

Techno-Economic and Environmental Assessment of a RESCO-Based Rooftop Solar Photovoltaic System: Evidence from Chaudhary Charan Singh University, Meerut

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ABSTRACT

This study evaluates the economic and environmental outcomes of a grid-connected rooftop solar photovoltaic (RSPV) plant installed at Chaudhary Charan Singh University Campus, Meerut. Commissioned in July 2018 under the Renewable Energy Service Company (RESCO) model, the 1,260 kW system offsets the institution's reliance on grid electricity and diesel generators without requiring upfront capital expenditure. Using monthly data spanning 2016–2025, the analysis applies financial benchmarking and environmental assessment techniques to capture the plant's contribution to sustainability. Results show a substantial reduction in diesel generator usage, with mean monthly consumption nearly halved in the post-solar period. The system consistently achieved plant load factors around 13 percent, aligning with regional solar performance standards. Carbon emission reductions, estimated using UNFCCC baseline factors, exceeded 9,400 tonnes of CO₂ by mid-2025, underscoring the project's environmental significance. Financial evaluation using effective tariff differentials revealed cumulative energy savings of nearly ₹4 crore over the study horizon, with monthly benefits averaging ₹4.8 lakh. Beyond direct savings, the system reduced grid dependency, stabilized energy costs, and enhanced the university's role as a public demonstrator of renewable energy transitions. Overall, the findings affirm that RSPV adoption under the RESCO model is a viable pathway for higher education institutions to advance economic sustainability and carbon mitigation in line with India's renewable energy targets.

Keywords: Rooftop Solar, Net Metering, Carbon Emission Reduction, Plant Load Factor, Diesel Displacement, Financial Savings, India.

INTRODUCTION

India's energy sector faces the dual challenge of rising electricity demand and the imperative to decarbonize in line with its Paris Agreement commitments. By March 2024,

India's renewable energy capacity surpassed 180 GW, of which solar accounted for more than 70 GW (CEA, 2023; MNRE, 2024). While grid-scale solar dominates, rooftop solar photovoltaic (RSPV) remains underexploited: only about 10 GW of rooftop capacity has been deployed against an estimated technical potential of 749 GW (IEA, 2023; IRENA, 2022). Bridging this gap is essential for meeting national targets, and institutional campuses represent one of the most promising segments for expansion. Universities, in particular, are well-suited for rooftop solar integration due to their large energy-intensive operations, daytime load profiles, and visibility as public demonstration sites. Rooftop Solar Photo Voltaic (Here-n-after RSPV) adoption enables them to reduce costly diesel reliance, lower electricity bills, and contribute directly to national emission reduction strategies (Garg & Shukla, 2020; Sharma *et al.*, 2021; Kumar *et al.*, 2024).

Chaudhary Charan Singh University Campus, Meerut (hereinafter “the University”), emerged as one of the pioneering institutions in Uttar Pradesh to deploy rooftop solar at scale. In July 2018, the University commissioned a **1,260-kW grid-connected rooftop solar plant** under the Renewable Energy Service Company (hereinafter “RESCO”) model, covering much of its **1,400-kW total connected load** spread across two major electricity connections. Under this model, the system was owned and operated by the developer, while the University agreed to purchase power at a contracted tariff of ₹3.91 per kWh. This eliminated the need for upfront capital investment while ensuring predictable energy costs. The University's initiative reflects a broader pattern of early adoption among Indian higher education institutions. Rupal *et al.* (2016) demonstrated energy and emission savings from institutional retrofits in Chandigarh; Kulkarni *et al.* (2020) documented a 450-kW rooftop system in Karnataka that reduced grid purchases by 76 percent, and Aggarwal and Parmar (2023) evaluated a 640 kWp campus installation in Himachal Pradesh. Together, these case studies highlight the role of universities as testbeds for renewable energy transitions, with CCSU Meerut among the pioneering adopters in north-central India.

This paper provides a comprehensive evaluation of the University's RSPV system between 2016 and 2025. It assesses the plant's performance across five dimensions: reduction in diesel generator consumption, avoided carbon emissions, plant load factor performance, financial savings using effective and unit rate methods, and changes in net grid dependency. By situating the University's experience within national and international policy frameworks and benchmarking it against comparable case studies, the paper demonstrates how RSPV adoption under the RESCO model delivers measurable benefits for both institutional sustainability and India's broader renewable energy transition.

