# MANAGE RISKS IN INDUSTRIAL ROOFTOP SOLAR POWER PROJECTS: MONTE CARLO SIMULATION BASED APPROACH

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**Abstract**

*This research applies a Monte Carlo simulation approach to analyze financial risks in an industrial rooftop solar power project, aligning with global energy transition goals and the net-zero commitment by 2050. Evaluating risk exposure is crucial for industrial enterprises adopting onsite renewable energy. Focusing on the rooftop solar project at FIT Voltaira, the study uses Crystal Ball software to simulate scenarios by assigning probability distributions to key input variables: solar energy yield, electricity price, and initial investment cost. The results show an 87.56% probability of achieving a positive Net Present Value (NPV) and an Internal Rate of Return (IRR) above the minimum acceptable rate, illustrating both potential opportunities and downside risks. Sensitivity analysis indicates that investment cost, solar yield, and electricity price are the most influential drivers of financial uncertainty. The study offers practical insights for investors—such as securing fixed-price EPC contracts and optimizing system design—while also providing a probabilistic evidence base for emerging rooftop solar policies, including the integration of carbon credits.*

***Research purpose:***
*This research evaluates the financial efficiency and risk management of industrial rooftop solar power projects in Vietnam, aligning with net-zero goals. Monte Carlo simulation is used to assess financial viability, providing appropriate investment policy recommendations in a high-risk environment.*

***Research motivation:***
*Global energy transition and Vietnam's net-zero pledge drive urgent demand for industrial rooftop solar, reducing costs and fostering sustainable development. Fluctuations in key financial factors create significant risks. This study addresses a gap in analyzing these projects amidst new Net Zero 2050 challenges.*

***Research design, approach, and method:***
*This study employs a Monte Carlo simulation approach using Crystal Ball software to analyze a rooftop solar project at FIT Voltaira Vietnam factory. Key uncertain input variables—solar energy yield, EVN's electricity price, and initial investment costs—were assigned probability distributions. The model was run 10,000 times to evaluate financial indicators.*

***Main findings:***
*Baseline analysis showed high feasibility (NPV>0, IRR 16% > 13% MARR, 8-year payback). Monte Carlo simulation confirmed high profitability potential, with an 87.56% probability of positive NPV and IRR exceeding MARR. Sensitivity analysis highlighted investment cost, solar yield, and electricity price as the most significant risk factors.*

***Practical/managerial implications:***
*Investors should prioritize controlling initial investment costs (e.g., fixed-price EPC contracts), maximizing solar yield (optimal design, monitoring), and aligning to electricity prices. This research also provides a scientific basis for Vietnam's evolving rooftop solar legal framework, emphasizing detailed financial analyses and new carbon credit incentives.*

***Keywords:*** *Rooftop solar power, Financial risk, Monte Carlo simulation, Net Present Value (NPV), Internal Rate of Return (IRR)*


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## 1. INTRODUCTION

In the context of global energy transition and Vietnam's commitment to achieve net-zero emissions by 2050 under the COP26 Agreement (DCC, 2021), the application of renewable energy sources like solar power has become urgent, especially in the industrial sector. Rooftop solar power is considered an optimal solution for factories with high loads and available roof space, as it not only helps reduce electricity costs but also contributes to sustainable development goals (VCCI, 2024; MOC, 2025).

In Vietnam, enterprises have adopted onsite renewable energy projects as part of their sustainability strategies. For instance, Sabeco partnered with SP Group to install a 10.44 MWp rooftop solar system across nine breweries, meeting nearly 25% of their electricity demand and generating 14,600 MWh annually. Golden Victory Vietnam collaborated with TotalEnergies ENEOS to deploy up to 7.5 MWp of solar, cutting 4,200 tons of $CO_2$ per year. Lego is building a carbon-neutral factory in Binh Duong with rooftop and nearby solar farms to cover 100% of its electricity needs. Tetra Pak installed a 5,900 $m^2$ rooftop solar system, reducing 700 tons of $CO_2$ annually. Other notable projects include De Heus and Bel Ga's 20 MWp plan across 30 facilities, Jinko Solar's proposal in Quang Ninh, and SkyX Solar's agreement with Huong Sen Comfor in Thai Binh. These initiatives demonstrate Vietnam's strong momentum in integrating solar energy into industrial operations (Thuy Tuong, 2023).

