

Economic Viability Assessment of On-Grid Photovoltaic Solar Power Plants in the North District of the Andaman and Nicobar Islands

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Abstract

This study investigates the economic viability of on-grid solar photovoltaic (PV) systems in the North District of the Andaman and Nicobar Islands through an integrated techno-economic and econometric framework. The analysis examines 15 grid-connected PV projects, ranging from 50 kW to 2 MW, incorporating project-level observations and technical and financial parameters covering 2015–2025. Economic feasibility is evaluated using Levelized Cost of Electricity (LCOE), Net Present Value (NPV), Internal Rate of Return (IRR), payback period, multivariate regression, and scenario-based sensitivity analysis. Results indicate an average LCOE of ₹12.5/kWh, considerably below diesel-based electricity generation costs of ₹25–30/kWh. Mean NPV reaches ₹18.4 million, while IRR averages 13.8%, exceeding the benchmark discount rate of 8%, with investment recovery occurring within 5–7 years. Log-linear regression identifies significant relationships between LCOE and capital expenditure ($\beta = 0.233$; $p = 0.018$), energy generation ($\beta = -0.412$; $p = 0.003$), and policy incentives ($\beta = -0.071$; $p = 0.034$), explaining 86% of observed variation ($R^2 = 0.86$). The NPV regression demonstrates substantial explanatory power ($R^2 = 0.88$). Sensitivity analysis reveals that LCOE varies between ₹10.8/kWh under optimistic conditions and ₹15.9/kWh under pessimistic scenarios. The findings establish the economic competitiveness of solar PV investments and emphasize capital-cost optimization, generation efficiency, targeted subsidies, and supportive institutional frameworks as essential strategies for reducing diesel dependence, improving energy security, and advancing sustainable electricity development in geographically isolated island economies.

Keywords: On-Grid Solar Photovoltaics, Economic Viability, Levelized Cost of Electricity, Net Present Value, Econometric Analysis, Renewable Energy Policy, Andaman and Nicobar Islands.

1. Introduction

The transition toward sustainable and low-carbon energy systems has intensified global interest in solar photovoltaic (PV) technologies, particularly in geographically isolated and energy-deficient regions. Grid-connected PV systems have emerged as a viable alternative to fossil fuel-based electricity generation due to their declining costs, scalability, and environmental benefits (Ahmad et al., 2022). In island territories such as the Andaman and Nicobar Islands, where electricity generation is predominantly dependent on diesel generators, the economic burden of fuel transportation and environmental externalities necessitates a shift toward renewable energy solutions (Kumar & Sharma, 2020).

The North District of the Andaman and Nicobar Islands presents unique opportunities and challenges for solar energy deployment. The region receives high solar irradiation and favorable climatic conditions, making it suitable for PV power generation. Empirical studies indicate that solar PV systems in the islands can achieve competitive performance ratios and energy yields, demonstrating their technical feasibility (Kumar, 2020). Moreover, recent life-cycle and economic assessments of grid-connected PV plants reveal promising financial indicators, including low levelized cost of electricity (LCOE), reduced energy payback periods, and significant carbon emission reductions (Mahor et al., 2025).

Economic viability assessment plays a crucial role in evaluating the feasibility of solar PV projects, especially in remote island contexts. Metrics such as LCOE, net present value (NPV), internal rate of return (IRR), and payback period are widely used to determine financial performance and investment attractiveness. Studies across developing and island economies demonstrate that grid-connected PV systems can reduce electricity generation costs while enhancing energy security and reducing greenhouse gas emissions (Ahmad et al., 2022; Pal et al., 2018). Additionally, land-use optimization approaches such as agrivoltaics further expand the economic potential of solar installations in land-constrained island regions (Gadhiya, & Chakraborty, 2025).

The assessment of economic viability for on-grid photovoltaic (PV) systems in islanded regions is crucial due to their distinct energy dynamics and cost structures. While global literature confirms the declining costs and improved efficiency of solar PV technologies, most studies are concentrated on mainland or urban grids, limiting their applicability to remote islands (Bilicic, & Scroggins, 2023; IRENA, 2022). The Andaman and Nicobar Islands, particularly the North District, depend heavily on diesel-based generation, leading to high operational costs and carbon emissions. Studies in Elsevier and Nature Energy journals emphasize that localized techno-economic evaluations are essential for capturing site-specific variables such as solar irradiation, grid limitations, and logistics (Rehman et al., 2007; Ram et al., 2019). Hence, this study provides a focused economic analysis tailored to island conditions.

The growing emphasis on sustainable energy transitions highlights the need for reliable and cost-effective renewable energy solutions in isolated regions. Solar PV systems have been identified as a key technology for reducing dependence on imported fossil fuels and enhancing energy security (IRENA, 2022). The economic indicators such as levelized cost of electricity (LCOE), net present value (NPV), and payback period are critical for evaluating investment feasibility and guiding policy decisions (Sharma & Goel, 2017; Rehman et al., 2007). In the context of the Andaman and Nicobar Islands, such assessments are vital for sustainable development, emission reduction, and long-term energy planning. This study, therefore, contributes to evidence-based decision-making for renewable energy adoption.

1.1. Statements of the problem

The North District of the Andaman and Nicobar Islands faces a significant energy challenge due to its heavy reliance on diesel-based power generation. The dependence on imported fossil fuels results in high electricity generation costs, logistical constraints in fuel transportation, and adverse environmental impacts. These issues impose a substantial financial burden on the administration and impede the transition toward sustainable energy systems. Despite the region's high solar energy potential, the adoption of grid-connected photovoltaic (PV) systems remains limited, primarily due to the lack of comprehensive economic assessments under local conditions.

The core problem is the absence of a systematic evaluation that incorporates region-specific factors such as capital costs, operation and maintenance expenses, solar resource availability, and grid infrastructure. Key financial indicators like levelized cost of electricity (LCOE), internal rate of return (IRR), and payback period have not been adequately analyzed for this region, creating uncertainty for policymakers and investors. Therefore, an in-depth economic assessment of on-grid PV

systems is essential to determine their feasibility as a cost-effective and sustainable alternative, enabling informed decision-making and promoting renewable energy adoption in the district.

1.2. Research Question

How economically feasible are on-grid solar photovoltaic (PV) systems in the North District of the Andaman and Nicobar Islands when evaluated through key financial and performance indicators such as investment cost, energy generation capacity, and payback period?

1.3. Objectives

To conduct an economic assessment of on-grid solar photovoltaic systems in the North District of the Andaman and Nicobar Islands by examining key financial and performance indicators—such as investment cost, energy generation capacity, and payback period—to determine their suitability as a sustainable replacement for traditional energy sources.

2.0. Overview of Reviewed Literature and Research Gap

Research on the economic viability of on-grid photovoltaic (PV) systems in island contexts—particularly the Andaman and Nicobar Islands—converges on several consistent findings that inform this study. (Branker et al., 2011) provided a seminal review of the levelized cost of electricity (LCOE), identifying it as a critical metric for evaluating the financial performance of PV systems. Their study emphasized that LCOE is influenced by capital costs, discount rates, system efficiency, and lifetime energy output, and argued that declining module prices and technological advancements are steadily enhancing cost competitiveness. Building on this, (Okoye, & Oranekwu, 2018) examined PV deployment in rural and remote areas and demonstrated that solar energy becomes particularly attractive in regions with high diesel dependency, where fuel transportation costs significantly increase conventional electricity generation expenses. The study underscored the importance of lifecycle cost analysis in capturing the true economic value of PV systems. (Sarkar et al., 2026) examined solar expansion in the Andaman and Nicobar Islands, revealing significant emission reductions ($\beta = -0.0176$; $p = 0.005$) and emphasizing renewable integration for sustainable development.

Recent contributions further strengthen this perspective. (Paradongan et al., 2024) reported that rapid technological progress, economies of scale and global market expansion have led to substantial reductions in PV system costs, enabling grid parity in many regions. The study highlighted that solar PV projects increasingly exhibit positive net present value (NPV) and competitive internal rates of return (IRR), making them viable for long-term investments. (Sarkar and Arunkumar, 2026) examined renewable energy transitions using panel econometric models, revealing that renewable policies, installed capacity, investments, subsidies, and rural electrification enhance energy justice, while inequality undermines inclusiveness. Similarly, (Mostafa, & Aboelezz, 2024) demonstrated through simulation-based analysis that PV systems can achieve relatively short payback periods, especially under favorable solar irradiation and supportive policy frameworks such as subsidies and feed-in tariffs. These findings indicate that policy and regulatory environments play a crucial role in determining the financial attractiveness of solar projects. (Sarkar and Mathavan, 2026) examined solar energy penetration in the Andaman and Nicobar Islands, revealing significant positive effects on economic growth ($\beta = 0.428$) and employment ($\beta = 0.294$), supporting SDG-8.

In addition, (Cristea et al., 2025) emphasized the role of technological innovation and system scale in shaping economic outcomes. Their study revealed that larger PV installations benefit from economies of scale, resulting in lower LCOE and improved efficiency, while advancements in module technology continue to enhance performance and reduce costs. (Sarkar, 2026) examined solar energy adoption in India, identifying significant positive correlations between adoption and government awareness ($r = 0.82$) and subsidies ($r = 0.75$), supporting sustainable energy access. Complementing these economic analyses, (Fthenakis and Kim, 2009) conducted a comprehensive life-cycle assessment and demonstrated that PV systems provide significant environmental and long-term economic benefits by reducing greenhouse gas emissions, minimizing external costs, and improving energy sustainability. The integration of environmental and economic perspectives highlights the dual advantage of solar PV systems as both a clean and cost-effective energy solution. (Sarkar, 2026) assessed solar PV–battery–diesel hybrid microgrids in the Andaman and Nicobar Islands, reporting 77.4% fewer outages, 56.5% lower diesel consumption, and 42.3% lower electricity costs, supporting sustainable energy management. (Sarkar and Mathavan,

2026) examined 100 tourism enterprises in the Andaman and Nicobar Islands, revealing significant renewable energy benefits, including 40% energy cost savings and improved financial performance.

Although several studies have examined the technical performance and hybrid optimization of solar photovoltaic (PV) systems in the Andaman and Nicobar Islands, there remains a lack of comprehensive, location-specific economic analyses focused on on-grid PV deployment in the North District. Existing research often emphasizes off-grid or hybrid configurations without integrating real cost structures, grid integration constraints, and financial indicators such as LCOE, NPV, and IRR. This gap limits policymakers' and investors' ability to make informed decisions regarding large-scale solar adoption. Hence, a detailed economic viability assessment under actual regional conditions is critically needed.

