A Techno-Economic Feasibility Assessment of Rooftop Solar PV Systems Using Machine Learning-Based Energy Forecasting

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Abstract - The increasing demand for reliable and sustainable energy solutions has accelerated the adoption of rooftop solar photovoltaic (PV) systems, particularly in facilities dependent on diesel generators for backup power. This study presents a comprehensive techno-economic feasibility assessment of a rooftop solar PV system using real operational energy data and machine learning-based forecasting techniques. Historical data comprising solar energy generation, diesel generator energy usage, runtime patterns, and specific yield are analyzed to evaluate system performance and energy contribution. Machine learning models, including linear regression, random forest, and time-series forecasting, are employed to predict future solar energy generation and assess potential reductions in diesel generator dependency. The forecasted energy outputs are integrated with economic analysis to compute key financial indicators such as levelized cost of electricity (LCOE), payback period, return on investment (ROI), and diesel cost savings. The results demonstrate that machine learning-enabled forecasting significantly improves the accuracy of energy prediction and enhances decision-making for system planning and investment

Key Words: Rooftop Solar Photovoltaic, Techno-Economic Feasibility, Machine Learning Forecasting, Solar Energy Generation, Diesel Generator Integration, Energy Cost Analysis, Levelized Cost of Electricity (LCOE), Renewable Energy Systems, Sustainable Energy Planning.

1.INTRODUCTION

We have an energy problem. As our population grows and industries expand, our power consumption is going through the roof. The reality, however, is that we are still powering this growth largely with coal and diesel. It's an outdated approach that is hurting both our wallets and the environment. Commercial buildings, for instance, often rely on diesel generators for backup power, but these machines are expensive to fuel and a hassle to maintain. We clearly need a better, cleaner solution.

Solar energy, particularly rooftop PV systems, offers a way out. In a country like India, where solar radiation is high year-round, utilizing empty roof space to generate electricity just makes sense. It's why so many organizations are installing these systems to lower costs and cut ties with diesel dependency.

However, simply installing solar panels isn't enough. We have to validate that the system is actually efficient and financially viable.

Figure 1: **Renewable vs Conventional Energy for Backup Power Systems**

Usually, feasibility studies rely on generic simulations. These are okay, but they often miss the nuances of real-world operating conditions. That is why this study takes a different approach. We are integrating Machine Learning into the mix. ML allows us to learn from historical data, identifying hidden patterns in how energy is generated and consumed. By looking at past solar and diesel usage, our models can predict future performance much more accurately than traditional methods.

The core aim of this study is straightforward: does the rooftop solar system actually work to reduce diesel use and save money in the long run? By applying ML forecasting to real-time data, we are calculating the hard numbers—ROI, payback periods, and cost savings. This isn't just theoretical; the results are designed to help decision-makers understand the true long-term value of switching to sustainable energy.

2. BACKGROUND OF STUDY

The Energy Reality Our appetite for energy is insatiable. Between a growing population, expanding industries, and our modern, tech-heavy lifestyles, the demand on the power grid is heavier than ever. The problem is, we are still largely feeding this demand with old habits—specifically, conventional sources like coal and diesel. It is an expensive and messy way to keep the lights on. You see this clearly in large commercial buildings; when the main grid fails, they rely on diesel generators. While these machines get the job done, they are far from ideal. They guzzle fuel, they are loud, and keeping them running requires constant, costly maintenance. With fuel prices climbing and the environment taking a hit, sticking with diesel just isn't sustainable anymore. We need a better way.

Why Solar Makes Sense Here Solar energy is the obvious alternative. It is reliable, renewable, and the technology has finally matured. For a country like India, it is a perfect fit. We are lucky enough to get strong sunshine almost year-round, so it makes total sense to turn unused rooftops into power generation hubs. A lot of organizations are catching on. They are installing rooftop photovoltaic (PV) systems to slash their electricity bills and cut ties with those inefficient diesel generators. But there is a catch: you cannot just install the panels and hope for the best. You need to know, for a fact, that the system will work for your specific location.

The Problem with Old Analysis Methods This is where "techno-economic feasibility" comes in. Basically, we need to answer two questions: Will it work technically? And will it save money? Usually, engineers check this using standard simulation tools. The issue is that these tools often rely on "perfect world" assumptions. They assume the weather will behave a certain way or that the load will remain constant. But the real world is messy. Clouds roll in, demand spikes, and equipment ages. If your feasibility study relies on static data, your financial predictions—like the payback period—are likely going to be wrong.

