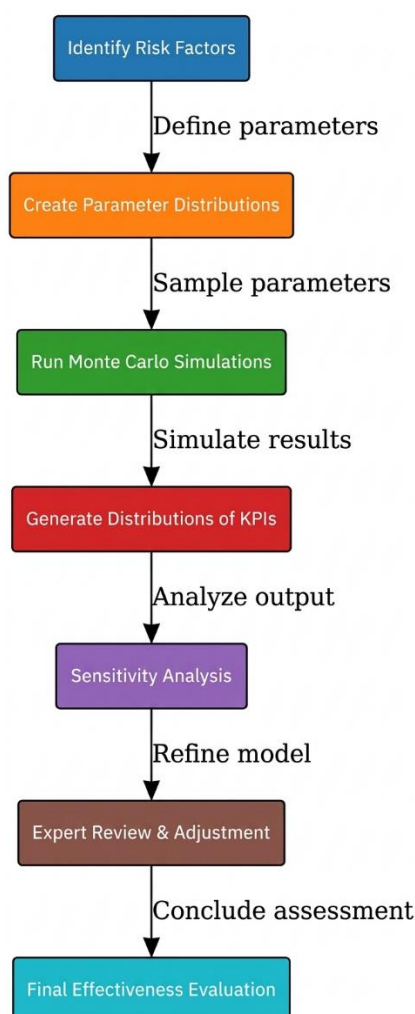


Figure 1: Monte Carlo simulation framework for assessing the efficiency of renewable energy projects.

The block diagram illustrates the structure of the Monte Carlo simulation process applied to evaluate the effectiveness of renewable energy projects. The procedure begins with the identification of risk factors and the construction of probability distributions for key parameters. Iterative computations are then performed, generating distributions of key performance indicators (KPIs) such as NPV and IRR, followed by a sensitivity analysis of the results. This stage makes it possible to determine which parameters exert the greatest influence on the simulation outcome.

The subsequent step involves expert validation and model adjustment, after which the final assessment of project efficiency is produced. Such visualization is particularly useful for representing complex analytical processes in a simplified and logically consistent form. The block diagram enhances the understanding of the simulation structure and is widely applicable in both technical reports and educational materials.

2.4 Statistical Methods for Risk Assessment

Statistical analysis in this study employs methods such as regression analysis, correlation analysis, and confidence interval estimation to evaluate the relationship between project efficiency indicators and external factors. These methods make it possible to identify the main risk drivers and quantify their influence on project outcomes.

2.4.1 Regression Analysis

Regression analysis is used to determine the relationship between project performance and influential variables such as electricity price, technological costs, and the level of government support. The analysis utilizes a multiple regression model, expressed as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_k X_k + \epsilon \quad (3)$$

Where (3):

- Y - dependent variable representing the project efficiency indicator (e.g., NPV, IRR);
- X_i - independent variables representing risk factors (e.g., energy price, investment cost, regulatory stability);
- β_i - regression coefficients;
- ϵ - random error term.

The results of the regression analysis help determine the significance of key factors and enable the prioritization of risk management measures [15].

2.4.2 Confidence Interval Estimation

This method provides an assessment of the range within which the true value of project efficiency indicators lies with a given probability level. Standard statistical techniques are used, such as the Wald method or bootstrap estimation, which allow for robust evaluation of parameter uncertainty and variability [16].

Confidence interval estimation helps quantify the statistical reliability of NPV, IRR, and other financial metrics under varying market conditions, providing a more transparent foundation for investment decision-making.

2.5 Expert-Based Risk Assessment Methods

In cases where statistical data are insufficient or unavailable, expert judgment methods are applied. These rely on structured interviews, group discussions, and the Delphi method to collect and consolidate the opinions of qualified specialists regarding different aspects of renewable energy projects.

The collected assessments are subsequently aggregated and analyzed to estimate the probability of risk occurrence and the extent of its potential impact [17]. This approach complements quantitative techniques by incorporating experiential and contextual knowledge, thereby enhancing the robustness of the overall risk evaluation framework.