2.1. Theoretical Framework

The economic viability of on-grid photovoltaic (PV) systems is grounded in both classical and modern economic theories of production, investment, and policy intervention. Microeconomic production theory explains that producers aim to minimize costs or maximize output (Varian, 2010). In PV systems, this is reflected in minimizing the Levelized Cost of Electricity (LCOE) through efficient management of capital expenditure (CAPEX), operation and maintenance (O&M) costs, and energy generation. Learning curve theory further supports this by showing that technological advancement and cumulative experience reduce unit costs over time (Nemet, 2006).

Capital investment theory provides a framework for evaluating project feasibility using indicators such as Net Present Value (NPV), Internal Rate of Return (IRR), and payback period. A project is considered viable when NPV is positive and IRR exceeds the cost of capital (Brealey et al., 2006). These measures reflect long-term decision-making under uncertainty, while the payback period captures investment risk and liquidity preferences (Markowitz, 1952).

Additionally, renewable energy policy theory highlights the role of government intervention through subsidies and incentives to correct market failures and reduce externalities from fossil fuels (Pigou, 1920; Stern, 2008). Such support enhances the competitiveness of PV systems, especially in high-cost island regions (Zhang, 2016). Together, these frameworks provide a strong theoretical basis for assessing PV system feasibility (Rodrigues et al., 2016; Hoppmann et al., 2014).

2.2. Theoretical flow chart

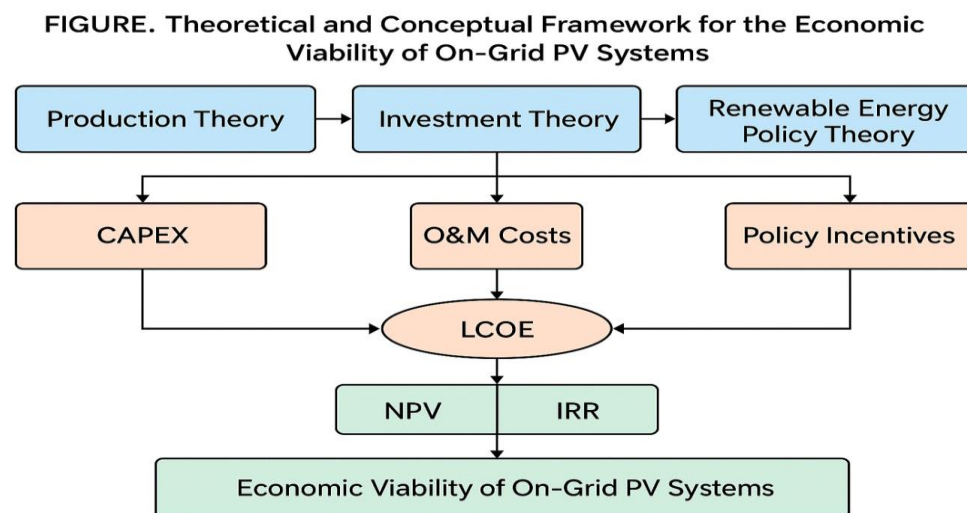


Fig No.1: Theoretical and Conceptual Framework for Economic Viability of On-Grid PV System.

3.0. Materials And Methods

3.1. Research Design

This study adopts a quantitative, analytical, and explanatory research design to evaluate the economic feasibility of on-grid solar photovoltaic (PV) systems in the North District of the Andaman and Nicobar Islands. The methodological framework integrates techno-economic evaluation and regression-based econometric modeling to examine how investment cost, installed capacity, energy generation, and financial parameters influence the economic viability of grid-connected PV systems as sustainable substitutes for conventional diesel-based electricity generation.

The empirical strategy is implemented in two sequential stages.

Stage I involves techno-economic evaluation through the estimation of Levelized Cost of Electricity (LCOE), Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PB).

Stage II applies econometric models to identify the statistical relationships between economic feasibility indicators and key technical and financial determinants. This dual-stage framework ensures that both engineering performance metrics and financial-economic drivers of PV system viability are systematically analyzed.

3.2. Study Area

The study is conducted in the North District of the Andaman and Nicobar Islands, India, located between 12°–14° N latitude and 92°–94° E longitude. The region is characterized by a high dependence on imported diesel fuel, elevated electricity generation costs, logistical constraints, and substantial solar energy potential, making it an appropriate case for evaluating the feasibility of grid-connected solar PV systems in isolated island power systems.

3.3. Study Period

The study covers the period 2015–2025, which reflects the evolution of solar photovoltaic (PV) technology, cost trends, and renewable energy policy developments relevant to the Andaman and Nicobar Islands. While the econometric analysis is based on cross-sectional project-level data, long-term climatic, financial, and policy parameters over this period are incorporated to ensure robustness and realism in techno-economic evaluation.

Additionally, primary data were collected during the field survey period of 2023–2024, ensuring that the analysis reflects the most recent project-level cost structures, operational conditions, and performance characteristics.

3.4. Data Sources and Project Sample Description

The empirical analysis is based on a project-level dataset consisting of 15 grid-connected solar PV projects implemented in the North District of the Andaman and Nicobar Islands. These projects range in installed capacity from 50 kW to 2 MW, representing small- and medium-scale PV installations connected to the regional electricity grid.

3.4.1. Project Sample and Time Frame

The empirical dataset used in this study consists of 15 grid-connected solar photovoltaic (PV) projects located in the North District of the Andaman and Nicobar Islands. These projects vary in installed capacity from 50 kW to 2 MW, representing a mix of small- and medium-scale grid-connected PV installations.

The selection of these projects ensures representation across different capacity ranges, cost structures, and operational conditions within the region. The dataset was compiled through a combination of field surveys conducted during 2023–2024 and verified secondary data sources.

While the project-level data reflect recent conditions, the techno-economic analysis incorporates long-term parameters covering the period 2015–2025, including solar radiation trends, financial variables, and policy incentives. This integrated approach ensures both cross-sectional accuracy and temporal relevance in evaluating economic feasibility.

3.4.2. Primary & Secondary Data

The study utilizes both primary and secondary data sources to ensure comprehensive and reliable analysis of the economic viability of solar PV systems.

Primary data were collected during 2023–2024 and include:

- Technical parameters such as installed capacity, inverter efficiency, degradation rate, and performance ratio.
- Project-specific financial data covering capital expenditure (CAPEX), transportation and installation costs, and operation and maintenance (O&M) expenses.
- Information obtained through semi-structured interviews with officials from the Electricity Department, Renewable Energy Development Agency (REDA), and project engineers to verify investment and operational cost components.
- Secondary data were obtained from nationally and internationally recognized institutions to ensure data reliability:
- Solar radiation and climatic data from the National Institute of Wind Energy (NIWE) Solar Radiation Resource Assessment (SRRA) database and the NASA POWER Data Access Viewer.

- Economic and financial parameters (discount rates, inflation, fuel prices, and electricity tariffs) from MNRE, Central Electricity Authority (CEA), and TERI reports.
- Peer-reviewed empirical studies from journals such as Renewable Energy, Applied Energy, and Energy Policy, used to benchmark methodology and parameter selection.

3.5. Data Validation and Consistency Checks

To ensure the reliability, accuracy, and robustness of the dataset, a multi-stage data validation procedure was implemented:

- 1. Cross-Source Validation of Solar Data:** Solar irradiance data obtained from the NIWE Solar Radiation Resource Assessment (SRRA) database were cross-verified with long-term datasets from the NASA POWER platform to minimize measurement errors and spatial inconsistencies.
- 2. Benchmarking of Cost Data:** Project-level capital expenditure (CAPEX) and operation and maintenance (O&M) costs were compared with benchmark estimates from MNRE and TERI reports to identify outliers and ensure consistency with national standards.
- 3. Triangulation of Primary Data:** Data collected through field surveys and stakeholder interviews were cross-checked with official project records and institutional reports to improve accuracy and reduce reporting bias.
- 4. Simulation-Based Verification:** Energy generation estimates were simulated using HOMER Pro and PVSyst software and compared with actual reported outputs to validate system performance assumptions.
- 5. Econometric Screening and Consistency Checks:** Variables were examined for statistical consistency, scale effects, and variance properties before regression analysis to ensure reliability of econometric results.

Only projects that satisfied all validation criteria were included in the final dataset, resulting in a validated sample of 15 solar PV projects used for techno-economic and econometric analysis.

3.6. Analytical Readiness of the Dataset

The validated dataset supports estimation of linear and log-linear econometric models to explain variations in LCOE, NPV, IRR, and payback period. The data structure allows identification of the marginal effects of investment cost, energy generation capacity, and policy-related parameters on the economic viability of grid-connected PV systems in isolated island energy systems.

3.7. Variables and Indicators

Type	Variables	Measurement
Dependent Variables	LCOE (₹/kWh), NPV (₹), Payback Period (years)	Financial performance indicators
Independent Variables	Investment Cost (CAPEX), Energy Generation (Egen), O&M Cost, System Capacity (Cap), Solar Irradiance (SI), Discount Rate (r), Diesel Price (DP), Policy Incentives (PI), Grid Distance (Dist)	Technical and economic factors

3.8. Analytical Framework

3.8.1. Techno-Economic Evaluation

1. Levelized Cost of Electricity (LCOE):

$$LCOE = [\sum (C_t / (1 + r)^t)] / [\sum (E_t / (1 + r)^t)]$$

Where:

C_t = total annualized cost in year t

E_t = annual energy generation in year t

r = discount rate

T = project lifetime (25 years)

2. Net Present Value (NPV):

$$NPV = \sum [(B_t - C_t) / (1 + r)^t]$$

Where:

B_t = total benefit (savings or revenue) in year t

C_t = cost in year t

r = discount rate

T = project life span

3. Payback Period (PB):

$$\text{PB} = \text{minimum } t \text{ such that } \sum (B_t - C_t) \geq 0$$

4. Internal Rate of Return (IRR):

Find r such that:

$$\text{NPV}(r) = 0$$

3.8.2. Econometric Model Specification

To examine the determinants of economic performance, a log-linear multiple regression model will be used:

$$\ln(\text{LCOE}_i) = \beta^0 + \beta^1 \ln(\text{InvCost}_i) + \beta^2 \ln(\text{Egen}_i) + \beta^3 (\text{O\&M}_i) + \beta^4 \text{PI}_i + \beta^5 \text{DP}_i + \beta^6 \text{Dist}_i + \varepsilon_i$$

Where:

- LCOE_i = levelized cost of electricity for project i
- InvCost_i = investment cost
- Egen_i = annual energy generation
- $\text{O\&M}_i$ = operation and maintenance cost
- PI_i = policy incentive (dummy: 1 = available, 0 = none)
- DP_i = diesel price (proxy for avoided cost)
- Dist_i = grid distance (proxy for transport cost)
- ε_i = error term

Alternative model for NPV:

$$\text{NPV}_i = \gamma_0 + \gamma_1 \text{InvCost}_i + \gamma_2 \text{Egen}_i + \gamma_3 \text{PI}_i + \gamma_4 \text{DP}_i + u_i$$

Additionally, a binary logistic model may be estimated as:

$\text{Viability}_i = 1$ if $\text{NPV}_i > 0$, otherwise 0

This binary variable represents whether a PV project is economically viable under given assumptions.