LITERATURE REVIEW

Educational and institutional campuses in India traditionally relied on diesel generators to ensure supply during grid outages, leading to high operating costs and localized emissions. Studies confirm that rooftop solar systems directly substitute this dependence. Rupal *et al.*

(2016) showed significant reductions in diesel usage in Chandigarh institutional buildings following efficiency and solar interventions. Kulkarni *et al.* (2020) reported similar outcomes at a 450-kW rooftop installation in Karnataka, where diesel use was displaced, and the electricity bill was reduced by 76%. Yadav *et al.* (2025) further reinforced these findings in a semi-arid academic campus in western India. Internationally, Arshad *et al.* (2021) noted diesel displacement in net-metered rooftop systems in Southeast Asia, highlighting the role of solar PV in reducing fossil-fuel reliance in educational contexts. Solar PV's contribution to greenhouse gas reduction is well documented. Varun *et al.* (2012) established that the life-cycle carbon intensity of PV is an order of magnitude lower than coal-fired generation, providing a robust basis for emission reduction claims. Sharma *et al.* (2023) demonstrated significant mitigation from an eastern Indian institutional rooftop system, while Aggarwal and Parmar (2023) documented large-scale reductions at a 640 kWp campus installation. Navothna and Thotakura (2023) reported long-term carbon savings from grid-integrated systems in tropical climates, and Das *et al.* (2023) showed similar results in megawatt-scale rooftop and ground-mounted projects in Assam. Global studies echo these findings: IEA (2023) and IRENA (2022) emphasize distributed PV's role in decarbonizing urban campuses and meeting Sustainable Development Goal 7.

PLF or capacity utilization factor is a standard measure of solar plant efficiency. Kulkarni *et al.* (2020) reported PLFs between 16–20% in Karnataka, while Yadav *et al.* (2025) found 15–18% in western India. Sharma *et al.* (2023) observed PLF values around 13–15% in eastern India, consistent with lower irradiance. Larger case studies, such as Aggarwal and Parmar (2023), confirmed values of 12–18% for a 640 kWp system, while Das *et al.* (2023) demonstrated similar CUF outcomes at MW-scale projects. Internationally, Leeabai *et al.* (2025) in Thailand and Zublie *et al.* (2023) in Malaysia reported comparable PLF values, suggesting cross-country robustness of performance outcomes. The CEA (2023) user guide provides a benchmark of 12–20% for rooftop projects in north and central India, aligning with campus-scale evidence. Financial evaluations consistently show rooftop PV to be viable for educational institutions. Kulkarni *et al.* (2020) reported a three-year payback period, while Sharma *et al.* (2021) demonstrated savings of 50–70% across multiple campuses. Gupta and Singh (2019) emphasized positive NPV and internal rates of return for Indian universities. Garg and Shukla (2020) highlighted institutional barriers but confirmed financial viability under supportive tariffs. International cases, including Yusri *et al.* (2023) in Malaysia and Gao *et al.* (2024) in China, reinforce the economic benefits for universities, while Leeabai *et al.* (2025) and Zublie *et al.* (2023) demonstrated robust financial returns in Southeast Asia. Reports by IRENA (2022) and IEA (2023) further note that falling solar costs and innovative financing models, such as RESCO and net-metering, underpin adoption.

Rooftop PV reduces grid reliance and strengthens institutional energy security. Kulkarni *et al.* (2020) found a 76% reduction in grid electricity purchases, while Yadav *et al.* (2025) and Sharma *et al.* (2023) documented sustained decreases in net demand. International experiences confirm similar outcomes: Gao *et al.* (2024) observed improved self-sufficiency

at Chinese university campuses, while Arshad *et al.* (2021) found net-metered rooftop systems displacing significant grid dependency. National frameworks, including CEA (2023) and MNRE (2022), identify such reductions as critical for easing peak demand stress and enhancing distribution network stability. Adoption of non-residential rooftop solar has been shaped by policy incentives, financing models, and institutional priorities. Kumar *et al.* (2024) emphasized environmental concerns, compatibility, and incentives as key adoption drivers for non-residential systems. Garg and Shukla (2020) underscored the role of subsidies and net-metering, while Gupta and Singh (2019) pointed to awareness and financial literacy as enablers. Internationally, IRENA (2022) highlighted policy frameworks in emerging economies, and IEA (2023) stressed the role of distributed PV in urban resilience. For India, MNRE's rooftop targets and RESCO promotion, coupled with CERC's regulatory frameworks, provide the enabling environment for institutional adoption.

METHODOLOGY

This study employed a quantitative case study approach to evaluate the financial and environmental impacts of the rooftop solar photovoltaic (RSPV) plant installed at the University under the RESCO model. The methodology combined secondary operational data analysis with established evaluation frameworks for renewable energy projects.

Data Collection and Scope

Monthly records of electricity bills, grid consumption, diesel expenditure, and solar generation were collected from institutional sources for the period January 2016 to June 2025. The dataset enabled comparisons between the pre-solar phase (2016–2018) and post-solar operation (2018–2025). Similar reliance on institutional consumption data is documented in Indian case studies of educational campuses (Kulkarni *et al.*, 2020; Sharma *et al.*, 2023; Aggarwal & Parmar, 2023).