2.6 Development of an Integrated Model for Investment Attractiveness Assessment

Based on the methods described above, an integrated model for assessing the efficiency and risks of renewable energy projects was developed. The model is grounded in a multifactor structure that combines indicators such as NPV, IRR, payback period, and probabilistic risk evaluations.

The model includes the following stages:

- 1) Risk factor identification - collection of data on external and internal variables affecting project performance;
- 2) Scenario modeling - development of value ranges for key project parameters;
- 3) Monte Carlo simulation - generation of probabilistic distributions for efficiency indicators;
- 4) Sensitivity analysis - identification of the most vulnerable project components;

- 5) Expert evaluation - refinement of simulation results based on expert insights;
- 6) Result synthesis - integration of findings and formulation of final indicators and recommendations.

This integrated approach ensures both quantitative precision and qualitative validation, providing a comprehensive tool for investment decision-making in the renewable energy sector.

2.7 Integration of Technical and Economic Aspects into the Analytical Framework

To improve the accuracy and realism of the assessment, the model incorporates both technical and economic parameters, reflecting the actual operational and technological state of the project [3]. Specifically, the model includes indicators such as:

- Capacity utilization factor;
- Degree of technological wear and obsolescence;
- Dynamics of component and raw material prices;
- Level of governmental and institutional support.

The inclusion of these parameters ensures that the model captures the technological maturity, economic dynamics, and policy environment, thereby enhancing the robustness of investment analysis.

2.8 Methodological Interrelation and Sequential Application

To ensure the reliability and consistency of the research findings, a structured methodological sequence was adopted, enabling a comprehensive and multi-layered project evaluation:

- 1) Analytical efficiency assessment - preliminary evaluation of NPV, IRR, and payback period;
- 2) Sensitivity and scenario analysis - assessment of project resilience to parameter changes;
- 3) Monte Carlo simulation - derivation of probabilistic characteristics and confidence distributions;
- 4) Statistical analysis - identification of key risk drivers through regression and correlation methods;
- 5) Expert evaluation - incorporation of qualitative insights to complement quantitative findings and address uncertainty.

This sequential approach allows for a systematic evaluation of renewable energy projects, balancing quantitative modeling with expert-driven interpretation, and serves as the foundation for the development of an evidence-based decision-support framework for sustainable investments (Table 1).

Table 1: Sequence of methods for evaluating the efficiency and risks of renewable energy projects.

| Stage | Methods | Purpose | Outcome |
|-------|---|-----------------------------------|--|
| 1 | NPV, IRR, Payback Period | Preliminary efficiency assessment | Baseline project indicators |
| 2 | Scenario Analysis, Sensitivity Analysis | Evaluation of project resilience | Range of performance indicators |
| 3 | Monte Carlo Simulation | Probabilistic assessment | Probability distributions of NPV and IRR |
| 4 | Regression Analysis, Confidence Intervals | Analysis of factor influence | Identification of key risk drivers |
| 5 | Expert Evaluation | Consideration of uncertainties | Final integrated risk assessments |

3 RESULTS

This section presents the results of the economic efficiency and risk assessment of renewable energy investment projects based on scenario modeling and probabilistic analysis.

The findings include an evaluation of investment attractiveness, identification of key risk factors, and a comparative analysis of different project types. The results also support the development of strategies for risk mitigation under varying market and regulatory conditions.

3.1 The Discounted Cash Flow (NPV) Method of Financial Efficiency Analysis of Projects

According to the discounted cash flow (DCF) analysis, both solar and wind power projects are economically viable. Under the baseline scenario, assuming a 20-year project lifetime, an 8% discount rate, and annual cash flows of USD 6.5–9.2 million, the estimated NPV amounts to USD 35.4 million, with an IRR of 11.5% and a payback period of approximately 6.2 years.

Two project types were analyzed for comparative purposes: solar power plants (SPP) and wind power plants (WPP). The main parameters and evaluation results are summarized in Table 2.