However, fluctuations in key financial factors—such as investment cost, electricity price, operating expenses, interest rates, and the proportion of onsite consumption—create significant risks that affect project cash flow, Net Present Value (NPV), Internal Rate of Return (IRR), payback period, and overall investment attractiveness. To rigorously capture these uncertainties, this study applies Monte Carlo simulation to the case of FIT Voltaira Vietnam Co., Ltd., a company specializing in electronic component manufacturing with high electricity consumption in Hai Phong city. Monte Carlo simulation is widely recognized as an essential tool for financial risk analysis, as it produces probability distributions of outcomes rather than single-point estimates, thereby providing a more comprehensive picture of uncertainty and the likelihood of project success (Pritchard, 2015). It is important to note that this study does not employ Business Dynamics/System Dynamics modelling. Instead, it focuses on Monte Carlo–based financial risk analysis to quantify uncertainty in cash-flow indicators.

Regarding the development project, the authors are considering the EPC type of contract[1]. EPC stands for Engineering, Procurement, and Construction, where a single contractor is responsible for all phases of the project, from design and engineering to procurement of all equipment and materials, and finally the construction and installation. It is different from PPA type of contract, which is a long-term agreement for selling and buying the electricity the project produces.

The remainder of this paper is structured as follows. Section 2 reviews literature on Monte Carlo–based financial risk analysis in project appraisal, including recent Vietnamese applications. Section 3 describes the case context (FIT Voltaira), input data, discounted-cash-flow model, and Monte Carlo setup (choice of input distributions, 10,000 trials, and sensitivity analysis). Section 4 presents the baseline results and probabilistic outcomes (NPV/IRR distributions, percentile ranges, and tornado-chart sensitivities). Section 5 concludes with managerial recommendations. Section 6 lists the references.

## 2. LITERATURE REVIEW

Monte Carlo analysis offers several practical benefits in project management. By identifying which input variables have the greatest impact on financial performance, the method helps investors focus on critical risks to implement appropriate control measures. It helps estimating a more realistic budget and investment efficiency by simulating multiple scenarios reflects the range of financial indicator fluctuations, thus avoiding decisions based on single or overly optimistic expectations. It also supports the assessment of cost overrun probability or failure to achieve expected returns. This is especially important in an unstable investment environment or when input variables have a high degree of variation.

Numerous studies demonstrate a consistent approach to applying Monte Carlo simulation, which involves identifying critical drivers, assigning defensible probability distributions, and simulating cash-flow paths to generate probability distributions for project outcomes. Dukić et al. (2016) analyzed an energy plant, finding high probabilities of success (86.1% for NPV and 91.9% for IRR) by assigning distributions to revenues, costs, and capital expenditures. Similarly, in oil & gas, Wicaksono et al. (2019) applied the simulation to a 10-year project and identified a high downside risk, noting an 82.15% probability of loss. At a portfolio scale, Salling and Leleur (2006) used Monte Carlo simulation to augment cost-benefit analysis for transport infrastructure projects, producing distributions and tornado charts for key metrics. Lee et al. (2017) ran Monte Carlo simulation to evaluate the economics of early-stage hydrogen systems, bounding the cost and providing cumulative-probability NPVs, which is useful given the high parameter volatility. In a gas-fired power plant analysis, Kryzia et al. (2020) explicitly introduced Monte Carlo simulation to a real-options model, demonstrating how it complements real options analysis by accounting for stochastic prices and technical parameters to inform

[1] See more at Utility Solar Project Development & EPC — Descriptive Information, https://ei-spark.lbl.gov/generation/utility-scale-pv/project/info/

operational switching decisions.

Recent Vietnamese studies have applied Monte Carlo simulation across diverse domains, including water resources, finance, real estate, and construction. In water management, To et al. (2017) demonstrated that the simulation can generate realistic flow data series, thereby supporting more effective water allocation in the Vu Gia Thu Bon river basin, though they cautioned that results remain highly sensitive to distributional assumptions and input data quality. In the financial sector, a master's thesis (Doan, 2017) conducted at VietinBank Phuc Yen applied Crystal Ball–based tool to project appraisal, showing how probability distributions of NPV and IRR can inform investment decisions, while also highlighting limitations in data reliability and distribution selection. Another a case study in Vinh applied Monte Carlo to assess the financial safety of an urban development project. It clarifies the probability of negative NPV outcomes and supports risk-hedging strategies, although intangible policy-related factors such as land regulation remain difficult to quantify (Bui et al., 2024). In construction management, Le and his colleagues (2016) used Monte Carlo to estimate schedule buffers, while Lai (2011) applied the technique to simulate overall project completion times. Both studies underscored that probabilistic scheduling improves risk assessment but noted the challenge of specifying correlations between activities. Similarly, technical reports by VNCOLD applied Monte Carlo to hydropower reservoir regulation, emphasizing the method's ability to capture flow uncertainty but warning of its sensitivity to climate assumptions.