Diesel Generator Analysis

To assess the impact on fossil-fuel backup, average monthly diesel consumption was calculated for pre- and post-solar phases. A Welch two-sample *t*-test was used to test for statistical significance in the difference of means. This approach follows earlier energy transition studies that compare pre- and post-intervention periods for assessing displacement of diesel use (Rupal *et al.*, 2016; Yadav *et al.*, 2025).

Carbon Emission Reduction

Avoided carbon dioxide emissions were estimated by multiplying solar generation with baseline emission factors. Three scenarios were applied: coal-based displacement, grid-average emission factor, and hydropower reference, in line with UNFCCC methodologies and Central Electricity Authority (CEA) reporting guidelines (CEA, 2023; Varun *et al.*, 2012). Benchmarking was undertaken against other institutional studies of rooftop PV systems in India (Sharma *et al.*, 2023; Das *et al.*, 2023).

Plant Load Factor (PLF)

Monthly PLF was calculated as the ratio of actual solar output to installed capacity. Statistical measures (mean, median, standard deviation, minimum, maximum) were derived to capture performance variability. Similar PLF evaluations are widely applied in campus and regional rooftop PV studies (Kulkarni *et al.*, 2020; Navothna & Thotakura, 2023; Aggarwal & Parmar, 2023).

Financial Analysis

Two methods were employed to estimate financial savings: (i) the effective rate method, comparing contracted solar tariff (₹3.91/kWh) with average effective grid tariff derived from monthly bills, and (ii) the unit rate method, comparing solar generation with the prevailing DISCOM tariff. These approaches follow standard financial evaluation practices applied in techno-economic assessments of rooftop PV in institutional contexts (Gupta & Singh, 2019; Garg & Shukla, 2020; Yusri *et al.*, 2023). Cumulative savings were then benchmarked against case studies in India and abroad (Leeabai *et al.*, 2025; Zublie *et al.*, 2023).

Grid Dependency

Net grid demand was computed by subtracting monthly solar generation from total grid consumption. This method directly quantified the structural reduction in reliance on the distribution company due to rooftop solar, similar to approaches used in other academic campus assessments (Kulkarni *et al.*, 2020; Yadav *et al.*, 2025).

Analytical Framework

Descriptive statistics, significance testing, and comparative benchmarking were combined to generate insights. The methodological framework integrates both financial and environmental evaluation, consistent with interdisciplinary studies on rooftop solar adoption in non-residential settings (Kumar *et al.*, 2024; Garg & Shukla, 2020).

RESULTS

Diesel Generator Impact

The commissioning of the rooftop solar photovoltaic (RSPV) plant in July 2018 led to a structural reduction in the University's reliance on diesel generators. Prior to solar adoption, the institution consumed on average **9,428 litres of diesel per month** (January 2016–June 2018). Following the integration of the RSPV system, average diesel consumption declined sharply to **4,390 litres per month** (July 2018–May 2023). This represents a reduction of more than **53% in monthly diesel use**, highlighting the substitution effect of solar electricity for conventional diesel-based backup generation.