Table 2: NPV evaluation results for renewable energy projects.

| Parameter | Value | Measurement Unit | Notes / Description |
|------------------------|-----------|------------------|--------------------------|
| Initial Investment | 50 | million USD | Construction + equipment |
| Project Lifetime | 20 | years | - |
| Discount Rate | 8 | % | Industry average |
| Annual Cash Flows | 6.5 - 9.2 | million USD/year | By scenario |
| NPV, baseline scenario | 35.4 | million USD | - |
| IRR | 11.5 | % | Internal rate of return |
| Payback Period | 6.2 | years | - |

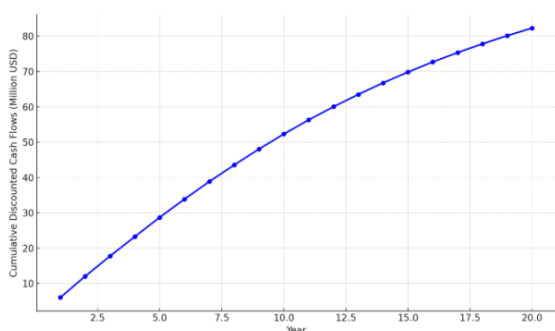


Figure 2: Cumulative discounted cash flow curve for the renewable energy project.

Figure 2 shows the cumulative discounted cash flow over the project lifecycle. The results indicate that the break-even point is reached around year 6, after which the project generates stable positive returns. The upward trend of cumulative discounted cash flows confirms the financial sustainability of the project under the assumed conditions.

Overall, both project types demonstrate positive financial performance, with key indicators exceeding minimum investment requirements. However, their long-term profitability remains sensitive to external market and regulatory factors.

3.2 Sensitivity Analysis and Scenario Evaluation

Sensitivity analysis shows that the most sensitive parameters for NPV are electricity price and equipment cost. A $\pm 20\%$ of electricity price leads to an \pm USD 8.5 million variation in NPV, and also for equipment cost, there is a change of \pm USD 5.2 million.

The sensitivity of profitability to the scenario (optimistic, baseline, and pessimistic) also shows that profit is very sensitive to market conditions. Efficiency measures improve dramatically in the best-case scenario, but returns decrease and risks increase in the other scenarios. These results support the value of hedging instruments and long-term contracts.

Table 3 presents the results of the sensitivity assessment for key financial and external factors, showing how variations in these parameters affect project performance metrics such as NPV and IRR.

These results confirm that the most sensitive parameters are the electricity price and equipment cost. Therefore, to enhance the project’s financial resilience, it is recommended to employ long-term power purchase agreements (PPAs) and optimize procurement strategies for technological components. Such measures help stabilize cash flows, mitigate exposure to market volatility, and improve overall investment predictability.

Table 3: Results of NPV sensitivity analysis.

| Factor | Range of Variation | Impact on NPV | Measurement Unit | Conclusion |
|----------------------|--------------------|---------------|---------------------------------|---------------------------|
| Electricity price | $\pm 20\%$ | ± 8.5 | million USD | Most sensitive |
| Equipment cost | $\pm 15\%$ | ± 5.2 | million USD | High impact |
| Interest rate | $\pm 2\%$ | ± 4.1 | million USD | Important finance factor |
| Operational lifetime | ± 2 | ± 3.8 | years \rightarrow million USD | Affects long-term returns |

Figure 3 illustrates the relationship between Net Present Value (NPV) and electricity price for the analyzed renewable energy project. The results show that NPV is highly sensitive to market price

fluctuations: a decrease below approximately 60 USD/MWh leads to negative project returns, while increasing prices (from 40 to 80 USD/MWh) result in a steady growth of NPV. This demonstrates the critical importance of stable pricing mechanisms and highlights the need for hedging strategies and revenue diversification. The analysis also allows identification of the break-even threshold, supporting investment decision-making under market uncertainty.

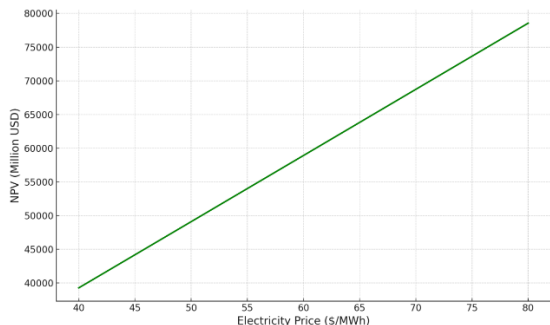


Figure 3: Relationship between NPV and electricity price.