Complementing these strands, several recent Vietnamese sectoral applications reinforce the practicality of Monte Carlo in investment appraisal and risk prioritization. A 2024 study in the Journal of Materials & Construction applies Monte Carlo to construction-investment evaluation, using Crystal Ball to propagate uncertainty from multiple cost and scale drivers in a large urban-area project and to improve feasibility assessment under parameter variability. In the PPP domain, Pham et al. (2023) propose a Monte Carlo–based procedure to prioritize risks in Vietnamese PPP projects, operationalized in Crystal Ball and mapped onto risk matrices to guide prevention and response strategies. In hospitality investment, Tran (2024) combines projected cash flows with Monte Carlo to quantify annual performance stability and scenario-dependent ROI for a hotel project, reporting convergence properties and distributional diagnostics from large-trial simulations in Crystal Ball.

Taken together, these studies underscore that Monte Carlo shifts analysis from deterministic point estimates to probabilistic outcome ranges, thereby enhancing decision-making under uncertainty. At the same time, they consistently reveal recurring challenges—data scarcity, the defensibility of input distributions (and correlations), and transparency of modeling assumptions—which remain only partially addressed in the domestic literature. Notably, peer-reviewed applications that (i) target industrial rooftop solar projects, (ii) model on-site consumption and EVN tariff pass-through jointly with EPC-cost volatility, and (iii) report probability statements for DCF indicators (e.g NPV>0; IRR>MARR) are still limited. The present study contributes to this gap by specifying a rooftop-solar cash-flow model for an energy-intensive manufacturer and implementing a Monte Carlo design that produces decision-relevant probability distributions for NPV/IRR under realistic variability in solar yield, electricity tariffs, and capital cost.

## 3. METHODOLOGY

In this study, the Crystal Ball software is used to implement the Monte Carlo simulation to evaluate the financial-economic efficiency of the rooftop solar project at the FIT Voltaira Vietnam factory. The main input variables were assigned probability distributions, including: (1) solar energy yield—based on the P90 value from the PVSyst; (2) the average electricity sale price from EVN—reflecting the actual tariff and a scenario of an annual price increase; and (3) initial investment costs—including equipment, technical services, and legal fees. Through series of simulations, the study constructs probability distributions for important financial indicators, thereby evaluating the project's probability of success and providing appropriate investment policy recommendations in a high-risk environment.

### 3.1 Input data

The financial model was built by collecting and processing data from technical records, investment reports, and other documents related to the rooftop solar project at the FIT Voltaira Vietnam factory. The goal of this step was to fully define the necessary parameters for the discounted cash flow model, which would serve as the basis for calculating financial indicators and performing the risk simulation. The input parameters were categorized into two main groups: revenue and cost components that make up the cash outflows over the project's entire lifespan.

Key input parameters in the project's cash flow model are defined below.

•Revenue: Cost savings from using the solar power system, based on the amount of self-consumed electricity and the unit price of electricity purchased from the EVN grid at the time of calculation, and the system's residual value in the final year of the project, which is determined by the initial investment value divided over the depreciation period (30 years for this project), reflecting the remaining non-depreciated asset value using the straight-line depreciation method.

•Initial Investment Costs: Equipment costs (solar panels, inverters, mounting systems, cables...); Construction, design consulting, licensing, insurance, project management, and contingency costs.

•Operation & Maintenance (O&M) Costs: Annual periodic operating costs, adjusted to increase by 3% each year to reflect inflation and the increasing costs of labor and maintenance materials over time.

•Equipment Replacement Costs: Estimated at 15% of the total initial investment cost, mainly including the cost of replacing inverters around the 10th–12th year of the project's lifespan, corresponding to the typical technical life of this equipment.

•Insurance Costs: System asset insurance costs, usually applied annually at a rate of 0.2% of the total initial investment value. This cost gradually decreases by 3% each year, reflecting the asset's decreasing value over time. The purpose is to protect equipment from risks like fire, natural disasters, or technical incidents, and it is often required if the project involves financing from banks or credit institutions.

•Financing Costs: Includes loan interest and principal repayment in case the project uses credit financing, calculated based on a fixed or variable term and interest rate. For this project, the investor borrowed 70% of the total capital at an interest rate of r = 10% for 7 years.