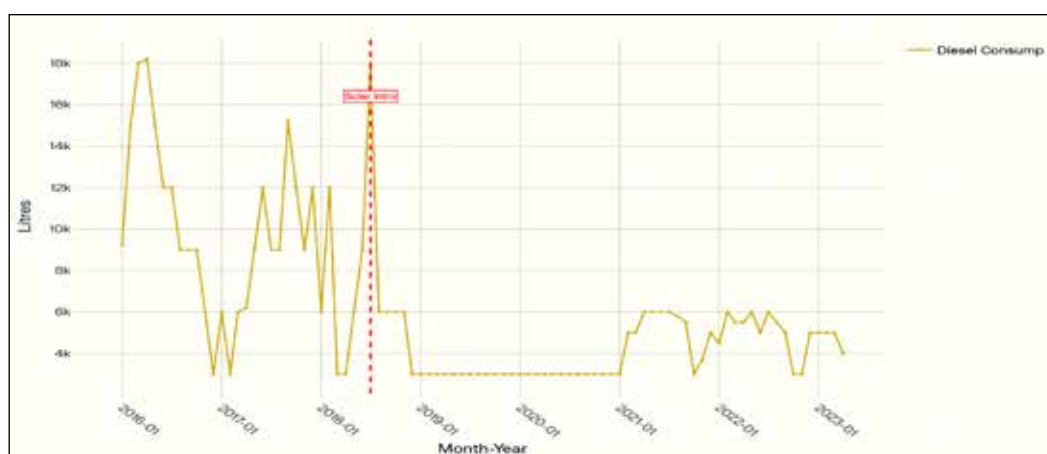


Fig. 1: Month-By-Month Diesel Consumption Up to May 2023

Source: Based on Author's Calculation from Secondary Data

The monthly trend (Figure 1) illustrates both the volatility of diesel usage in the pre-solar period and the stabilization that occurred after the solar system came online. Before July 2018, diesel consumption frequently spiked above 12,000 litres in certain months, reflecting heavy generator dependence during grid shortages. In contrast, post-2018, the series flattens considerably, with values generally clustered between 3,000–6,000 litres per month. A distinct anomaly is observed during the **COVID-19 lockdown period (March 2020–mid-2021)**, when on-campus activity was curtailed, and grid demand was minimal. As a result, diesel consumption dropped close to zero for several consecutive months. This fall cannot be attributed to the solar plant alone but reflects the broader collapse of electricity demand during pandemic-related closures. Once campus activities resumed, diesel usage rose slightly, though it remained well below pre-2018 levels, confirming the enduring role of rooftop solar in curbing generator dependence. The statistical robustness of the reduction was confirmed through a Welch two-sample *t*-test, which yielded a **t-statistic of 6.10** and a **p-value of 4.52×10^{-7}** , well below the 0.01 threshold. This strongly rejects the null hypothesis of no difference in means, establishing that the observed reduction in diesel consumption is not due to random variation but is directly attributable to the operation of the rooftop solar plant.

Table 1: Diesel generator: Pre–Post comparison (up to May 2023)

Period	Mean Diesel Consumption (litres/month)
Pre-solar (Jan 2016 – Jun 2018)	9,428 litres
Post-solar (Jul 2018 – latest)	4,390 litres

Source: Based on Author's Calculation from Secondary Data

Carbon Emission Reductions

The rooftop solar plant has delivered significant reductions in greenhouse gas emissions since its commissioning in July 2018. Using the UNFCCC baseline methodology and Central Electricity Authority emission factors, avoided carbon dioxide emissions were calculated across three scenarios:

1. Displacement of thermal coal
2. Hydropower baseline (Actual)
3. The Central Electricity Authority (CEA) published grid-average factor.

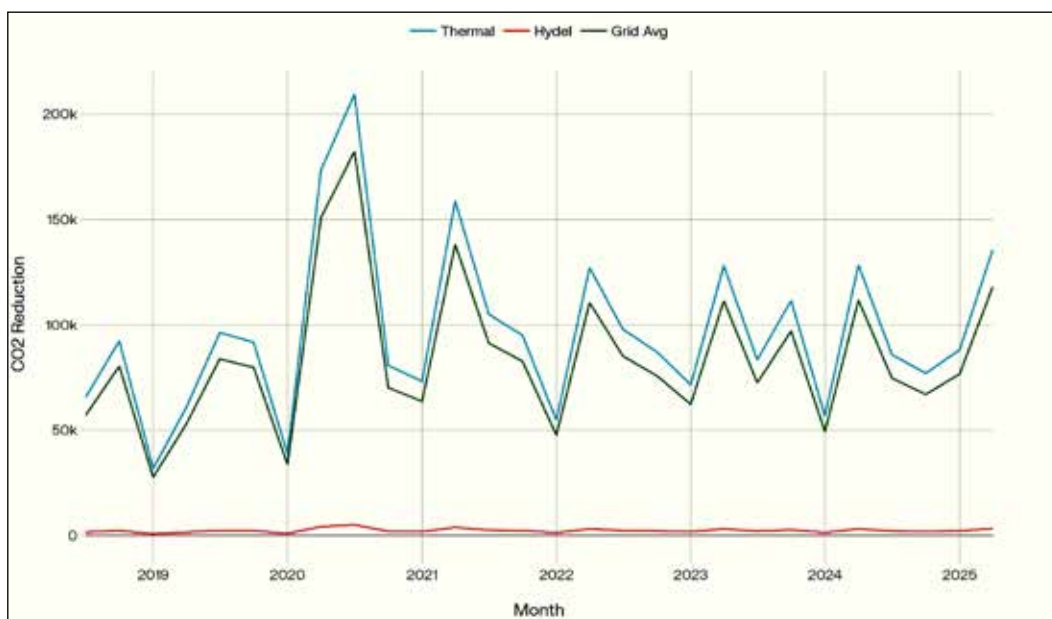


Fig. 2: Annual CO₂ Emissions Avoided by the CCSU Rooftop Solar Plant under Different Baseline Scenarios (2018–2025)