3.3 Risk Modeling Using the Monte Carlo Method

To obtain a more accurate probabilistic evaluation of project efficiency, a Monte Carlo simulation model was applied. The input parameters included probability distributions for equipment cost, electricity price, discount rate, and other key variables.

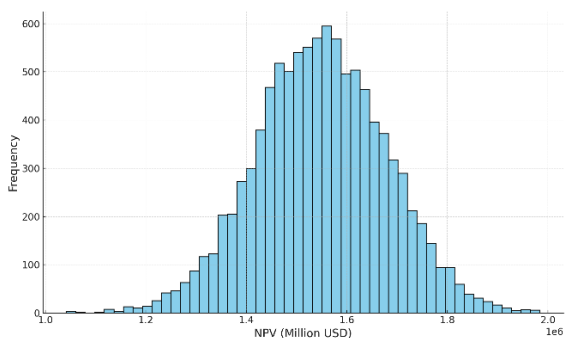


Figure 4: NPV distribution histogram for the wind power project (Monte Carlo simulation).

Figure 4 presents the distribution of Net Present Value (NPV) for the wind power project based on 10,000 simulation iterations. The results indicate a mean NPV of 34.8 million USD with a standard deviation of 4.5 million USD. The probability of negative NPV is below 5%, while the likelihood of achieving payback exceeds 80% under baseline conditions.

These findings confirm the robustness of the project and its high probability of generating positive returns despite underlying uncertainties.

3.4 Influence of External Factors and Risks

The analysis of external factors, including tariff policies, technological innovation, and political stability, revealed several important findings. The introduction of tariff incentives or subsidies can increase project NPV by 15–20%, while political instability and regulatory changes may raise overall project risk by up to 30%. At the same time, technological innovations can reduce capital expenditures by 10–12%, improving both payback period and return on investment.

Figure 5 shows the relative impact of key risk factors on project efficiency. Electricity price fluctuations have the strongest influence (25%), followed by technological risks (20%) and regulatory changes (15%), while other factors such as political stability and market conditions have a moderate effect.

These results highlight the critical importance of managing price volatility and regulatory risks to ensure project stability and investment attractiveness.

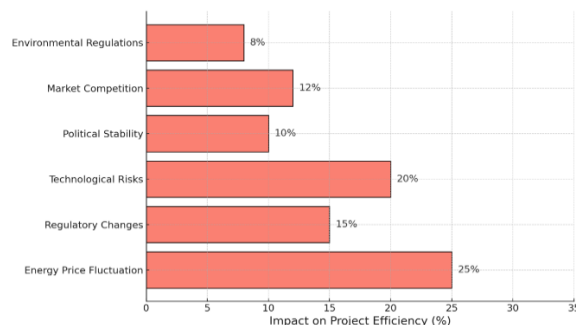


Figure 5: Impact of risk factors on the efficiency of a renewable energy project.

3.5 Comparison of Different Implementation Scenarios

As part of the study, three development scenarios were analyzed: optimistic, baseline, and pessimistic. Table 4 summarizes the key performance indicators (KPIs) for each scenario, providing a comparative overview of project outcomes under varying market and policy conditions.

This analysis shows that under the optimistic scenario, the project’s efficiency increases significantly; however, under the pessimistic scenario, the level of risk rises substantially, necessitating the implementation of additional risk management measures.