•Corporate Income Tax (CIT) Costs: Although the project generates cost savings rather than sales, tax effects are reflected by applying the applicable corporate income tax rate to incremental taxable income arising from these savings.

Table 1 lists the total investment cost at 16,126,275,500 VND, with an additional 8% VAT of 1,031,620,920 VND, bringing the total to 17,157,896,420 VND.

*Table 1 Project's investment costs*

| | | Unit | Quantity | Unit price | Total in VND |
|---|---|---|---|---|---|
| **I** | **Equipments** | | | | **12,895,261,500** |
| 1 | Canadian Solar Panel | kWp | 1,241.37 | 3,750,000 | 4,655,137,500 |
| 2 | HUAWEI SUN2000 - 100KTL – M1 Pro Inverter | pcs | 11 | 145,000,000 | 1,595,000,000 |
| 3 | Monitoring System and Weather Station – SUNGROW China / Meteocontrol | Bộ | 1 | 190,000,000 | 190,000,000 |
| 4 | Solar Panel Mounting Structure | kWp | 1,241.37 | 1,000,000 | 1,241,370,000 |
| 5 | ACDB, AC Isolator & Reactive Power Compensation Cabinet – Schneider / Mitsubishi | kWp | 1,241.37 | 900,000 | 1,117,233,000 |
| 6 | DC Cable | kWp | 1,241.37 | 2,200,000 | 2,731,014,000 |
| 7 | Grounding Cable PVC/PVC/Cu | kWp | 1,241.37 | 400,000 | 496,548,000 |
| 8 | Waterproof Connector MC4 1500V 30A IP67 | kWp | 1,241.37 | 700,000 | 868,959,000 |
| **II** | **Technical services** | **kWp** | **1,241.37** | **2,200,000** | **2,731,014,000** |
| **III** | **Permits** | **Set** | **1** | **500,000,000** | **500,000,000** |
| | | | | Subtotal | 16,126,275,500 |
| | | | | VAT 8% | 1,031,620,920 |
| | | | | Total (VAT included) | 17,157,896,420 |

**3.2 Risk Modelling Setup**

To comprehensively assess financial risk in a fluctuating real-world environment, this step involves performing a Monte Carlo simulation to reflect the probability of different financial scenarios. The process is as follows:

(i) Selecting highly uncertain input variables: Based on their impact and volatility, the research team chose key variables: Solar energy yield (kWh/kWp/year); EVN's electricity sale price (VND/kWh); and Initial investment cost

(ii) Assigning probability distributions to the variables: Probability distributions were chosen based on data from PVSyst, technical documents, and expert assessments. For example, solar energy yield was modeled using a normal distribution with an expected value of 880 kWh/kWp/year and a standard deviation determined based on P50, P90 scenarios. The electricity price and initial investment costs were assigned a triangular distribution because historical data is limited and it's necessary to show the minimum, maximum, and most likely values.

(iii) Running the simulation: The model was run 10.000 times in Crystal Ball software. Each trial involves the software randomly selecting a set of input values from the assigned probability distributions to recalculate the NPV and IRR.

*Table 2 Projected distribution of project inputs*

| | Input | Mean | Standard Deviation | Explanation |
|---|---|---|---|---|
| 1 | Solar energy yield (kWh/kWp/year) | 880 | 60 | Solar energy yield is modeled with a normal distribution centered at P50. The standard deviation is derived from the P50–P90 gap using σ ≈ (P50 − P90)/1.28, reflecting inter-annual variability. |
| 2 | Electricity price purchased from EVN (VND/kWh) | 2,256 | 120 | Electricity prices apply to customers who produce medium voltage grades. Assumption: future electricity tariffs will escalate by 5–7% annually, which is used as the basis for the standard deviation |
| 3 | Initial investment cost (VND) | 17,157,896,420 | 1,500,000,000 | Fluctuations are estimated at 8–10% in bad cases such as material slippage, increase in the USD/VND exchange rate or change in technical conditions in EPC bidding. |

**4. RESULTS AND DISCUSSION**

Based on the collected data, a project cash flow model was built to calculate important financial efficiency indicators including Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period. The input variables were held constant at their average values or reasonable assumptions based on real conditions in Vietnam, without considering fluctuations or risks. The baseline financial analysis results for the project are summarized as follows:

- NPV 2,678,354,415 VND > 0 indicates that the project is economically and financially viable.
- IRR 16% > 13% (MARR) shows that the project has good profitability according to the internal rate of return standard.
- The payback period of 8 years is significantly shorter than the 30-year lifespan, indicating a quick capital recovery and a large profit margin for the remaining period.