Source: Based on the author's calculation from Secondary Data

Monthly results show strong seasonality, with higher reductions during spring and autumn when solar output is maximized, and lower values during the monsoon. Annual reductions increased steadily from approximately 720,000 kilograms of CO₂ in 2018 to nearly 1.5 million kilograms in 2020, before stabilizing between 1.0 and 1.2 million kilograms in subsequent years. A temporary dip occurred during the COVID-19 lockdown when on-campus electricity demand collapsed, but post-2021 reductions rebounded in line with restored academic activity. Annual aggregates (Figure 3) further highlight the scale of impact. In 2018, the half-year operation of the plant generated approximately 720,000 kilograms of avoided CO₂ under the coal baseline. By 2020, annual reductions

peaked at nearly 1.5 million kilograms, before stabilizing in the range of 1.0–1.2 million kilograms in subsequent years. The grid-average scenario yielded annual savings between 600,000 and 1.3 million kilograms, while the hydropower case remained below 50,000 kilograms annually. In this case, the hydro scenario represents the actual reduction in emissions, since the university receives the majority of its grid electricity from large and small hydroelectric power plants. Nevertheless, a scenario-based analysis was necessary to provide a correct and replicable picture across different contexts.

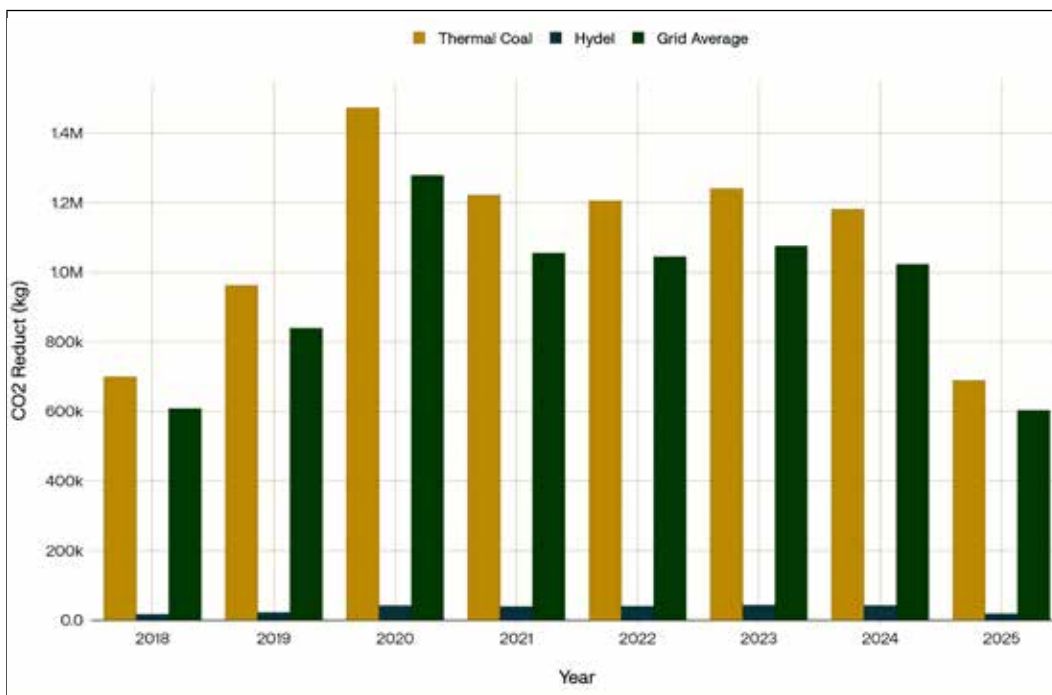


Fig. 3: Annual CO₂ Emissions Avoided by the CCSU Rooftop Solar Plant under Different Baseline Scenarios (2018–2025)

Source: Based on the author's calculation from Secondary Data

The anomalously high reduction in 2020 coincides with the first full year of operation at optimal performance, followed by slightly lower but steady reductions during the COVID-19 lockdown when total campus energy demand contracted. Post-lockdown, reductions rebounded but did not exceed 2020 levels, reflecting the alignment of solar generation with campus activity cycles.

This bar chart (Figure 4) represents the monthly average CO₂ emissions avoided (in kilograms) through the reduction of diesel fuel consumption after the adoption of solar energy. The calculation was performed by averaging diesel consumption for each month (e.g., all Januaries, all Februaries, etc.) before and after solar installation (post-July 2018),

then multiplying the monthly difference by a standard emission factor of 2.68 kg CO₂ per litre of diesel combusted. This emission factor is sourced from the United States Environmental Protection Agency (EPA) Greenhouse Gas Equivalencies Calculator and supported by the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, both of which recommend values in the range of 2.65–2.68 kg CO₂ per litre for diesel generator combustion. This approach is consistent with environmental reporting protocols and Clean Development Mechanism (CDM) methodologies.