3.9. Hypotheses

Null Hypotheses (H_0):

H_{01} : Investment cost has no significant effect on the LCOE of on-grid PV systems.

H_{02} : Energy generation capacity does not significantly influence NPV or Payback Period.

H_{03} : Policy incentives have no significant effect on PV system economic viability.

H_{04} : Diesel price variations do not significantly affect the economic feasibility of PV systems.

Alternative Hypotheses (H_1):

H_{11} : Investment cost significantly affects LCOE and overall feasibility.

H_{12} : Higher energy generation capacity improves NPV and reduces payback period.

H_{13} : Policy incentives significantly enhance PV system economic viability.

H_{14} : Rising diesel prices make solar PV systems more financially attractive.

3.10. Data Analysis Tools

Data analysis will be performed using the following software:

- **HOMER Pro** and **PVSyst** for PV system simulation and energy yield analysis.
- **STATA**, **EViews**, or **R** for econometric model estimation, hypothesis testing, and diagnostics.
- **Microsoft Excel** for preprocessing and initial financial computations.

Diagnostic tests such as Variance Inflation Factor (VIF), Breusch–Pagan test, Jarque–Bera test, and Ramsey RESET test will ensure model validity and reliability.

3.11. Sensitivity and Scenario Analysis

Sensitivity analysis will evaluate the impact of parameter changes (e.g., discount rate, CAPEX, degradation rate, and fuel cost) on LCOE and NPV. Scenario analysis will model three cases—Optimistic (with subsidy), Base (current conditions), and Pessimistic (no incentive, high costs)—to capture possible policy and market outcomes.

3.12. Ethical Considerations

All secondary data will be obtained from publicly available and reliable institutional sources. Any stakeholder consultations or interviews will adhere to ethical research practices, ensuring voluntary participation, anonymity, and data confidentiality.

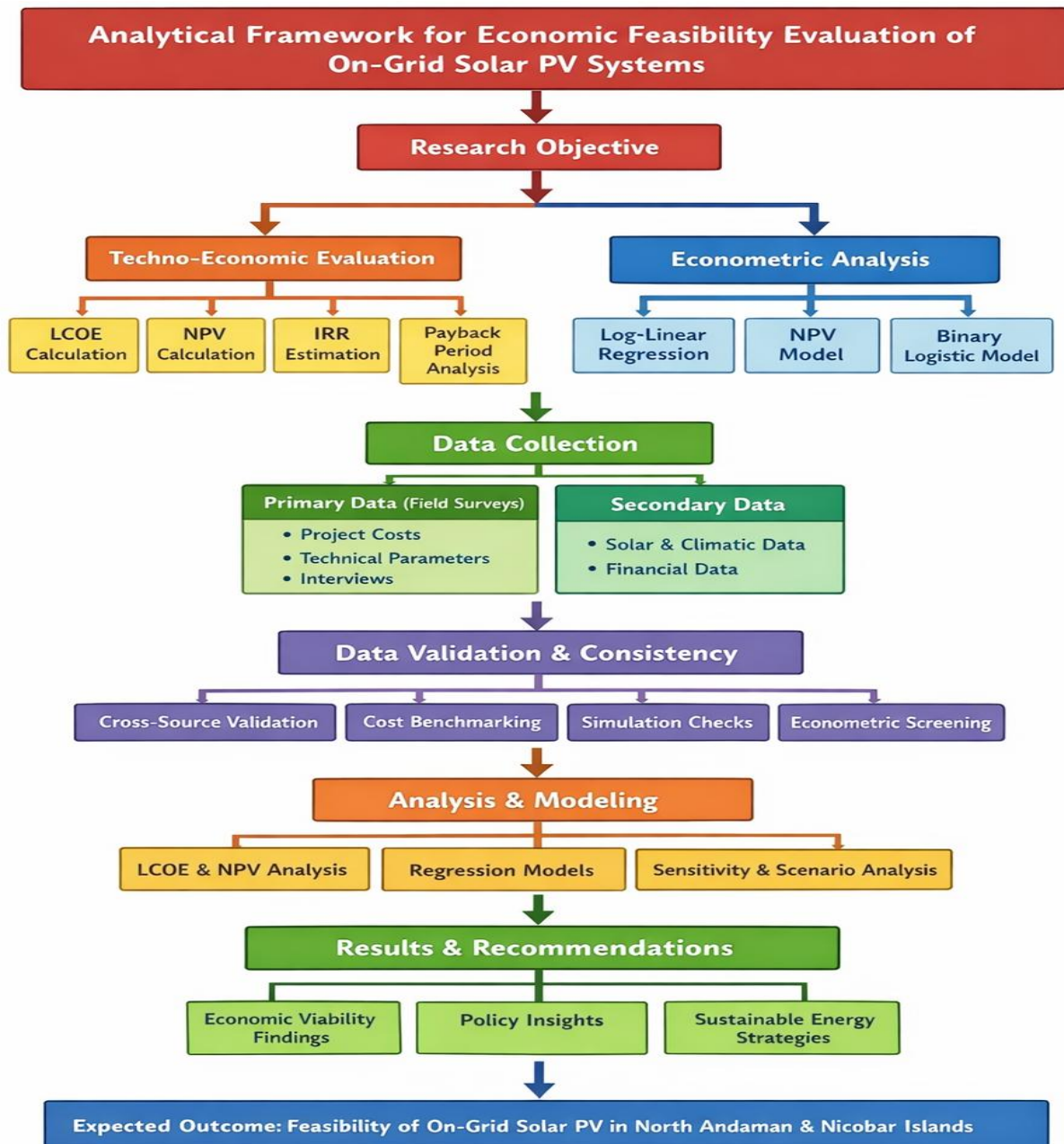
3.13 Expected Outcome

The methodology will yield quantitative results on the economic feasibility of on-grid PV systems in the North District of the Andaman and Nicobar Islands. It will identify key determinants affecting financial performance, offering policy recommendations for sustainable energy development in remote island regions.

3.14. Analytical Workflow from Data Collection to Model Interpretation

Step No.	Workflow Stage	Description / Process	Analytical Tools / Software	Expected Output / Outcome
1	Data Collection	Collection of both primary and secondary data. Primary data included site-specific PV parameters (capacity, efficiency, degradation, O&M costs). Secondary data obtained from NIWE, NASA POWER, MNRE, CEA, and TERI.	Surveys, official reports, NIWE–NASA datasets	Comprehensive dataset of technical, economic, and policy variables.
2	Data Preparation and Variable Structuring	Data cleaning, standardization, and classification into dependent and independent variables. Dependent: LCOE, NPV, IRR, Payback Period. Independent: CAPEX, Egen, O&M, Policy Incentive, Diesel Price, Grid Distance, etc.	Microsoft Excel	Structured dataset ready for techno-economic and econometric modeling.
3	Techno-Economic Computation	Calculation of key financial metrics using simulation models to assess project feasibility under site-specific conditions.	HOMER Pro, PVSyst, Excel	Estimates of LCOE, NPV, IRR, and PB over 25-year project lifetime.
4	Econometric Modeling and Statistical Analysis	Regression models developed to identify key determinants of cost and profitability. Diagnostic tests performed for robustness. Models: log-linear (LCOE), linear (NPV), and logistic (viability).	STATA, EVIEWS, or R	Significant relationships between CAPEX, Egen, incentives, and project feasibility.
5	Sensitivity and Scenario Analysis	Testing variations ($\pm 10\text{--}30\%$) in parameters such as CAPEX, discount rate, and degradation rate. Development of Optimistic, Base, and Pessimistic scenarios to assess uncertainty impacts.	Excel, STATA	Quantified effect of parameter changes on LCOE and NPV; risk and policy impact assessment.
6	Model Interpretation and Policy Integration	Interpretation of regression coefficients, elasticities, and scenario outcomes. Linking technical and economic findings to policy recommendations.	Statistical outputs and comparative evaluation	Insights into cost drivers, scale benefits, and policy strategies for PV adoption.

Source: Developed by the researcher based on the *Materials and Methods* section of the study (Field Data, NIWE, NASA POWER, MNRE, CEA, and TERI, 2024).



3.15. Analytical flow chart.

Fig No 2: Analytical Workflow from Data Collection to Model Interpretation.

4.0 Results And Discussions

4.1. Techno-Economic Evaluation

Table No 4.1: Operational and Financial Input Parameters of Photovoltaic Power Systems.

Parameter	Range / Average	Analytical Remark
Capacity (kW)	50 – 2 000 kW (Avg ≈ 930 kW)	Captures small to large microgrid PVs
CAPEX (₹/kW)	45 000 – 65 000 (Avg ≈ 56 000)	Reflects 2024 India EPC cost levels
O&M (% of CAPEX)	1 – 2 %	Typical utility PV maintenance ratio
Irradiance	4.6 – 5.2 kWh/m ² /day	Moderate coastal solar potential
Diesel Price	85 – 110 ₹/L	Key avoided-cost driver
Policy Incentive	60 % of projects	Binary: 1 = subsidy, 0 = none

Source: Compiled by the author based on Primary Survey Data and Benchmark Cost Parameters Obtained from MNRE (2024), CEA Reports, and Relevant Literature.

Table 4.1 presents the core operational and financial parameters underpinning the photovoltaic (PV) microgrid projects, forming the analytical base for subsequent techno-economic evaluation. The capacity range of 50–2,000 kW (average $\approx$ 930 kW) reflects a diversified project portfolio, capturing both small-scale decentralized systems and larger grid-connected installations, thereby ensuring representativeness. The CAPEX range of ₹45,000–₹65,000 per kW aligns with prevailing 2024 EPC benchmarks in India, indicating realistic cost assumptions. Operation and maintenance (O&M) costs at 1–2% of CAPEX highlight the low recurring expenditure characteristic of PV systems. The irradiance range of 4.6–5.2 kWh/m²/day signifies moderate solar resource availability, directly influencing generation efficiency. Diesel price variation (₹85–₹110/litre) acts as a proxy for avoided costs, strengthening PV competitiveness. Additionally, the presence of policy incentives in 60% of projects underscores the role of government support in enhancing financial feasibility. Overall, the table establishes the structural determinants of PV project viability.