Based on the cash flow, a net cash flow chart was created to visually represent the entire process of cash inflows and outflows over the 30-year lifespan of the solar system at the FIT Voltaira Vietnam factory. Figure 1 clearly shows the initial investment phase with a large negative cash flow, followed by stable positive cash flows from annual electricity cost savings, and finally a sharp increase in cash flow in the final year due to the salvage value of the system. the baseline financial model results show that the project has high feasibility under stable input conditions

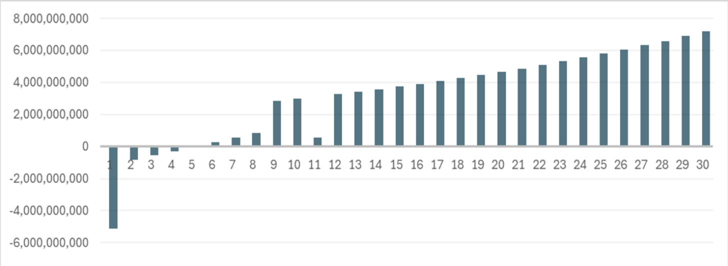


*Figure 1 Project cash flow in 30 years*

The Monte Carlo simulation was performed with 10.000 iterations using Crystal Ball software. The three key input variables (solar energy yield, EVN's electricity price, initial investment cost) were assigned normal and triangular distributions based on real data and reasonable assumptions. The simulation results show that the project has high profitability potential while also providing a comprehensive view of the potential financial risks.

*Table 3 Results from Monte Carlo simulation*

| Statistics | IRR (%) | NPV (thousand VND) |
|---|---|---|
| **Trials** | 10,000 | 10,000 |
| **Base Case** | 16% | 2,678,354 |
| **Mean** | 17% | 2,690,537 |
| **Median** | 16.0% | 2,672,830 |
| **Mode** | --- | --- |
| **Standard** | 3.0% | 2,346,172 |
| **Variance** | 0% | 5.50E+12 |
| **Skewness** | 0.5050 | 0.0759 |
| **Kurtosis** | 3.70 | 3,11 |
| **Coeff. of Variability** | 0.1920 | 0.8720 |
| **Minimum** | 7% | -6,362,314 |
| **Maximum** | 33% | 12,103,079 |
| **Mean Std. Error** | 0% | 23,461 |

The results show that the average NPV is 2.69 billion VND, and the average IRR is 17%, both exceeding the minimum acceptable financial threshold (MARR = 13%). This indicates that the project is expected to be profitable. The standard deviation of NPV is 2.35 billion VND, and the standard deviation of IRR is 3%, which shows that the simulation results are spread out and reflect the inherent uncertainty of the inputs. The range of NPV values is from -6.36 billion to 12.1 billion VND, while IRR can fluctuate from 7% to 33%.