Table 4: Comparison of scenarios for the wind power project.

| Parameter | Optimistic Scenario | Baseline Scenario | Pessimistic Scenario | Measurement Unit |
|-----------------------------|---------------------|-------------------|----------------------|------------------|
| NPV | 45.7 | 34.8 | 22.3 | million USD |
| IRR | 14.8 | 11.5 | 8.2 | % |
| Payback Period | 5.4 | 6.2 | 8.1 | years |
| Probability of positive NPV | 95 | 85 | 65 | % |

3.6 Summary and Key Findings

Summarizing the obtained results, the following conclusions can be drawn:

- Renewable energy projects demonstrate high investment attractiveness when evaluated using modern methods such as discounted cash flow analysis and Monte Carlo simulation;
- The most sensitive parameters to external influences are the electricity price and equipment cost, which have the greatest impact on NPV and IRR;
- Scenario variability indicates that, with proper strategic and operational management, the risk of negative returns can be minimized to negligible levels;
- External factors, including regulatory changes and technological innovations, significantly affect payback periods and profitability, highlighting the need for continuous monitoring and adaptive investment strategies.

These findings confirm that the combination of quantitative modeling, scenario analysis, and expert-

based evaluation provides a robust foundation for decision-making in the renewable energy sector, enabling investors to balance profitability and risk under uncertain market conditions.

3.7 Visualization of Results

Figure 6 presents a summary chart illustrating the NPV distribution across three project scenarios-optimistic, baseline, and pessimistic. The visualization highlights the shifts in expected value and probability range, allowing for a clear comparison of financial outcomes and risk exposure under different development conditions.

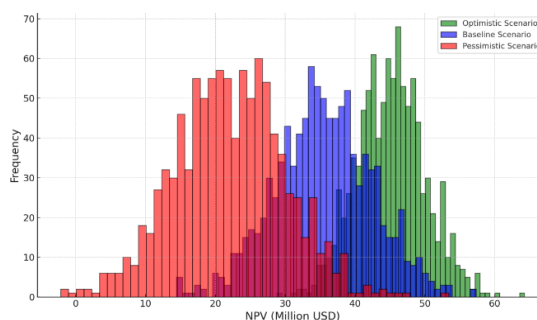


Figure 6: Distribution of NPV across different project implementation scenarios.

Such graphical representation serves as an effective tool for strategic communication with stakeholders, as it visually conveys both the expected profitability and the uncertainty margins associated with each scenario.

The histogram illustrates the distribution of the Net Present Value (NPV) of a renewable energy investment project under three scenarios: optimistic, baseline, and pessimistic. Each scenario models possible financial outcomes based on a normal probability distribution with distinct mean values and standard deviations.

- The green curve represents the optimistic scenario, characterized by the highest expected returns;
- The blue curve corresponds to the baseline case;
- The red curve denotes the pessimistic scenario, reflecting the least favorable market and policy conditions.

The frequency of values provides insight into the likelihood of achieving specific profitability levels. This comparative approach enables a comprehensive assessment of uncertainty and risk, highlighting the potential variability of financial outcomes. The

absence of a title within the figure enhances its flexibility for integration into various analytical or policy reports.

Such visualization serves as an essential tool for investors and analysts, facilitating the evaluation of probabilistic performance metrics and supporting data-driven investment decisions in the renewable energy sector.

4 DISCUSSION

This section provides an interpretation of the obtained results, comparing them with the findings of other researchers and discussing the key factors affecting the efficiency and risk profile of renewable energy (RE) projects. The discussion synthesizes the insights derived from the applied analytical framework, including investment efficiency assessment, scenario modeling, sensitivity analysis, and Monte Carlo simulations.

The discussion not only contextualizes the results within the broader scientific discourse but also forms the basis for practical recommendations and identifies directions for further research in renewable energy investment evaluation.

4.1 Comparative Analysis with International Experience

The findings are consistent with international studies emphasizing the importance of scenario-based analysis and risk-adjusted profitability measures. The analyzed renewable energy projects demonstrate high profitability under baseline conditions and strong sensitivity to market uncertainties.

A comparison of NPV across scenarios shows that optimistic assumptions significantly improve financial outcomes, whereas pessimistic conditions highlight sensitivity to electricity price volatility and regulatory risks. These results confirm the importance of probabilistic methods, such as Monte Carlo simulation, in investment decision-making.

Figure 7 shows the comparison of NPV values under three scenarios. The optimistic scenario yields the highest NPV (USD 45.7 million), followed by the baseline case (USD 34.8 million), while the pessimistic scenario results in the lowest value (USD 22.3 million).