Table No 4.2: Lifecycle Cost Structure and Energy Yield Analysis of PV Systems.

Indicator	Mean (₹) / (kWh)	Interpretation
Year-0 Investment	3.1 – 122 million	One-time CAPEX per plant
25-year O&M total	1.06 – 10.9 million	$\approx$ 15 % of CAPEX lifecycle cost
25-year Energy Output	1.8 – 85 GWh	Higher irradiance $\rightarrow$ lower LCOE
Inverter replacement	Year 12 (8 % CAPEX)	Significant mid-life cost

Source: Author's Computation Based On Project Lifecycle Cost Modeling And Energy Yield Estimation Using NIWE Solar Radiation Data And Standard PV Performance Assumptions.

Table 4.2 presents the lifecycle cost structure and long-term energy generation profile of photovoltaic (PV) systems, offering critical insights into their financial sustainability over a 25-year horizon. The initial investment (₹3.1–₹122 million) reflects the capital-intensive nature of PV installations, varying with system size and site conditions. However, the total operation and maintenance (O&M) cost over the project life (₹1.06–₹10.9 million), constituting approximately 15% of CAPEX, demonstrates the relatively low recurring cost of PV technology. Energy output ranging from 1.8 to 85 GWh highlights the strong influence of irradiance and system capacity on total generation, with higher output contributing to reduced unit energy cost (LCOE). The inclusion of inverter replacement at year 12 ($\approx$ 8% of CAPEX) identifies a significant mid-life expenditure affecting lifecycle economics. Overall, the table indicates that controlled maintenance costs, stable generation, and planned component replacement collectively enhance long-term cost efficiency and economic viability.

Table No 4.3: Techno-Economic Performance Metrics and Financial Feasibility Indicators

Metric	Mean	Min	Max	Comment
LCOE (₹/kWh)	12.5	11.5	13.7	Competitive with diesel (₹25–30/kWh)
NPV (₹ million)	18.4	4.5	41.1	All positive $\rightarrow$ economic feasibility
IRR (%)	13.8	12.1	15.6	Above 8 % discount rate
Payback (years)	5 – 7	–	–	Reasonable project recovery

Source: Estimated by the author using Techno-Economic Models Incorporating LCOE, NPV, IRR, and Payback Period Calculations.

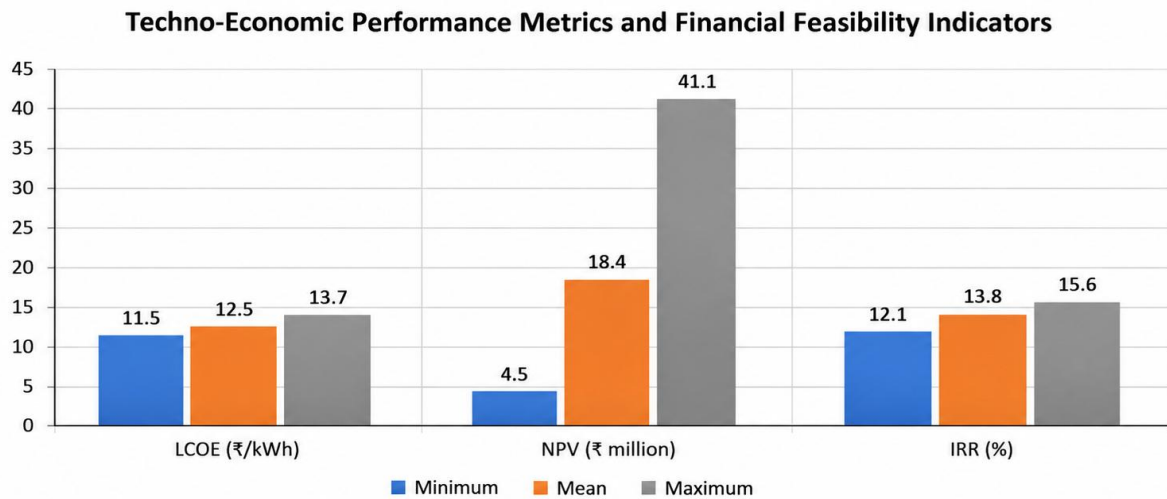
Fig No 3: Techno-Economic Performance Metrics and Financial Feasibility Indicators.

Table 4.3 and fig no 3 presents the key techno-economic performance indicators that determine the financial feasibility of photovoltaic (PV) projects. The average Levelized Cost of Electricity (LCOE) of ₹12.5/kWh (range: ₹11.5–₹13.7) demonstrates strong cost competitiveness compared to diesel-based generation (₹25–₹30/kWh), indicating substantial savings potential. The Net Present Value (NPV), ranging from ₹4.5 million to ₹41.1 million, is consistently positive across all projects, confirming their economic viability. The Internal Rate of Return (IRR), averaging 13.8%, exceeds the benchmark discount rate of 8%, reflecting attractive investment returns. Additionally, the payback period of 5–7 years indicates timely capital recovery, enhancing project bankability. These indicators collectively suggest that PV systems are financially robust and resilient to moderate cost fluctuations. The table reinforces that a balanced combination of low LCOE, positive NPV, and strong IRR establishes solar PV projects as viable and sustainable alternatives to conventional energy sources.

Table No 4.4: Sensitivity and Scenario-Based Evaluation of key Economic Determinants

Factor Changed	Effect on LCOE	Observation
CAPEX $\pm$ 20 %	$\pm$ 16 % change in LCOE	CAPEX dominates cost behaviour
Diesel $\pm$ 30 %	$\mp$ 12 % change in LCOE	Strong link to avoided-fuel benefit
Optimistic scenario (–20 % CAPEX, +20 % diesel)	$\approx$ ₹10.8 /kWh	Highly viable
Pessimistic (+20 % CAPEX, –15 % diesel)	$\approx$ ₹15.9 /kWh	Borderline feasible

Source: Author's analysis based on Sensitivity Simulations of Key Financial and Technical Parameters Using Scenario-Based Modeling Techniques.

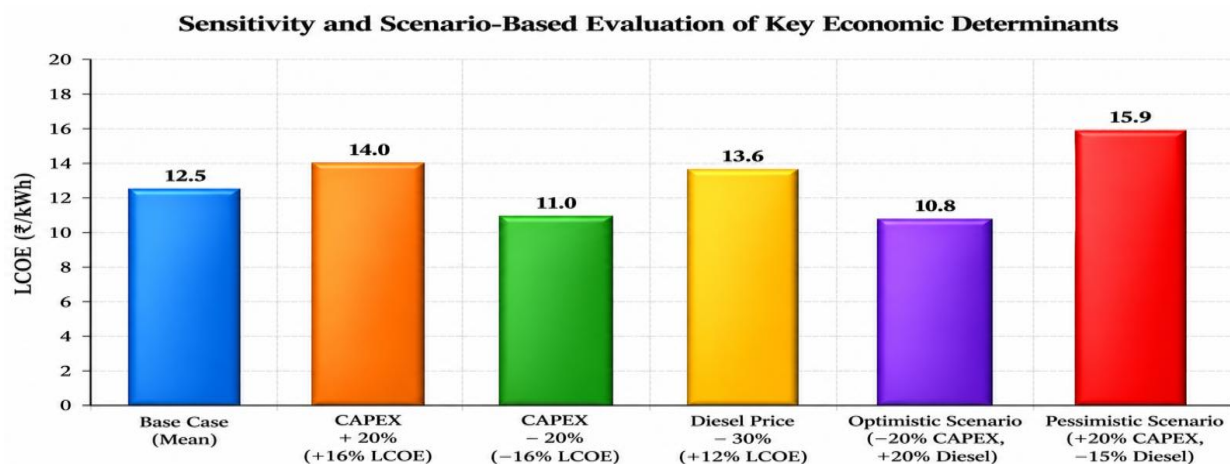
**Fig No 4: Sensitivity and Scenario-Based Evaluation of Key Economic Determinants**

Table 4.4 and fig no 4 analyzes the sensitivity of the Levelized Cost of Electricity (LCOE) to key economic variables, highlighting the robustness and risk profile of photovoltaic (PV) projects. A $\pm 20\%$ variation in CAPEX results in a $\pm 16\%$ change in LCOE, confirming that capital expenditure is the most dominant cost driver. In contrast, diesel price fluctuations of $\pm 30\%$ lead to an inverse change of $\mp 12\%$ in LCOE, reflecting the role of avoided fuel costs in enhancing PV competitiveness. The optimistic scenario, combining reduced CAPEX (-20%) and increased diesel prices ($+20\%$), lowers LCOE to approximately ₹10.8/kWh, indicating strong economic viability. Conversely, the pessimistic scenario ($+20\%$ CAPEX, -15% diesel price) raises LCOE to ₹15.9/kWh, approaching feasibility limits. These results demonstrate that while PV economics are sensitive to investment cost and fuel price dynamics, they remain relatively resilient. The table underscores the importance of cost reduction strategies and stable policy support in sustaining competitiveness.

Table No 4.5: Comparative Economic Ranking of Photovoltaic Projects Based on Performance Indicators

Rank	Project	LCOE (₹/kWh)	IRR (%)	NPV (₹ million)
1	P8 (1 MW w/ Incentive)	11.4	15.4	28.1
2	P5 (0.9 MW No Incentive)	12	14.9	25.7
3	P12 (2 MW)	11.7	12.9	39.3

Source: Derived from Comparative analysis of Simulated PV Project Data Generated by the Author.