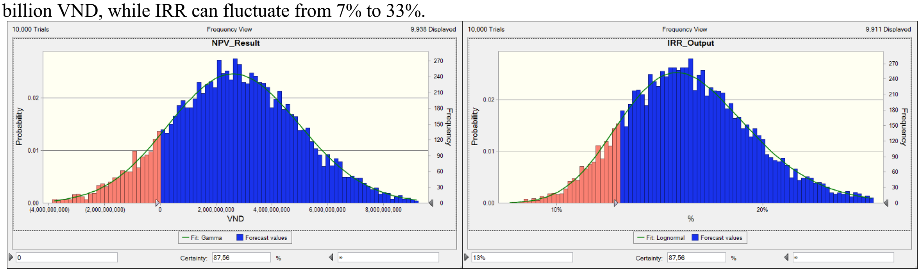


*Figure 2 NPV and IRR distribution*

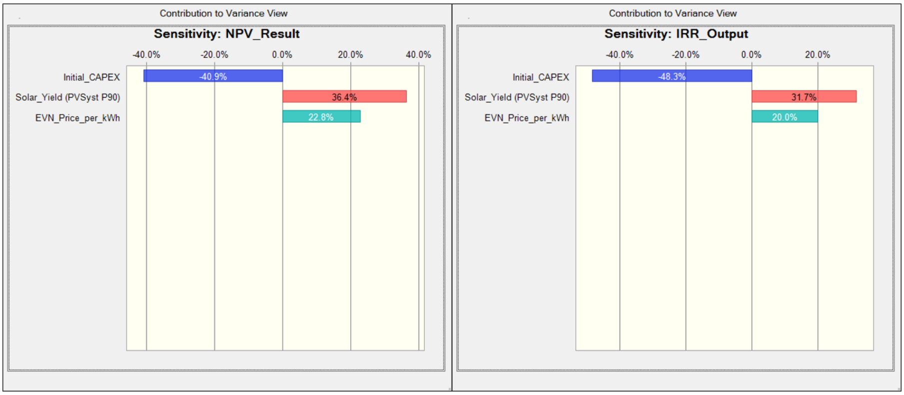


*Figure 3 Sensitivity Analysis of NPV and IRR*

Notably, the skewness of NPV is slightly positive (+0.0759), meaning the NPV distribution is slightly skewed to the right, showing that most scenarios are close to the mean, but there are a few cases with exceptionally high NPV values. This is a positive sign because the probability of a high gain tends to be higher than the probability of a significant loss. Meanwhile, the IRR distribution has a higher skewness (+0.5050) and a kurtosis of 3.70, indicating a more pronounced right skew and a long tail on the higher values. This reflects that in many favorable scenarios, the IRR can reach very high levels (up to 33%), while the risk of the IRR falling below the MARR is low. From an investor's perspective, this means that while the project has risks, most scenarios show favorable outcomes, and the IRR has high potential for profitability under favorable input conditions.

The probability distribution of NPV shows an average value of approximately 2.68 billion VND with a standard deviation of about 2.35 billion VND. The simulated NPV values range from –6.36 billion to 12.1 billion VND, with the 90% confidence interval spanning –0,

74 billion to 6.3 billion VND.

Remarkably, the probability of NPV being greater than 0—meaning the project achieves a positive financial return—is up to 87.56%. At the same time, over 46% of the scenarios result in an NPV above 3 billion VND, and about 13% result in an NPV above 5 billion VND, which shows that high-profit margins can still be achieved under favorable operating conditions.

The IRR simulation results also show significant stability. The IRR distribution is fitted by the software as a Lognormal distribution, which is suitable for a variable that is always positive and skewed to the right. The average IRR is 16%, which is higher than the minimum acceptable rate of return (MARR = 13%), with a standard deviation of about 3%. The distribution has a minimum value of 7% and a maximum of 33%, with the probability of IRR exceeding MARR also at 87.56%. This is a positive sign, indicating that the project not only has a potential for profit but also a high probability of exceeding the minimum profit threshold set by the investor.

The sensitivity analysis in Crystal Ball (via the Tornado chart) has identified the factors with the strongest influence on the simulation results. For NPV, the biggest influencing variable is initial investment cost (with a negative contribution of 40.9% to total variance), followed by solar yield (36.4%) and EVN electricity price (22.8%). Meanwhile, for IRR, the initial investment cost plays an even more decisive role, with an impact of up to 48.3%, surpassing the influence of solar yield (31.7%) and electricity price (20.0%). This result accurately reflects the nature of IRR as an indicator of capital utilization efficiency, which makes it very sensitive to the total initial cost.

From these analyses, it can be concluded that the project has high financial potential, with a probability of exceeding the expected threshold over 87% for both NPV and IRR. Concurrently, financial risks are mainly concentrated in three key factors: investment cost, solar yield, and replacement electricity price—these are the three aspects that the investor needs to prioritize controlling during the design, EPC contract negotiation, and project operation phases.

## 5. CONCLUSION AND RECOMMENDATION

The Monte Carlo simulation analysis results show that the rooftop solar project at the FIT Voltaira Vietnam factory has a high degree of financial feasibility and an acceptable level of risk in the context of real-world fluctuations. With a probability of achieving NPV > 0 and IRR > MARR at 87.56%, the project not only ensures economic efficiency in the average scenario but also has significant profit potential under favorable operating conditions. Sensitivity analysis further highlights that the three most influential factors on financial outcomes are initial investment cost, solar energy yield, and the electricity price purchased from EVN.

The initial investment cost has the strongest negative influence, particularly on IRR. Any cost overrun resulting from unexpected expenses or fluctuations in equipment prices can quickly erode profitability. To mitigate this risk, investors are strongly recommended to secure fixed-price EPC contracts with reputable and experienced contractors. Such contracts should include clear provisions on warranties, performance guarantees, and penalty clauses for delays, thereby minimizing the possibility of cost escalation and ensuring greater stability in project cash flows.