Bringing in Machine Learning This is why we are turning to Machine Learning (ML). Unlike a static spreadsheet, ML models can learn. They look at historical data—past solar generation, real diesel usage, actual weather patterns—and they find hidden patterns that traditional methods miss.

In this project, we are not just guessing. We are taking real-time operational data and feeding it into these models to analyze a hybrid system (solar PV mixed with diesel generators). The goal is to predict exactly how much energy we can generate and precisely how much money we can save. We are looking for the real numbers on things like the Levelized Cost of Energy (LCOE) and Return on Investment (ROI). By doing this, we can give decision-makers a realistic roadmap, proving whether rooftop solar is actually worth the investment in the long run..

3. LITERATURE REVIEW

Recent research into rooftop solar PV systems and hybrid energy networks has shifted focus toward achieving a balance between technical reliability and economic viability. Sambhi et al. proposed a hybrid solar–diesel microgrid model specifically for academic campuses, evaluating how different battery configurations influence energy distribution and diesel offset to enhance overall sustainability [1]. To further minimize operational costs, Rahman and Singh explored the impact of diesel generator integration within hybrid microgrids, demonstrating that optimized dispatch strategies can drastically reduce fuel consumption and generator runtime [2].

Techno-economic feasibility remains a cornerstone of institutional solar adoption. Khamharnphol et al. conducted a comprehensive assessment of 100 kWp rooftop systems for hospitals, using real-world irradiance profiles to confirm that large-scale institutional deployments offer substantial long-term economic advantages [3]. Similarly, Boruah et al. analyzed grid-connected rooftop PV systems with battery storage for commercial buildings, finding that while battery integration improves grid independence, the financial outcome is highly sensitive to local electricity tariff structures [4].

The physical performance and environmental efficiency of these systems are also heavily researched. Gulkowski focused on specific yield as a primary benchmark, comparing multiple rooftop installations to show how factors like tilt, orientation, and shading influence annual energy generation [5]. However, environmental challenges vary by region; Patel et al. evaluated rooftop PV performance under tropical conditions, quantifying how seasonal fluctuations and temperature coefficients lead to performance ratio degradation over time [6].

On the financial and policy side, Ghosh and Bandyopadhyay examined how varying net-metering policies and subsidy models influence the attractiveness of solar investments, highlighting that supportive policy environments are essential for accelerating adoption [7]. Adding a long-term perspective, Chen et al. conducted a life cycle cost analysis comparing monocrystalline and polycrystalline technologies, confirming that declining module prices are significantly improving cost recovery timelines for modern systems [8].

The integration of advanced computational methods has recently revolutionized energy forecasting. Asiedu et al. compared single and hybrid machine learning models, such as Random Forest and Gradient Boosting, proving that hybrid approaches provide much higher accuracy across different seasonal horizons [9]. Building on this, Ali et al. explored deep learning architectures, specifically CNN–LSTM hybrids, to manage non-linear weather fluctuations in smart grid ecosystems [10]. Collectively, the literature suggests that while hybrid solar-diesel systems are technically sound, there is a clear need for studies that combine real-time operational data with machine learning to provide more realistic and data-driven economic forecasts.

Table 1: Summary of Related Works

Ref .No	Author (Year)	Core Methodology	Key Contribution	Research Gap
[1]	Sambhi (2023)	Hybrid Microgrid Modeling	**Diesel offset** & energy resilience	No **ML-based forecasting**
[2]	Rahman (2024)	Dispatch Strategy	Minimized **fuel consumption**	Relies on **simulated data**
[3]	Khamharnphol (2023)	Techno-economic Assessment	High **ROI** for institutions	No **battery integration**
[4]	Boruah (2024)	Optimization Tools	**LCOE & NPV** analysis	Idealized **load patterns**
[5]	Gulkowski (2022)	Yield Benchmarkin	**Specific Yield** efficiency	Ignores **economic feasibility**
[6]	Patel (2025)	Performance Ratio Analysis	**Degradation** in tropical climates	Limited **long-term data**
[7]	Ghosh (2023)	Policy Modeling	**Net-metering** profitability	Lacks **technical data**
[8]	Chen (2023)	Life Cycle Cost Analysis	**Payback period** recovery	No **policy-driven incentives**

Ref .No	Author (Year)	Core Methodology	Key Contribution	Research Gap
[9]	Asiedu (2024)	**Hybrid ML Models**	High **forecasting accuracy**	No **real-world integration**
[10]	Ali (2024)	**Deep Learning (LSTM)**	Handled **non-linear weather**	High **computational cost**

4. PROPOSED FRAMEWORK

The proposed methodology focuses on evaluating the techno-economic viability of a rooftop solar PV system by integrating real-world operational data with predictive machine learning models. The entire framework is built around a logical flow that bridges raw field data with comprehensive financial forecasting to determine if a project is truly sustainable in the long run.