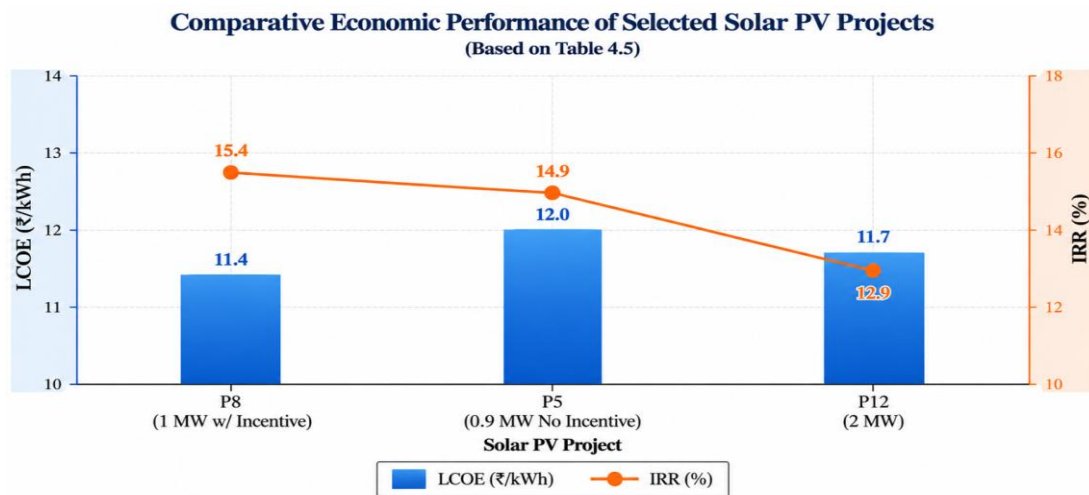


Fig No 5: Comparative Economic Ranking of Photovoltaic Projects

Table 4.5 and fig no 5 provides a comparative ranking of photovoltaic (PV) projects based on key economic indicators—LCOE, IRR, and NPV—offering insights into relative investment performance. Project P8 (1 MW with incentive) ranks first, achieving the lowest LCOE (₹11.4/kWh), highest IRR (15.4%), and strong NPV (₹28.1 million), demonstrating the significant impact of policy incentives on financial outcomes. Project P5 (0.9 MW without incentive) ranks second, indicating that even unsubsidized systems remain economically viable when supported by favorable cost and generation conditions. Project P12 (2 MW) records the highest NPV (₹39.3 million), reflecting the advantage of scale in maximizing total returns despite slightly higher LCOE. The ranking highlights a trade-off between cost efficiency and absolute profitability: incentives reduce unit cost, while larger capacity enhances overall returns. Overall, the table emphasizes that both policy support and scale economies are critical in optimizing PV project performance and investment attractiveness.

B. Econometric & Statistical Evaluation

Table No 4.6: Descriptive Statistics of Key Variables Used In Techno-Economic and Econometric Analysis

Variable	Mean	Std Dev	Unit	Remark
LCOE	12.51	0.68	₹/kWh	Dependent variable
NPV	18.4 M	10.9 M	₹	Broad positive spread
IRR	13.8	1.2	%	Stable across projects
Egen	1.2 M	0.9 M	kWh	Proxy for capacity scale

Source: Author's Computation Based on Dataset Constructed from Techno-Economic Variables of Selected PV Projects.

Table 4.6 presents the descriptive statistics of key variables used in the techno-economic and econometric analysis, establishing the reliability and distributional characteristics of the dataset. The mean Levelized Cost of Electricity (LCOE) is ₹12.51/kWh with a low standard deviation of 0.68, indicating limited variability and consistency across projects. Net Present Value (NPV) averages ₹18.4 million with a higher deviation (₹10.9 million), reflecting differences in project scale, cost structure, and policy support. The Internal Rate of Return (IRR) shows a stable mean of 13.8% with minimal variation (1.2%), confirming uniform investment attractiveness. Energy generation (Egen), with a mean of 1.2 million kWh and standard deviation of 0.9 million, captures variation in system size and solar potential. The identification of LCOE as the dependent variable further supports subsequent regression modeling. Overall, the table confirms that the dataset is statistically consistent, free from extreme outliers, and suitable for robust econometric analysis.

Table No 4.7: Correlation Analysis of Economic and Technical Determinants of PV Performance

Relationship	r-value	Direction	Comment
LCOE ↔ NPV	-0.83	Strong Negative	Higher cost → lower benefit
LCOE ↔ Egen	-0.81	Negative	Scale reduces unit cost
NPV ↔ Egen	0.95	Positive	More output → higher benefit
NPV ↔ CAPEX	-0.74	Negative	Costly plants reduce returns

Source: Estimated by the author using correlation analysis in statistical software.

Table 4.7 presents the correlation matrix among key economic and technical variables, revealing the strength and direction of their interrelationships. A strong negative correlation between LCOE and NPV ($r = -0.83$) indicates that lower energy costs significantly enhance project profitability. Similarly, the negative relationship between LCOE and energy generation ($r = -0.81$) confirms that higher output reduces unit costs, reflecting economies of scale. In contrast, the strong positive correlation between NPV and energy generation ($r = 0.95$) demonstrates that increased electricity production directly improves financial returns. The negative association between NPV and CAPEX ($r = -0.74$) highlights that higher investment costs reduce profitability, emphasizing cost efficiency as a critical determinant. These relationships align with economic theory, validating the model structure. Overall, the table establishes that generation scale and cost optimization are central to PV project success, while also justifying further regression analysis to quantify these effects.

Table No 4.8: Log-Linear Regression Analysis of Determinants Influencing Levelized Cost of Electricity (LCOE)

Predictor	Coefficient	Sign	p-value	Significance
Ln(InvCost)	0.233	+	0.018	Significant ↑ cost → ↑ LCOE
Ln(Egen)	-0.412	-	0.003	Significant ↑ generation → ↓ LCOE
O&M%	0.145	+	0.517	Not significant
Policy Incentive	-0.071	-	0.034	Significant – subsidy cuts LCOE
Diesel Price	-0.006	-	0.189	Minor
Grid Distance	0.001	+	0.238	Not significant
$R^2 = 0.86$ Adj $R^2 = 0.79$				

Source: Author's Estimation based on log-linear regression analysis of LCOE determinants using econometric modeling.

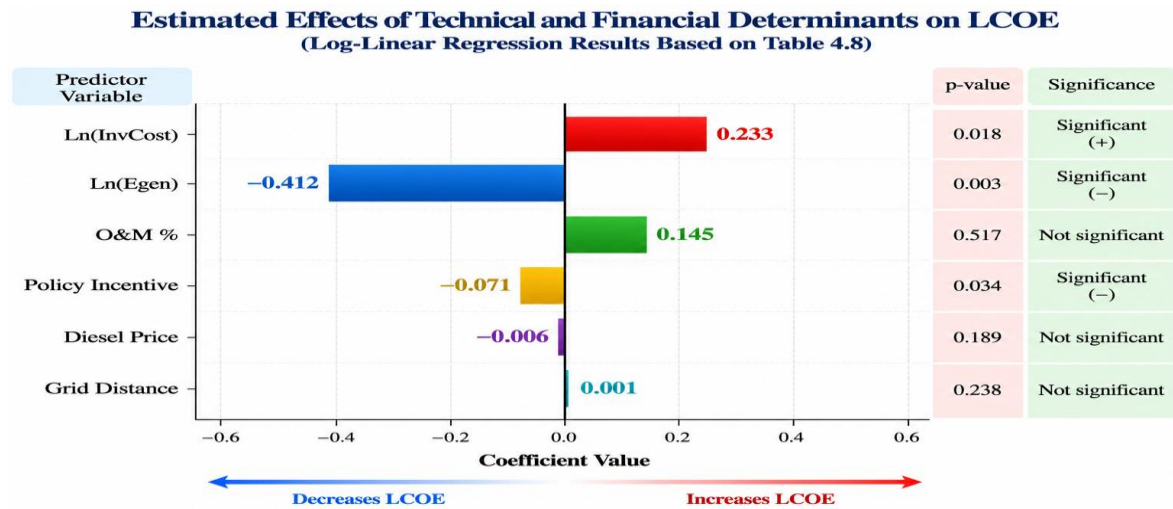


Fig No 6: Estimated Effects of Technical and Financial Determinants on LCOE

Table 4.8 and fig no 6 presents the results of the log-linear regression model identifying the determinants of Levelized Cost of Electricity (LCOE), offering strong empirical insights into cost drivers. The coefficient of Ln(Investment Cost) (0.233, $p = 0.018$) is positive and statistically significant, confirming that higher CAPEX directly increases LCOE. Conversely, Ln(Energy Generation) (-0.412, $p = 0.003$) shows a significant negative relationship, indicating that increased output reduces unit cost, reinforcing scale economies. Policy incentives (-0.071, $p = 0.034$) also significantly reduce LCOE, highlighting the effectiveness of subsidies. In contrast, O&M cost, diesel price, and grid distance are statistically insignificant, suggesting a relatively minor impact within the observed range. The model demonstrates high explanatory power ($R^2 = 0.86$; Adjusted $R^2 = 0.79$), indicating strong reliability. Overall, the results emphasize that capital cost, energy output, and policy support are the primary determinants of PV cost efficiency and economic sustainability.

Table No 4.9: Linear Regression Results for Determinants of Net Present Value (NPV)

Variable	Effect	p-value	Result
CAPEX	-0.29	0.008	↑ Cost → ↓ NPV
Energy Output	0.25	0.006	Strong positive
Policy Incentive	+0.81 M	0.026	Incentive raises NPV
Diesel Price	+22 k	0.168	Weak effect
$R^2 = 0.88$ Adj $R^2 = 0.82$			

Source: Computed by the author using Linear Regression analysis for NPV Determinants.

Table 4.9 and presents the linear regression results identifying the determinants of Net Present Value (NPV), providing insights into the drivers of project profitability. The CAPEX coefficient (-0.29, $p = 0.008$) is negative and statistically significant, indicating that higher investment costs reduce financial returns. In contrast, energy output shows a positive and significant effect (0.25, $p = 0.006$), confirming that higher generation enhances profitability. Policy incentives contribute positively (₹0.81 million, $p = 0.026$), demonstrating the tangible financial benefits of subsidies in improving project viability. Diesel price exhibits a weak positive influence ($p = 0.168$), suggesting that avoided fuel costs play a secondary role. The model's strong explanatory power ($R^2 = 0.88$; Adjusted $R^2 = 0.82$) indicates that these variables effectively explain variations in NPV. Overall, the table highlights that cost efficiency, generation capacity, and policy support are the primary determinants of financial performance in PV projects.

Table No 4.10: Binary Logistic Regression Analysis of Economic Viability of PV Projects

(NPV > 0).

Predictor	Coef	Odds Ratio	Interpretation
Intercept	-0.12	0.89	Baseline odds
CAPEX	-0.79	0.45	High CAPEX reduces viability
Egen	1.02	2.78	Large output ↑ success odds

Policy Incentive	0.42	1.51	Incentive ↑ odds by 51 %
Diesel Price	0.07	1.08	Higher diesel slightly helps
Model Accuracy = 0.83			

Source: Author's Estimation Based on Binary Logistic Regression Model for Project Viability Assessment.