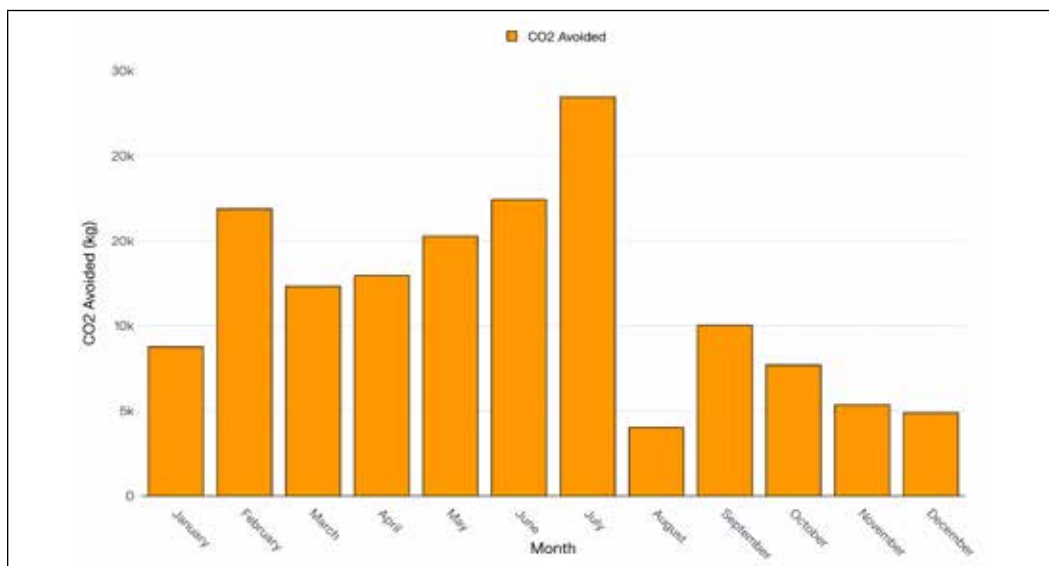


Fig. 4: CO₂ Avoided by Diesel Replacement

Source: Based on the author's Calculation from Secondary Data

The resulting chart shows that emissions avoided vary seasonally, with the highest benefits in July (23,450 kg CO₂), February (16,884 kg), and June (17,420 kg), reflecting months with either higher previous diesel reliance or pronounced solar effects on generator displacement. Lower values in August (4,200 kg) and December (4,884 kg) suggest periods of less change in diesel use or naturally lower generator demand. This breakdown allows for detailed tracking of temporal patterns, helping to identify when and how solar adoption most effectively reduces fossil fuel dependency. The monthly perspective also complements annual summaries, guiding targeted interventions for further emissions reductions.

Plant Load Factor (PLF) Trends

Plant Load Factor (PLF) provides an indicator of how efficiently a power plant utilizes its installed capacity. For the University's rooftop solar system, PLF was computed on a monthly basis from July 2018 to June 2025. The time-series (Figure 5) shows fluctuations

typical of grid-connected photovoltaic plants, with performance strongly influenced by seasonal irradiance and operational conditions.

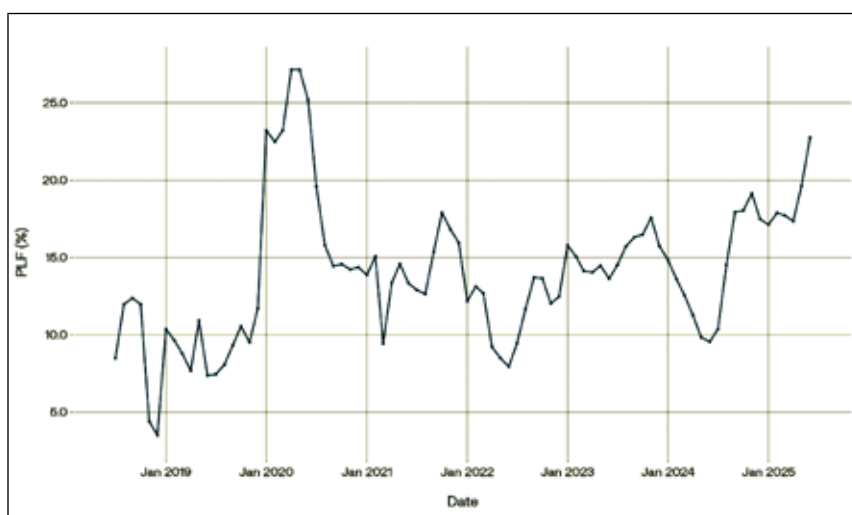


Fig. 5: Monthly PLF (%) trend

Source: Based on the author's Calculation from Secondary Data

The average PLF over the full observation period was 13.14 percent, with a median of 12.78 percent. Monthly values ranged between a minimum of 3.5 percent and a maximum of 27.16 percent, with a standard deviation of 4.55 percent. This variation reflects both the inherent intermittency of solar resources and periods of reduced on-campus demand, such as during the COVID-19 lockdown in 2020–2021, when the plant occasionally operated below 5 percent capacity utilization.