Data Collection and Parameter Identification The study begins by pulling real-time operational data directly from an active rooftop solar installation that uses diesel generators for backup. This stage is all about gathering high-quality inputs, such as **daily solar energy generation**, **diesel generator consumption**, and **specific yield**. Unlike generic simulations that use "perfect world" assumptions, this approach captures the site-specific performance, including how the solar panels actually behave during generator operation and the exact runtimes of different diesel units.

Data Preprocessing and Feature Engineering Raw sensor data is rarely clean, so this phase is dedicated to refining the dataset. We handle missing entries and inconsistent logs using statistical methods, but a more critical step is transforming **diesel generator runtimes** into decimal formats for easier math. We also perform feature engineering to calculate the **Solar Contribution Ratio** and **Diesel Dependency**, which help us see exactly how much the building relies on fuel versus clean energy throughout the day.

Exploratory Data Analysis Before any predictions happen, the data is put through rigorous graphical testing to spot trends. We look for the **correlation** between solar output and diesel usage to see if spikes in generation lead to an immediate drop in fuel burn. This trend analysis is vital for recognizing seasonal shifts in **specific yield**, ensuring that the machine learning models we build later are based on the messy reality of the site's weather patterns.

Machine Learning Based Forecasting The core of the system uses machine learning to predict future solar output. We implement regression models like **Linear Regression** and **Random Forest**, alongside **SARIMA** for time-series forecasting. These algorithms are designed to learn from history, identifying the non-linear relationship between time and energy production. We validate their accuracy using standard error metrics like **RMSE** and **MAE** to ensure the forecasts are reliable enough for financial planning.

Technical and Economic Evaluation This is where we translate technical predictions into financial reality. We take the forecasted solar energy and calculate the potential for **Diesel Displacement**—essentially figuring out how much fuel can be kept in the tank. These findings are then fed into formulas to determine the **Levelized Cost of Electricity (LCOE)**, the **Payback Period**, and the **Return on Investment (ROI)**, giving decision-makers a clear picture of the project's profitability.

Tools and Implementation Environment The entire methodology is developed using **Python**, leveraging powerful libraries like **Pandas** and **NumPy** for handling large datasets. The machine learning architecture is built with **Scikit-learn**, while **Matplotlib** provides the necessary visuals for interpreting trends. The system is designed to be lightweight, running on standard computing hardware so that it can be easily deployed for real-world energy planning and site screening.

Figure 2: Machine Learning-Based Techno-Economic Feasibility Framework for Rooftop Solar PV Systems

5. RESULTS AND DISCUSSION

Real-World Performance and the Impact of Seasons Looking at the numbers, it is clear that the rooftop solar system is doing exactly what it was designed to do. The performance is steady, but it definitely follows the rhythm of the seasons. **Summer months** are obviously the peak, with the system pulling in maximum energy thanks to the clear skies. On the flip side, we see a noticeable drop during the **monsoon and winter seasons**. It is not a failure of the technology; it is simply the reality of local weather patterns. Even with these dips, the system still manages to carry a huge chunk of the building's energy load. The **specific yield** stayed right where we wanted it, confirming that the setup is efficient and the hardware is holding up well under actual, everyday use.

How the Machine Learning Models Held Up One of the most interesting parts of this study was seeing how the predictive models actually performed. The **machine learning models** we used—specifically **Random Forest** and **SARIMA**—did a fantastic job. They were much more accurate than the basic linear models we tested for comparison. They really shined during **seasonal transitions**, where the weather starts to get a bit unpredictable. Of course, they were not perfect; on days when the weather suddenly shifted from clear to cloudy, we saw some small errors. But for the most part, the forecasts were incredibly solid. This is a big win for facility management because it means they can actually trust these predictions when planning their energy usage.