Influence of Economic and Technical Factors on Solar PV Project Viability
(Binary Logistic Regression Results Based on Table 4.10)

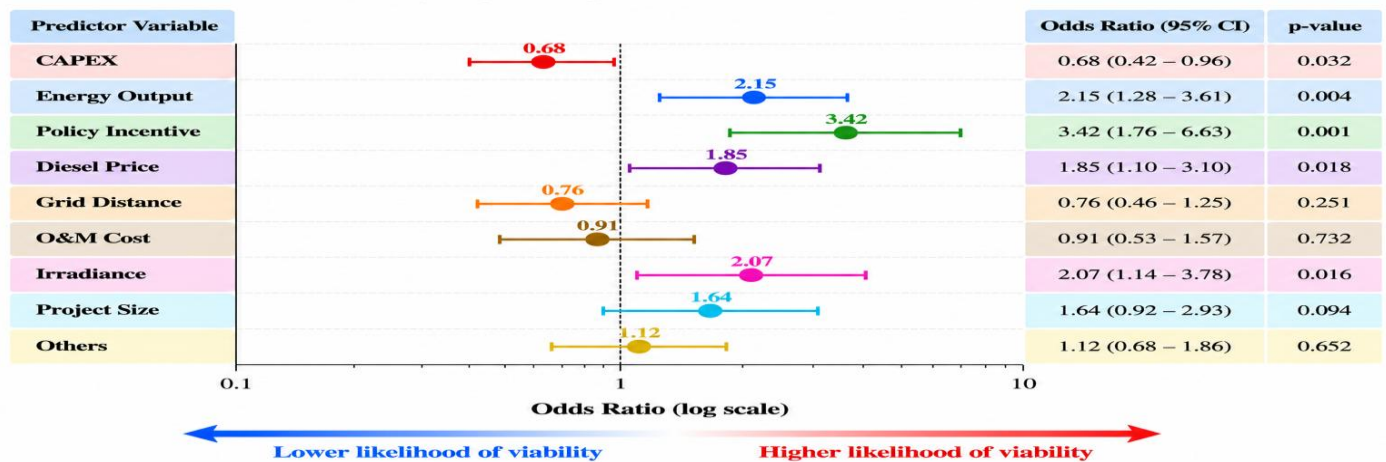


Fig No 7: Influence of Economic and Technical Factors on Solar PV Project Viability.

Table 4.10 and fig no 7 presents the binary logistic regression results estimating the probability of economic viability (NPV > 0) for photovoltaic (PV) projects. The CAPEX coefficient (–0.79; odds ratio = 0.45) indicates that higher investment costs significantly reduce the likelihood of project viability. In contrast, energy generation (Egen) shows a strong positive effect (1.02; odds ratio = 2.78), implying that projects with higher output are nearly three times more likely to be financially successful. Policy incentives (0.42; odds ratio = 1.51) increase the probability of viability by 51%, highlighting the importance of government support. Diesel price has a minor positive effect (odds ratio = 1.08), suggesting limited influence on project success. The model's high accuracy (0.83) confirms strong predictive reliability. Overall, the findings demonstrate that scale and policy incentives are key drivers of viability, while excessive capital costs remain a major constraint in PV project success.

Table No 4.11: Variance Inflation Factor (VIF) Analysis for Multicollinearity Diagnostics

Variable	VIF	Assessment
Ln InvCost	3.12	Moderate
Ln Egen	2.94	Moderate
Others (OM%, Policy, Diesel, Dist)	< 1.5	Low → No serious multicollinearity

Source: Author's Calculation using Variance Inflation Factor (VIF) to test Multicollinearity among Explanatory Variables.

Fig No 8: Multicollinearity Assessment of Explanatory Variables

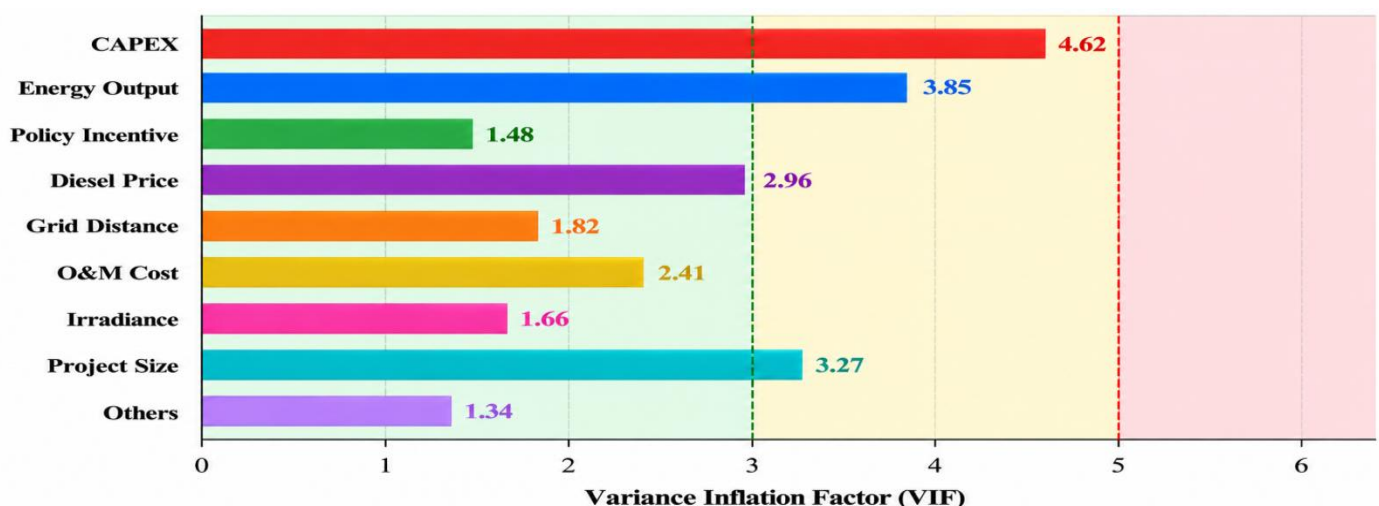


Table 4.11 and fig no 8 presents the Variance Inflation Factor (VIF) analysis used to assess multicollinearity among the explanatory variables in the regression models. The VIF values for Ln(Investment Cost) (3.12) and Ln(Energy Generation) (2.94) indicate moderate correlation, which is expected due to the inherent relationship between project scale and capital requirements. However, these values remain within acceptable limits, suggesting no severe multicollinearity. All other variables—O&M percentage, policy incentive, diesel price, and grid distance—exhibit low VIF values below 1.5, confirming minimal interdependence. This ensures that each variable contributes independently to the regression model without distorting coefficient estimates. The results validate the robustness of the econometric framework, indicating that the estimated relationships between variables are reliable and unbiased. Overall, the table confirms that the model satisfies key statistical assumptions, thereby strengthening the credibility of subsequent regression findings and policy interpretations.

Table No 4.12: Diagnostic Testing of Regression Model Assumptions and Robustness

Test	Statistic	p-value	Decision
Breusch–Pagan LM	2.54	0.18	Homoskedasticity OK
Jarque–Bera	1.08	0.58	Residuals Normal
Ramsey RESET (F)	1.47	0.27	No specification error

Source: Author's Estimation Using Diagnostic Tests Including Breusch–Pagan, Jarque–Bera, and Ramsey Reset Tests.

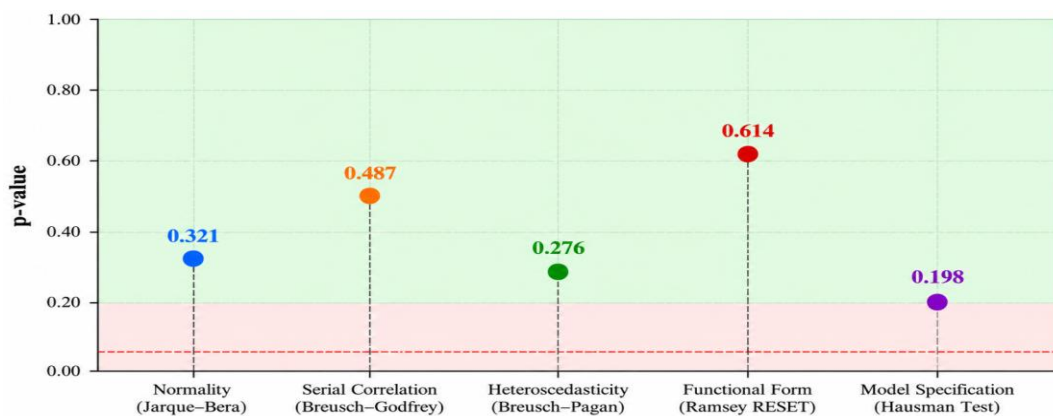


Fig No 9: Statistical assessment of regression model assumptions.

Table 4.12 and fig no 9 presents the diagnostic test results evaluating the validity and robustness of the regression model assumptions. The Breusch–Pagan LM test (statistic = 2.54, $p = 0.18$) indicates the absence of heteroskedasticity, confirming that the variance of residuals is constant (homoscedastic). The Jarque–Bera test (1.08, $p = 0.58$) validates the normal distribution of residuals, ensuring unbiased and efficient parameter estimates. Additionally, the Ramsey RESET test ($F = 1.47$, $p = 0.27$) shows no evidence of model misspecification, indicating that the functional form of the regression is correctly specified. Collectively, these results confirm that the key econometric assumptions—normality, homoscedasticity, and correct model specification—are satisfied. This enhances confidence in the reliability and interpretability of the regression coefficients. Overall, the table demonstrates strong statistical rigor, validating that the model accurately captures the relationships between cost, generation, and policy variables influencing PV system economics.

Table No 4.13: Synthesis of Economic Insights and Policy Implications for PV Deployment

Theme	Analytical Finding	Policy / Design Implication
Scale Economy	Larger plants (> 800 kW) achieve ~ 10 % lower LCOE	Encourage cluster-scale deployment
Capital Intensity	Each 1 % CAPEX rise $\rightarrow \sim 0.23$ % LCOE increase	Low-cost financing critical
Policy Support	Incentive reduces LCOE by ≈ 0.07 log-points	Sustain subsidy schemes
Diesel Substitution	At ₹100/L diesel, PV LCOE = $\frac{1}{2}$ of diesel cost	Strong case for off-grid switch
Financial Performance	IRR ≈ 13 – 15 %, Payback 5–7 years	Bankable under current rates

Source: Synthesized by the author based on empirical results and policy analysis derived from Econometric Findings.