These results highlight the impact of external conditions on project profitability and emphasize the need for effective risk management strategies.

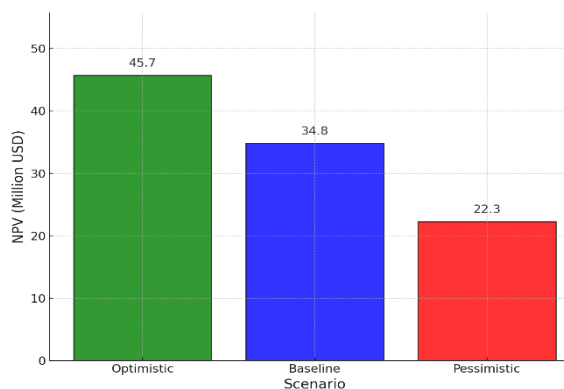


Figure 7: Comparison of NPV under different project implementation scenarios.

4.2 Impact of Key Risk Factors on Project Efficiency Indicators

The sensitivity analysis revealed that the most influential parameters affecting NPV and IRR include electricity price fluctuations, equipment costs, discount rate, and project lifespan [13], [15]. As demonstrated in Table 3, a $\pm 20\%$ change in the electricity price results in an approximate \pm USD 8.5 million variation in NPV, confirming the project’s high sensitivity to market price volatility.

Figure 8 illustrates the relative impact of major risk factors on project performance. Notably, changes in electricity price and equipment costs produce the largest deviations in NPV and IRR, aligning with the findings of Study [18], which emphasizes the necessity of long-term power purchase agreements (PPAs) and income stream diversification to mitigate financial risks.

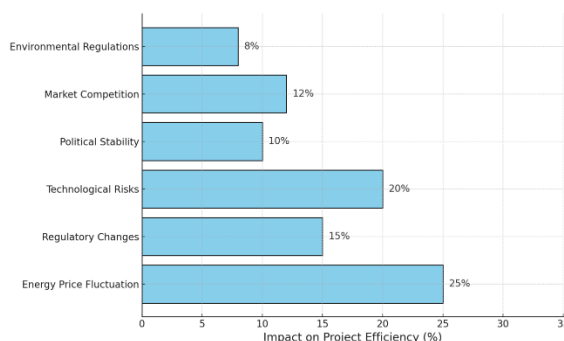


Figure 8: Impact of risk factors on project efficiency indicators.

This horizontal bar chart presents the key risks influencing the effectiveness of renewable energy project implementation. Each bar indicates the magnitude of impact of a specific factor, expressed as a percentage.

The most critical risk is associated with electricity price fluctuations (25%), followed by technological risks (20%) and regulatory changes (15%). Other factors-such as political stability, market competition, and environmental regulations-exert a moderate yet significant influence on project outcomes.

The absence of an internal title makes the figure versatile and easily adaptable for integration into reports, presentations, and technical documents. The values are labeled directly on the bars, allowing for immediate data interpretation without additional legends.

This visualization is particularly effective for identifying project vulnerabilities and developing targeted risk mitigation strategies. The results emphasize the necessity of implementing hedging mechanisms, long-term planning, and diversified financial instruments to reduce project exposure to external market volatility.

4.3 Monte Carlo Risk Modeling: Interpretation and Conclusions

The Monte Carlo simulation model was applied to evaluate the probability distribution of NPV for the project. The results indicate that the likelihood of a negative NPV is below 5%, suggesting a high probability of successful project implementation. The histogram in Figure 9 shows that most simulated scenarios yield positive NPV values, with a distribution centered near the mean (USD 35 million) and a standard deviation of USD 5 million, reflecting potential variability in project outcomes.