The Relationship Between Solar and Diesel Usage The biggest takeaway here is how the solar panels affected the **diesel generator runtime**. It is a simple, direct relationship: when the sun is out and the solar output is high, the generators stay off. This led to a very real, measurable drop in **fuel consumption** and daily operating costs. The solar system is particularly good at handling those big daytime power spikes that would usually burn through a lot of diesel. That said, the data shows we are not yet at the point where we can get rid of the generators entirely. Because of high power needs at night and low light in the early mornings, **completely eliminating diesel** is not possible. The generators still have a job to do, but they are working much less than before.

Financial Reality and Economic Feasibility Finally, the math checks out. When we looked at the **Levelized Cost of Electricity (LCOE)** and the **Payback Period**, it became obvious that solar is the smarter financial move over the long term. Even though you have to pay upfront for the installation, the **operational savings** from not buying as much diesel fuel add up quickly. We accounted for variables like maintenance and shifting fuel prices, and the project still looks very robust. Essentially, the results prove that putting solar on the roof is not just a sustainable choice—it is a smart business decision that provides real long-term value.

6. CHALLENGES AND LIMITATIONS

No matter how advanced the machine learning algorithms are, the framework is ultimately at the mercy of **data quality**. If the sensors at the site were glitching or if historical records were poorly maintained, the accuracy of the entire feasibility report will naturally take a hit. One obvious gap in the current approach is that we aren't directly pulling in **weather parameters** like real-time cloud density or humidity. While the model learns from past energy trends, it can still be caught off guard by sudden, erratic weather shifts that aren't reflected in historical patterns.

It is also important to remember that machine learning isn't a "set it and forget it" tool. Because solar panels slowly lose efficiency as they age and a building's power needs often shift over the years, **regular model updates** are a necessity to keep the forecasts honest. Then there is the financial side of things, which is always moving. Any sudden spike in **diesel prices** or a change in government **electricity tariffs** can flip the economic outlook overnight, potentially lengthening the **payback period** we calculated today. Finally, while we focused heavily on the balance between solar and diesel, this study didn't go deep into the weeds with **battery storage integration** or the complex feedback loops of the national **power grid**, both of which remain areas for future exploration.

CONCLUSION & FUTURE SCOPE

Project Conclusion The biggest takeaway from this entire study is that moving to a solar-diesel hybrid setup is much more than just an environmental statement; it is a solid, data-backed financial decision. By ditching the usual "perfect world" simulations and digging into **real-time operational data**, we were able to see exactly how these systems hold up when the weather is messy and power demand is high. Our findings confirm that rooftop solar can reliably shoulder a massive portion of the daytime energy load. A huge part of this success is thanks to the **machine learning models** we tested. Specifically, **Random Forest** and **SARIMA** proved that we can forecast solar output with enough precision to actually plan daily operations around the sun.
On the financial side, the numbers are just as encouraging. When you look at the **Levelized Cost of Electricity (LCOE)** and the **payback period**, it is clear that solar-generated power is far more affordable than burning through expensive diesel in the long run. While we haven't reached the point where we can **eliminate diesel generators entirely**—mostly because of night-time needs and low-light mornings—the reduction in generator runtime is a massive win. It translates directly into lower **fuel consumption**, fewer maintenance headaches, and a much lighter carbon footprint. Essentially, this research provides a realistic roadmap for any institution that wants to cut their electricity bills while moving toward a more sustainable future.

Future Scope of the Study Even with these promising results, we are really just at the starting line. The most logical next step for this research is to bring **Battery Energy Storage Systems (BESS)** into the mix. If we can store the excess energy produced during those high-sun hours and use it at night, we could potentially push diesel generators into a purely emergency role. There is also a huge opportunity to make the **machine learning forecasts** even sharper. By plugging in **live weather data**—think real-time cloud cover, humidity, and temperature feeds—the models could become much more resilient against sudden, erratic atmospheric shifts.
Looking further ahead, we could transform this framework from a research project into a live, **web-based energy management dashboard**. This would give facility managers a way to track their **ROI** and system health on their phones in real-time. Finally, as we collect more data, we could even train the system to handle **predictive maintenance**. Instead of just telling us how much power we'll get, the model could warn us if a solar panel or a generator is about to fail based on subtle changes in performance. These kinds of advancements would turn this feasibility tool into a fully automated, intelligent energy ecosystem that basically manages itself.

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