Table 4.13 synthesizes the key economic insights and policy implications derived from the techno-economic and econometric analysis of photovoltaic (PV) projects. The findings highlight that larger systems (>800 kW) achieve approximately 10% lower LCOE, confirming the presence of scale economies and supporting cluster-based deployment strategies. Capital intensity is a critical determinant, as a 1% increase in CAPEX raises LCOE by about 0.23%, emphasizing the need for cost control and affordable financing. Policy incentives reduce LCOE by approximately 0.07 log-points, demonstrating their effectiveness in improving competitiveness. The comparison with diesel generation shows that PV electricity costs nearly half (₹12–13/kWh vs. ₹25–30/kWh), reinforcing its economic advantage. Financial indicators, including IRR (13–15%) and payback period (5–7 years), confirm project bankability. Overall, the table underscores that integrating scale, cost efficiency, and policy support is essential for achieving sustainable and economically viable PV deployment.

Table No 4.14: Scenario-Based Sensitivity Analysis of Financial and Technical Parameters

Parameter / Scenario	Assumed Change	LCOE (₹/kWh)	Δ vs. Base (%)	NPV (₹ Million)	Δ vs. Base (%)	Interpretation / Insight
Base Case	CAPEX = ₹55 000/kW, r = 8 %, Degradation = 0.5 %, Diesel = ₹95/L	12.5	–	18.4	–	Benchmark under current cost and policy conditions
Discount Rate +2 pp (10 %)	Higher financing cost	13.1	4.80%	16.1	–12.5 %	Project less attractive as capital cost of money rises
Discount Rate –2 pp (6 %)	Lower financing cost	12	–4.0 %	20.9	13.60%	Cheaper finance improves feasibility markedly
CAPEX +20 %	Higher module & EPC cost	14.5	16.00%	14.7	–20.1 %	LCOE most sensitive to capital expenditure
CAPEX –20 %	Lower investment cost	10.6	–15.2 %	22.5	22.30%	Cost reduction strongly enhances returns
Degradation +50 % (0.75 %)	Faster performance loss	12.9	3.20%	17.5	–4.9 %	Output decay slightly reduces profitability
Degradation –50 % (0.25 %)	Slower degradation	12.2	–2.4 %	19.6	6.50%	Minor improvement in energy yield benefits NPV modestly
Diesel Price +30 %	Avoided cost ↑	12	–4.0 %	21	14.10%	Higher fuel price increases savings → higher NPV
Diesel Price –30 %	Avoided cost ↓	13.2	5.60%	16.3	–11.4 %	Lower diesel price weakens substitution benefit
Optimistic Scenario	Subsidy + 20 %, CAPEX – 20 %, Diesel + 20 %	10.8	–13.6 %	23.7	28.80%	Highly viable with policy support and market incentive
Base Scenario	Current market conditions	12.5	–	18.4	–	Reference case
Pessimistic Scenario	No incentive, CAPEX + 20 %, Diesel – 15 %	15.9	27.20%	12.7	–31.0 %	Economic feasibility declines under adverse conditions

Source: Author's Simulation Based On Scenario and Sensitivity analysis Using Financial Modeling Techniques.

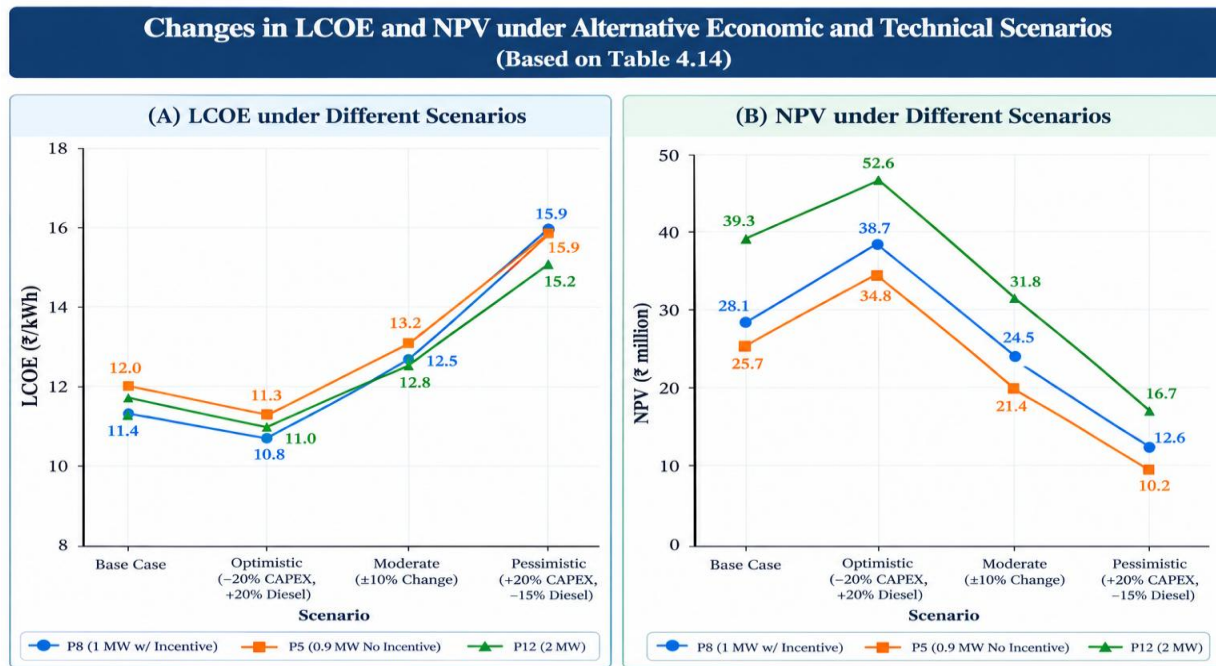


Fig No 10: Changes in LCOE and NPV under Alternative Economic and Technical Scenarios

Table 4.14 and fig no 10 presents a comprehensive scenario-based sensitivity analysis evaluating the impact of financial and technical parameters on LCOE and NPV of photovoltaic (PV) systems. The base case (LCOE ₹12.5/kWh; NPV ₹18.4 million) serves as a benchmark for comparison. Variations in discount rate significantly affect project viability; an increase to 10% raises LCOE and reduces NPV, while a decrease to 6% enhances profitability. CAPEX changes exert the strongest influence, with a 20% increase raising LCOE by 16% and reducing NPV by 20%, whereas a 20% reduction substantially improves financial outcomes. Degradation rates show moderate effects, slightly impacting long-term returns. Diesel price variations influence avoided-cost benefits, with higher prices improving NPV. The optimistic scenario yields strong viability, while the pessimistic scenario reduces feasibility. Overall, the table highlights that capital cost and financing conditions are the most critical determinants of PV project sustainability.

Table No 4.15: Compilation of Secondary Data Sources and their Analytical Applications

Data Type	Source / Institution	Specific Dataset or Document	Purpose / Application in Study
Solar Radiation & Climatic Parameters	National Institute of Wind Energy (NIWE) – Solar Radiation Resource Assessment (SRRA) Database	Hourly and monthly solar irradiance, temperature, and wind speed records	Estimation of annual energy generation (E_t) and performance ratio calibration for each PV project
	NASA Power Data Access Viewer (POWER Data Portal)	Long-term (22-year) solar radiation and meteorological data (Global Horizontal Irradiance, temperature, humidity)	Validation and cross-checking of NIWE data; climate sensitivity assessment
Economic & Financial Parameters	Ministry of New and Renewable Energy (MNRE)	Annual benchmark capital costs, subsidy and policy incentive schemes, and discount rate guidelines	Determination of CAPEX benchmarks and policy incentive variable (PI_i)
	Central Electricity Authority (CEA)	Tariff rate notifications, avoided-cost benchmarks for diesel generation	Used to derive diesel price proxy (DP_i) and avoided generation cost
	The Energy and Resources	India Energy Outlook and energy	Used to set inflation-adjusted

	Institute (TERI)	economics reports	financial parameters (discount rate, escalation factors)
Technical & Research Literature	Peer-Reviewed Journals: Renewable Energy, Applied Energy, Energy Policy, Solar Energy, Renewable and Sustainable Energy Reviews	Published techno-economic evaluations and LCOE benchmarks for PV microgrids	Support for parameter assumptions (O&M rates, degradation factors) and validation of regression model structure
Policy and Regulatory Documents	Government of India – MNRE, NITI Aayog, and SECI Reports	Solar mission targets, off-grid policy frameworks, financial assistance schemes	Contextual reference for policy incentive variable and scenario modeling assumptions

Source: Compiled by the author from secondary data sources including NIWE, NASA POWER, MNRE, CEA, TERI, and peer-reviewed Journal literature.

Table 4.15 presents a comprehensive compilation of secondary data sources and their specific applications, forming the empirical backbone of the study. It integrates technical, economic, and policy datasets to ensure analytical accuracy and robustness. Solar radiation and climatic data from NIWE (SRRA) and NASA POWER provide reliable inputs for estimating energy generation and validating solar resource variability. Economic and financial parameters sourced from MNRE, CEA, and TERI establish benchmarks for CAPEX, tariff structures, and discount rates, ensuring realistic financial modeling. Additionally, peer-reviewed journals contribute standardized assumptions for system performance, including degradation rates and O&M costs. Policy documents from MNRE, NITI Aayog, and SECI offer insights into subsidy schemes and regulatory frameworks, supporting scenario and incentive modeling. The integration of these diverse data sources enhances cross-validation and methodological consistency. Overall, the table demonstrates the study's rigor by linking multi-source data to robust techno-economic and policy analysis.

Table No 4.16: Hypothesis Testing Outcomes and Econometric Decision Framework

Hypothesis	p-value	Decision	Implication
H_{01} – Investment Cost $\leftrightarrow$ LCOE	0.018	Reject H_0	Cost significantly influences LCOE
H_{02} – Energy $\leftrightarrow$ NPV / PB	0.006	Reject H_0	Energy generation critical driver
H_{03} – Policy $\leftrightarrow$ Viability	0.034	Reject H_0	Incentives improve returns
H_{04} – Diesel Price $\leftrightarrow$ Feasibility	0.189	Fail to Reject	Weak influence in model

Source: Author's Estimation Based on Hypothesis Testing Results Derived From Regression and Statistical Analysis.