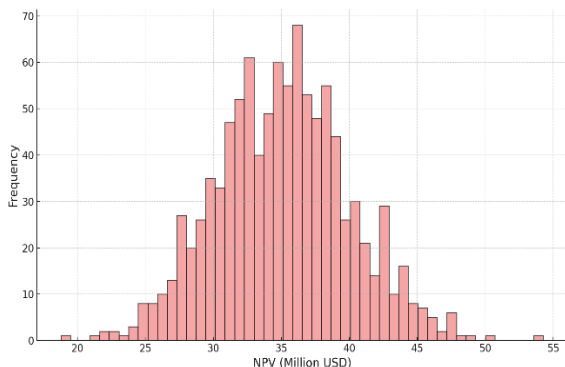


Figure 9: Distribution of NPV from Monte Carlo simulation results.

These findings are consistent with previous research [14], highlighting the effectiveness of Monte Carlo simulations in assessing investment risk and uncertainty in the energy sector. The analysis of IRR further confirms that its mean value exceeds the minimum acceptable threshold, reaffirming the project’s investment appeal. Overall, probabilistic evaluation provides a quantitative foundation for risk-informed decision-making and strategic capital allocation.

4.4 Influence of External and Regulatory Factors

The analysis of external factors revealed that changes in tariff policy, regulatory requirements, and political instability can significantly affect project performance indicators [5], [14]. As shown in Table 5, under favorable conditions, project NPV can increase by 20-25%, while under unfavorable conditions it may decrease by 30% or more.

Figure 10 presents the sensitivity of NPV to these external factors. Electricity price fluctuations have the strongest impact (25%), followed by technological changes (20%) and regulatory adjustments (15%). Other factors, including political stability, market competition, and environmental regulations, exert a moderate effect on project outcomes.

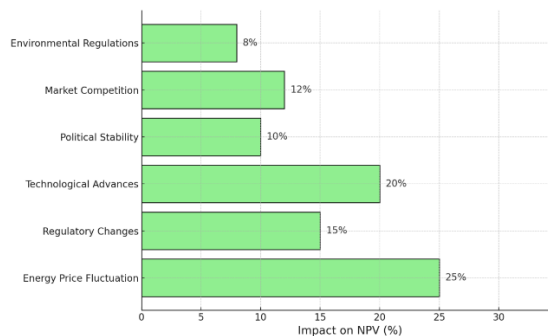


Figure 10: Sensitivity of NPV to external factors affecting renewable energy projects..

These findings highlight the importance of regulatory predictability, policy stability, and institutional support for the economic resilience of renewable energy projects. To mitigate external risks, strengthening policy frameworks, enhancing investment guarantees, and promoting collaborative governance mechanisms between public and private sectors are recommended. Additionally, monitoring technological innovation and integrating adaptive

business models are essential to maintain competitiveness and investment stability.

4.5 Practical Recommendations and Directions for Further Research

Based on the analysis, the following practical recommendations are proposed for investors and project managers in the renewable energy sector:

- Implement insurance and hedging mechanisms to mitigate risks associated with price volatility and regulatory changes.
- Apply scenario analysis and Monte Carlo simulations to assess probabilistic project performance.
- Develop long-term power purchase agreements (PPAs) and diversify revenue streams to reduce dependency on single market factors.
- Engage proactively with regulatory authorities to support stable tariff policies and encourage technological innovation.
- Monitor emerging technologies continuously and ensure adaptive investment management.

For future research, it is recommended to:

- Analyze the impacts of climate change and environmental regulations on project performance.
- Develop risk assessment models incorporating next-generation technologies, such as energy storage systems and smart grid infrastructure.
- Expand region-specific studies to capture policy, market, and technological variations.

4.6 Limitations and Prospects for Future Development

Despite the comprehensiveness of the applied methods, limitations include the reliance on input data quality and assumptions about probability distributions. The absence of long-term data for emerging technologies may reduce the precision of projections.

Potential improvements:

- Integrate dynamic system models for renewable energy markets.
- Utilize machine learning for enhanced market forecasting.
- Expand geographic and policy-specific analyses to improve predictive accuracy.

Overall, integrating risk assessment, scenario-based analysis, and probabilistic modeling enhances decision-making reliability and supports resilient investment strategies.