Table 2: Plant Load Factor Summary

Statistic	Value
Mean	13.14%
Median	12.78%
Standard Deviation	4.55%
Minimum	3.50%
Maximum	27.16%

Source: Based on the author's Calculation from Secondary Data

Performance peaks above 25 percent in early 2020 correspond to months with high solar irradiance and stable grid conditions, whereas troughs are observed in the monsoon period and during extended campus closures. From 2022 onwards, PLF values stabilize

in the 12–18 percent range, consistent with typical operating benchmarks for rooftop PV installations in northern India. The recovery trend in 2024–2025, with PLF climbing back towards 20 percent, indicates sustained plant reliability and effective grid integration.

Financial Benefits

The effective rate method normalizes tariff variation by dividing the monthly grid electricity bill by total consumption, producing an average effective tariff. Savings are then calculated as the difference between this effective rate and the contracted solar tariff of ₹3.91 per kWh under the RESCO model. This approach captures the real cost conditions faced by the University, including temporal variation in grid charges. The unit rate method instead multiplies solar generation directly by the prevailing DISCOM tariff. Each solar unit is assumed to offset a grid unit billed at the marginal rate. This approach is simpler but tends to overestimate benefits, since it ignores fixed or demand charges in the grid tariff. Similar methodological distinctions are noted in financial evaluations of rooftop PV in India and abroad, where both effective tariff-based and unit-rate approaches are used to estimate cost savings (Kulkarni *et al.*, 2020; Garg & Shukla, 2020; Gupta & Singh, 2019).

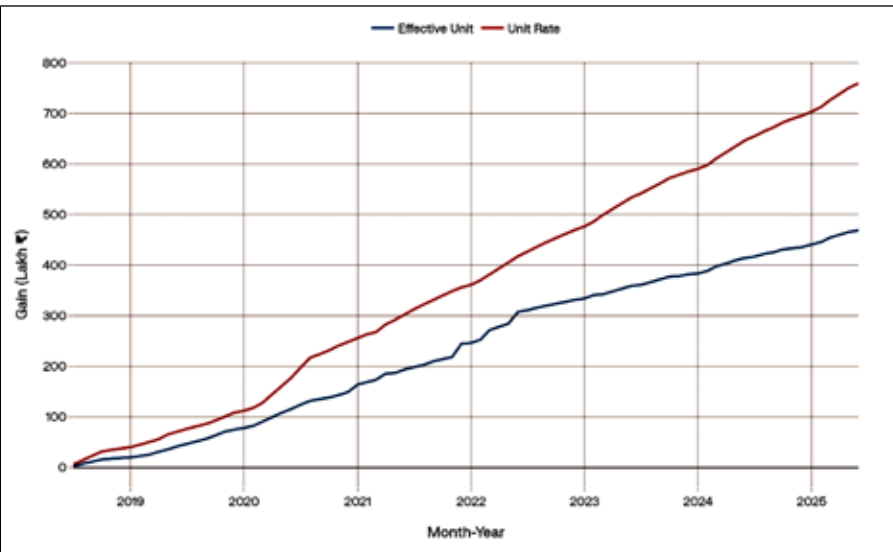


Fig. 6: Cumulative Financial Savings from RESCO RSPV Solar Plant (Rs. Lakh)

Source: Based on the author's Calculation from Secondary Data

Results show steadily increasing financial gains over the 2018–2025 period (Figure 6). By June 2025, the effective rate method yielded cumulative savings of approximately ₹4.8 crore, while the unit rate method estimated around ₹7.6 crore. The divergence between these values highlights the sensitivity of financial outcomes to accounting methods, a finding echoed in other techno-economic assessments (Yusri *et al.*, 2023; Gao *et al.*, 2024).

Grid Dependency-Pattern Changes

Before the introduction of rooftop solar in July 2018, monthly net grid demand generally ranged between 250,000 and 350,000 kWh (Figure 7). With the commissioning of the RSPV system, this dependency declined substantially, falling to a new range of 150,000–220,000 kWh. This indicates that solar power directly offset around one-third of the University’s conventional electricity requirement.