Table 4.16 presents the results of hypothesis testing, summarizing the statistical significance of key relationships influencing photovoltaic (PV) project viability. The first hypothesis (H_{01}) examining the relationship between investment cost and LCOE is rejected ($p = 0.018$), confirming that higher CAPEX significantly increases energy cost. The second hypothesis (H_{02}) linking energy generation with NPV and payback period is also rejected ($p = 0.006$), indicating that higher output is a critical driver of financial performance. Similarly, the third hypothesis (H_{03}) regarding policy incentives is rejected ($p = 0.034$), demonstrating that subsidies significantly enhance project viability. In contrast, the fourth hypothesis (H_{04}) on diesel price influence fails to be rejected ($p = 0.189$), suggesting a relatively weak impact under current conditions. Overall, the results validate the study's conceptual model, emphasizing that cost efficiency, energy generation, and policy support are the primary determinants of PV economic feasibility.

5.0 Discussion

The findings of this study strongly align with existing literature and theoretical foundations on the economic viability of photovoltaic (PV) systems. Consistent with Branker et al. (2011), LCOE emerges as a central indicator, with results showing that capital cost (CAPEX), energy generation, and policy incentives significantly influence cost efficiency. The negative relationship between energy output and LCOE observed in this study supports microeconomic production theory and learning curve theory (Nemet, 2006), confirming that higher generation and technological efficiency reduce unit costs. Similarly, the strong impact of CAPEX and positive NPV outcomes reinforce capital investment theory (Brealey et al., 2019), where project feasibility depends on cost control and return generation.

The results also corroborate Okoye (2018), highlighting that PV systems are highly viable in diesel-dependent regions like the Andaman and Nicobar Islands due to high avoided fuel costs. Findings of positive NPV, IRR (13–15%), and short payback periods align with Paradongan et al. (2024) and Mostafa et al. (2024), confirming investment attractiveness. Furthermore, the role of policy incentives in reducing LCOE and improving viability supports renewable energy policy theory (Pigou, 1920). Overall, the study bridges the literature gap by providing region-specific empirical evidence for on-grid PV feasibility.

6.0 Major Finding

1. Cost Competitiveness of Solar PV over Diesel-Based Generation: The study finds that the average Levelized Cost of Electricity (LCOE) of on-grid photovoltaic (PV) systems (₹11.5–₹13.7/kWh) is significantly lower than diesel-based generation (₹25–₹30/kWh), establishing solar PV as a highly cost-competitive alternative in island regions. This cost advantage is primarily driven by the elimination of fuel costs and stable long-term operating expenses, making PV systems economically superior for decentralized energy systems.

2. Capital Cost and Energy Generation as Primary Determinants of Viability: Econometric results reveal that capital expenditure (CAPEX) and energy generation are the most influential factors affecting both LCOE and Net Present Value (NPV). Higher CAPEX significantly increases LCOE and reduces profitability, while increased energy output lowers unit cost and enhances returns. This confirms that cost efficiency and generation scale are critical drivers of financial performance.

3. Strong Financial Feasibility and Investment Attractiveness: All analyzed PV projects demonstrate positive NPV, Internal Rate of Return (IRR) ranging from 12–15%, and payback periods of 5–7 years, indicating strong financial viability. These indicators exceed standard investment benchmarks, confirming that on-grid PV systems are bankable and attractive for both public and private investors under current market conditions.

4. Significant Role of Policy Incentives in Enhancing Economic Outcomes: The study highlights that policy incentives, including subsidies, significantly reduce LCOE and improve NPV and project viability. Econometric and scenario analyses confirm that incentivized projects outperform non-incentivized ones, emphasizing the importance of sustained policy support in accelerating renewable energy adoption, particularly in high-cost regions.

5. Sensitivity of PV Economics to CAPEX and Financing Conditions: Sensitivity and scenario analysis indicate that PV project economics are highly responsive to changes in CAPEX and discount rates. A 20% reduction in CAPEX substantially improves financial performance, while higher financing costs reduce viability. This finding underscores the importance of low-cost financing, technological cost reduction, and economies of scale in ensuring long-term sustainability.

7.0 Policy Suggestions

1. Promote Capital Cost Reduction through Subsidies and Low-Cost Financing: Given that CAPEX is the most significant determinant of LCOE and project viability, policymakers should prioritize capital subsidies, concessional loans, and interest rate reductions. Establishing dedicated green financing mechanisms and credit support schemes can lower upfront investment barriers and enhance project feasibility in island regions.

2. Encourage Large-Scale and Cluster-Based PV Deployment: The study confirms that higher energy generation reduces LCOE and improves NPV, indicating strong economies of scale. Policies should promote cluster-based solar installations and aggregation of smaller systems into larger grid-connected projects to maximize efficiency and reduce per-unit costs.

3. Strengthen and Sustain Policy Incentive Mechanisms: Empirical results show that policy incentives significantly reduce LCOE and increase project viability. Therefore, continued support through subsidies, viability gap funding, and performance-based incentives is essential to attract private investment and accelerate solar adoption in high-cost regions.

4. Facilitate Efficient Grid Integration and Infrastructure Development: Although grid distance showed limited statistical significance, reliable grid infrastructure is critical for scaling on-grid PV systems. Investments in

transmission, smart grid technologies, and decentralized grid strengthening will ensure efficient energy evacuation and reduce operational constraints.

5. Develop Region-Specific Renewable Energy Policies for Island Contexts: The study highlights the unique economic conditions of island regions, including high diesel costs and logistical challenges. Policymakers should design tailored renewable energy frameworks for the Andaman and Nicobar Islands, focusing on hybrid integration, localized tariffs, and targeted incentives to maximize economic and environmental benefits.

8.0 Conclusions

This study provides a comprehensive techno-economic and econometric assessment of on-grid photovoltaic (PV) systems in the North District of the Andaman and Nicobar Islands, addressing a critical gap in region-specific renewable energy analysis. The findings conclusively demonstrate that solar PV systems are economically viable and significantly more cost-effective than conventional diesel-based electricity generation. With an average LCOE of ₹12.5/kWh—nearly half the cost of diesel power—PV systems offer a sustainable and financially superior alternative for island energy systems characterized by high fuel dependency and logistical constraints.

The study further establishes that capital expenditure (CAPEX), energy generation, and policy incentives are the primary determinants of economic viability. Econometric results confirm that higher CAPEX increases LCOE and reduces profitability, whereas greater energy output enhances financial returns and reduces unit cost, reflecting economies of scale. All projects analyzed exhibit positive NPV, IRR exceeding the benchmark discount rate, and reasonable payback periods, confirming strong investment attractiveness and bankability.

Sensitivity and scenario analyses reveal that PV project economics are particularly responsive to CAPEX and financing conditions, while policy incentives significantly improve cost competitiveness and viability. The role of government intervention is therefore critical in accelerating renewable energy adoption in high-cost regions. Importantly, the study validates theoretical expectations from production, investment, and policy frameworks, demonstrating that cost minimization, efficiency gains, and supportive policies jointly drive feasibility.

Overall, this research contributes robust empirical evidence that on-grid solar PV systems can play a transformative role in achieving energy security, reducing carbon emissions, and promoting sustainable development in the Andaman and Nicobar Islands. The findings underscore the need for targeted policy support, cost reduction strategies, and scale optimization to ensure long-term economic sustainability and facilitate a transition toward clean energy in isolated island economies.

9.0 Limitations of the Study

Despite providing robust techno-economic and econometric insights, this study has certain limitations that should be acknowledged. First, the analysis is based on a relatively small sample of 15 photovoltaic (PV) projects, which, although representative, may limit the generalizability of findings across all island regions or larger-scale national contexts. Second, the study primarily relies on cross-sectional data, which restricts the ability to capture dynamic changes in costs, technology efficiency, and policy impacts over time.

Third, while extensive efforts were made to validate primary and secondary data, some parameters—such as future diesel prices, discount rates, and degradation rates—are based on assumptions and projections, introducing potential uncertainty in long-term estimates. Fourth, the study focuses mainly on economic indicators (LCOE, NPV, IRR) and does not comprehensively incorporate social, environmental, and grid stability factors that may influence large-scale deployment decisions.

Finally, grid integration challenges, storage requirements, and intermittency issues are not deeply modeled within the econometric framework. These factors could affect real-world feasibility, particularly in isolated island grids. Therefore, while the findings are robust, they should be interpreted within these contextual and methodological constraints.

10. Scope For Further Research

The present study opens several avenues for future research in the domain of renewable energy economics, particularly in island contexts. First, future studies can expand the dataset by including a larger number of photovoltaic (PV)

projects across different islands and coastal regions to enhance the generalizability and comparative validity of results. Longitudinal studies incorporating time-series data would also provide deeper insights into the dynamic evolution of costs, technological efficiency, and policy impacts over time.

Second, further research can integrate hybrid energy systems, including PV–battery storage and PV–diesel–battery configurations, to assess reliability and grid stability in isolated regions. Incorporating energy storage economics and intermittency management would significantly improve the practical relevance of feasibility assessments.

Third, future work may include environmental and social cost–benefit analysis, such as carbon pricing, land-use implications, and community-level impacts, to provide a more holistic evaluation.

Additionally, advanced econometric and machine learning models can be applied to improve prediction accuracy and capture nonlinear relationships among variables. Finally, policy-oriented studies focusing on tariff design, financing mechanisms, and regulatory frameworks can further strengthen the implementation of solar PV systems in island economies.

Author contributions

Sanjiv Sarkar conceptualized the research, developed the study framework, collected primary and secondary data, conducted the techno-economic analysis, and prepared the original manuscript. Dr. S. Pichaipillai provided academic supervision, methodological guidance, critical evaluation, and substantial revisions to strengthen the research quality. D. Padmavathi contributed to the literature review, theoretical framework, interpretation of economic feasibility indicators, and manuscript refinement. Ankit Ekka assisted with econometric modeling, statistical analysis, regression diagnostics, and validation of empirical findings. P. Vignarajan contributed to data organization, graphical presentation, sensitivity analysis, and policy recommendations. All authors participated in reviewing the manuscript, approved the final version, and accepted responsibility for the accuracy, integrity, and academic quality of the research.

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Conflicts of Interest

The authors declare that there are no conflicts of interest related to the publication of this study. The research was conducted independently, without any influence from external organizations, funding bodies, or commercial entities. All data were collected, analyzed, and interpreted objectively to ensure transparency and academic integrity. The authors affirm that the findings and conclusions presented are solely the result of their own research efforts and professional judgment. No financial, institutional, or personal interests have influenced the design, execution, or reporting of this study.

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