5 CONCLUSIONS

This study assessed the economic efficiency and investment risks of renewable energy projects, focusing on solar and wind power plants. Key findings include:

- Renewable energy projects demonstrate strong potential for positive economic returns, subject to external factors such as electricity prices, regulatory policies, and technological developments.
- Scenario analysis and Monte Carlo simulations provide robust probabilistic insights, supporting informed investment decisions under uncertainty.
- The main risk drivers are energy price volatility, regulatory changes, and technological uncertainty. Mitigation strategies include long-term contracts, risk management instruments, and adaptive investment practices.

In conclusion, renewable energy projects are economically viable and strategically sound when accompanied by effective risk management and continuous monitoring of market and technological conditions.

REFERENCES

- [1] Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2022: Mitigation of Climate Change*. Cambridge: Cambridge University Press, 2022. [Online]. Available: <https://www.ipcc.ch/report/ar6/wg3>.
- [2] Frankfurt School-UNEP Centre and BNEF, *Global Trends in Renewable Energy Investment 2018*. Frankfurt am Main, 2018. [Online]. Available: <https://www.fs-unep-centre.org/global-trends-in-renewable-energy-investment-2018>.
- [3] International Renewable Energy Agency (IRENA), *Renewable Power Generation Costs in 2018*. Abu Dhabi, 2019. [Online]. Available: <https://www.irena.org/publications>.
- [4] Fraunhofer ISE, *Photovoltaics Report*. Freiburg: Fraunhofer Institute for Solar Energy Systems, 2024. [Online]. Available: <https://www.ise.fraunhofer.de/en/publications/studies/photovoltaics-report.html>.
- [5] International Energy Agency (IEA), *Renewables 2024*. Paris, 2024. [Online]. Available: <https://www.iea.org/reports/world-energy-investment-2024>.
- [6] W. Short, D. J. Packey, and T. Holt, *A Manual for the Economic Evaluation of Energy Efficiency and Renewable Energy Technologies*, NREL/TP-462-5173, National Renewable Energy Laboratory, 1995. [Online]. Available: <https://www.nrel.gov/docs/legosti/old/5173.pdf>.

- [7] D. Akinyele, J. Belikov, and Y. Levron, "Battery storage technologies for electrical applications: Impact in stand-alone photovoltaic systems," *Energies*, vol. 10, no. 11, Art. no. 1760, 2017, doi: 10.3390/en10111760.
- [8] H. Jebelli et al., "A probabilistic framework for risk assessment of renewable energy investments," *Renewable and Sustainable Energy Reviews*, 2020.
- [9] J. Mun, *Modeling Risk: Applying Monte Carlo Risk Simulation, Strategic Real Options, Stochastic Forecasting, and Portfolio Optimization*. Hoboken, NJ: Wiley, 2010.
- [10] Global Wind Energy Council (GWEC), *Global Wind Report 2024*. Brussels, 2024. [Online]. Available: <https://gwec.net/global-wind-report-2024>.
- [11] Energy Institute, *Statistical Review of World Energy 2024*. London, 2024. [Online]. Available: <https://www.energyinst.org/statistical-review>.
- [12] J. Mun, *Modeling Risk*. Hoboken, NJ: Wiley, 2006.
- [13] A. Saltelli et al., *Global Sensitivity Analysis: The Primer*. Hoboken, NJ: Wiley, 2008.
- [14] J. Mun, *Modeling Risk: Applying Monte Carlo Risk Simulation, Strategic Real Options Analysis, Stochastic Forecasting, and Portfolio Optimization*, 3rd ed., 2019.
- [15] D. C. Montgomery, E. A. Peck, and G. G. Vining, *Introduction to Linear Regression Analysis*. Hoboken, NJ: Wiley, 2021.
- [16] OECD, *Financing Climate Futures: Rethinking Infrastructure*. Paris: OECD Publishing, 2018.
- [17] B. M. Ayyub, *Elicitation of Expert Opinions for Uncertainty and Risks*. Boca Raton, FL: CRC Press, 2001.
- [18] S. Tsianikas, W. Zhou, D. W. Coit, et al., "Economic trends and comparisons for optimizing grid-outage resilient photovoltaic and battery systems," *Applied Energy*, vol. 256, Art. no. 113892, 2019, doi: 10.1016/j.apenergy.2019.113892.