Solar energy yield is the second most critical driver, directly affecting both NPV and IRR. Underperformance in yield may result from suboptimal design, shading effects, or system degradation over time. To maximize output, the system design must be optimized according to specific site conditions, including rooftop orientation, tilt angle, and shading analysis. In addition, the use of advanced monitoring technologies such as SCADA, combined with strict maintenance and cleaning schedules, can ensure high and consistent generation throughout the project's lifetime.

The electricity price purchased from EVN is an external factor and subject to market or policy adjustments. Changes in tariff levels can significantly affect the project's revenue stream and payback period. To adapt to this risk, investors should continuously update financial models with revised tariff scenarios, maximize self-consumption of generated electricity, and explore additional income sources from environmental attributes such as I-REC or carbon credits. These measures help diversify revenue streams and reduce dependence on a single variable.

From a policy perspective, this research is highly relevant as Vietnam is completing its legal framework for renewable and rooftop solar power through three new decrees issued in March 2025. Decree No. 57/2025/ND-CP (2025a) introduces the Direct Power Purchase Agreement (DPPA) mechanism, enabling renewable generators and large consumers to transact either via private lines or through the national grid under negotiated contracts, while respecting price caps. This creates a more competitive market setting and encourages industrial enterprises to directly secure stable energy supplies. Decree No. 58/2025/ND-CP (2025b) provides detailed guidance on renewable and new energy development, including incentives for storage-integrated projects, clear provisions for rooftop solar in industrial zones, support for domestic R&D and manufacturing, and transitional rules for legacy rooftop systems. These measures help standardize technical requirements and reduce regulatory uncertainty. Decree No. 61/2025/ND-CP (2025c) clarifies licensing procedures and exemptions, notably allowing unlimited capacity for self-consumption systems not connected to the grid, exemptions up to 30 MW for self-consumption systems with grid connection, and up to 1 MW for small-scale sales to others. This lowers administrative barriers for enterprises adopting rooftop solar while still ensuring operational transparency. Together, these decrees represent a major shift from spontaneous deployment to a more managed, transparent, and incentive-aligned framework. For investors, this reinforces the importance of robust financial risk analysis, such as Monte Carlo simulation, to test cash-flow resilience under different tariff and regulatory scenarios, and to fully capture new opportunities such as DPPA arrangements and internal carbon credits.

In this context, the Monte Carlo simulation method is proven to be a reliable tool for quantifying uncertainty and assessing the probability of investment success. Unlike traditional methods that assume fixed inputs, this model provides investors with a comprehensive view of possible outcomes and enables strategic adjustments based on organizational risk tolerance. Applying this approach to rooftop solar projects in Vietnam's industrial zones not only enhances the quality of investment appraisal but also provides a scientific basis for regulators to formulate transparent, quantitative, and modern energy transition policies.

In conclusion, as the solar market becomes increasingly regulated in terms of technical standards, electricity pricing, and environmental responsibilities, advanced risk analysis tools such as Monte Carlo simulation should be considered an integral part of the investment evaluation process. The findings of this study provide a solid foundation for investors and contribute to the effective, substantive, and sustainable development of renewable energy policy in Vietnam. .

## 6. REFERENCES


Bui, T. T., Luong X. D., Do D. L, Luc, A. T. (2024) Application of Monte Carlo simulation method in financial safety analysis of investment projects. Journal of Management and Economics.

Department of Climate Change (DCC) of MAE, (2021). Net zero emissions: From commitment to action. Ministry of Agriculture and Environment of Vietnam. http://www.dcc.gov.vn/tin-tuc/3808/Phat-thai-rong-bang-0---Tu-cam-ket-den-hanh-dong.html

Doan Thi Chi (2017) Application of Monte Carlo simulation model in investment project appraisal at VietinBank – Phuc Yen Branch (Master's thesis).

Dukić, M., Trninić, M., & Muždeka, S. (2016). Monte Carlo simulation in valuation of investment projects. In Proceedings of the 27th DAAAM International Symposium (pp. 686–692). DAAAM International. DOI: 10.2507/27th.daaam.proceedings.099

Government of Vietnam. (2025a). Decree No. 57/2025/ND-CP on direct power purchase agreement (DPPA). Retrieved from https://vanban.chinhphu.vn/?pageid=27160&docid=213012

Government of Vietnam. (2025b). Decree No. 58/2025/ND-CP detailing several provisions of the Electricity Law on renewable and new energy development. Retrieved from https://vanban.chinhphu.vn/?pageid=27160&docid=213011

Government of Vietnam. (2025c). Decree No. 61/2025/ND-CP on electricity activity licensing. Retrieved from https://vanban.chinhphu.vn/?pageid=27160&docid=213013

Kryzia, D., Kopacz, M., & Kryzia, K. (2020). The valuation of the operational flexibility of the energy investment project based on a gas-fired power plant. Energies, 13(7), 1567. https://doi.org/10.3390/en13071567

Lai, H. D., Luu T. V. (2011). Construction schedule simulation using Monte Carlo method. Vietnam Institute for Building Science and Technology.

Le, D. L., Nguyen Q. T., Nguyen H. H., Vu K. C. (2016). Using Monte Carlo simulation method to estimate contingency time in construction scheduling, HUCE Journal of Construction Science and Technology.

Lee, B., Heo, J., Choi, N. H., & Moon, C. (2017). Economic evaluation with uncertainty analysis using a Monte-Carlo simulation method for hydrogen production from high-pressure PEM water electrolysis in Korea. International Journal of Hydrogen Energy, 42(39), 24612–24619. https://doi.org/10.1016/j.ijhydene.2017.08.033

Ministry of Construction of Vietnam. (2025). Reducing electricity costs by harnessing rooftop solar power. Retrieved from https://moc.gov.vn/en/news/86928/reducing-electricity-costs-by-harnessing-rooftop-solar-power.aspx

Pritchard, C. L. (2015). Risk management: Concepts and guidance (5th ed.). CRC Press.

Pham, M. H., Pham, T. A., Do, T. S., & Nguyen, T. V. (2023). Risk analysis and assessment in public–private partnership (PPP) projects using Monte Carlo simulation: Evidence from Vietnam. Journal of Construction & Urban Management, 88(2), 74–77.

Sahu, S. K. (2016). Monte Carlo simulation in platinum mine project evaluation (MBA thesis). University of the Witwatersrand.

Salling, K. B., & Leleur, S. (2006). Assessment of transport infrastructure projects by the use of Monte Carlo simulation: The CBA-DK model. Proceedings of the Winter Simulation Conference, 1537–1544. https://doi.org/10.1109/WSC.2006.322924

Thuy Tuong (2023). Firms in Vietnam adopt sustainable practices, grip onsite renewable energy. The Investor. Retrieved from https://theinvestor.vn/firms-in-vietnam-adopt-sustainable-practices-grip-onsite-renewable-energy-d4971

To, V. T., Nguyen, T. P., Ngo, L. L. and Ribbe L. (2017). Study on generating flow data series using Monte Carlo simulation to support rational allocation of water resources in the Vu Gia–Thu Bon river basin. Journal of Water Resources Science and Technology. VJOL.

Tran Tri Dung (NA). Random model and Monte Carlo simulation for Son La–Hoa Binh hydropower. https://vncold.vn/Modules/CMS/Upload/10/KhoaHocCongNghe/110321/TTriDung0.pdf.

Thi, T., Duong, X. L., & Do, D. D. (2024). Application of Monte Carlo simulation in assessing investment risks of construction projects: A case study of Nghi Phu–Hung Lo urban area. Journal of Materials & Construction, 14(3), 172–175.

Tran, T. T. V. (2024). Application of Monte Carlo simulation in investment risk analysis of a hotel project: A case study of M Garden City Hotel. Journal of Materials & Construction, 14(6), 105–111.

Vietnam Chamber of Commerce and Industry (VCCI). (2024). Rooftop Solar Power: Solutions for Businesses to Achieve Sustainability Goals. Vietnam Business Forum Magazine. Retrieved from https://vccinews.com/news/58318/rooftop-solar-power-solutions-for-businesses-to-achieve-sustainability-goals.html

Vietnam Electricity (EVN). (2025). Retail electricity tariff (according to Decision No. 1279/QD-BCT dated 09/05/2025 of the Ministry of Industry and Trade). Retrieved from https://www.evn.com.vn/d/vi-VN/news/Bieu-gia-ban-le-dien-theo-Quyet-dinh-so-1279QD-BCT-ngay-0952025-cua-Bo-Cong-Thuong-60-28-502668

Vu Phong Energy Group (VPEG). (2022, June 5). What is an EPC contract and what are its advantages? Retrieved from https://vuphong.vn/epc-la-gi/

Wicaksono, F. D., Arshad, Y. B., & Sihombing, H. (2019). Monte Carlo net present value for techno-economic analysis of oil and gas production sharing contract. International Journal of Technology, 10(4), 829–840. https://doi.org/10.14716/ijtech.v10i4.2051