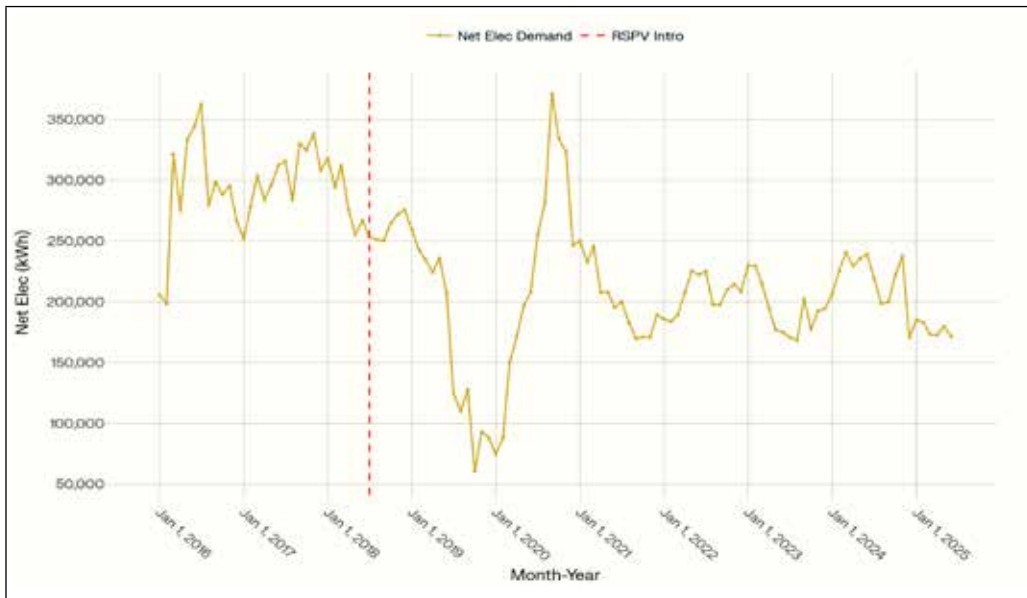


Fig. 7: Grid Dependency – Net Electricity Demand from Grid (2016-2025)

Source: Based on the author’s Calculation from Secondary Data

A sharp dip is visible during 2020–2021, when net grid demand fell below 100,000 kWh in several months. This was a combined outcome of suppressed electricity use during the COVID-19 lockdown and continued solar generation feeding into the system. Once normal campus activities resumed, demand partially rebounded but never returned to pre-2018 levels, demonstrating the lasting structural effect of rooftop solar integration.

DISCUSSION

The results of this study demonstrate that rooftop solar photovoltaic (RSPV) adoption under the RESCO model has significantly reduced the University’s reliance on diesel generation, mitigated carbon emissions, stabilized plant load factor performance within expected ranges, delivered substantial financial savings, and decreased dependency on grid-supplied electricity. Together, these outcomes highlight both the economic and environmental effectiveness of distributed renewable energy systems in higher education institutions.

Diesel Generator Displacement

One of the most visible outcomes has been the reduction in diesel generator usage. Average monthly consumption fell from 9,428 litres before July 2018 to 4,390 litres after solar commissioning, representing a 53 percent decline. This displacement of diesel aligns with case studies from institutional settings in India, where rooftop solar has been shown to replace backup generation and reduce operational costs (Rupal *et al.*, 2016; Kulkarni *et al.*, 2020). The COVID-19 lockdown period provided further confirmation, as demand for diesel generation nearly vanished when campus activity was suspended. While part of the decline can be attributed to pandemic-related closures, the long-term trend confirms that rooftop solar has fundamentally reduced the University's dependence on fossil-based generation.

Carbon Emission Reductions

The system also delivered considerable emission savings. Annual avoided CO₂ emissions were estimated between 0.7 and 1.5 million kilograms, depending on baseline scenario assumptions. This magnitude of reduction positions the University alongside other campuses reporting annual savings of 0.6–1.3 million kilograms (Yadav *et al.*, 2025; Sharma *et al.*, 2023; Aggarwal & Parmar, 2023). These outcomes reinforce the potential of institutional-scale PV in helping India meet its climate targets, particularly given that coal remains the marginal source of electricity in most regions (Varun *et al.*, 2012; Sengupta *et al.*, 2022). By internalizing emission reductions at the campus level, institutions act as microcosms of national decarbonization strategies, with tangible contributions toward Sustainable Development Goal 7 (Kumar *et al.*, 2024).

Plant Load Factor Performance

Plant Load Factor averaged 13.14 percent over the observation period, with values ranging from 3.5 percent during lockdown months to peaks above 25 percent in high-irradiance seasons. This is consistent with Central Electricity Authority benchmarks of 12–20 percent for rooftop systems in northern India (CEA, 2023). Case studies in Karnataka, Assam, and eastern India report comparable CUF/PLF performance (Kulkarni *et al.*, 2020; Das *et al.*, 2023; Sharma *et al.*, 2023). While the University's average is slightly lower than campuses in western and southern India (where irradiance is higher), it is fully in line with expectations for the north-central climatic zone. Importantly, the steady recovery in PLF post-2022 indicates strong system reliability and effective maintenance.

Financial Viability

Financial analysis shows that cumulative savings reached approximately ₹4.8 crore under the effective rate method and ₹7.6 crore under the unit rate method by June 2025. This divergence reflects methodological assumptions: the effective rate accounts for average

grid tariffs, while the unit rate assumes each solar unit offsets the marginal DISCOM tariff. Similar distinctions are noted in techno-economic studies where both levelized cost and effective tariff approaches are used (Gupta & Singh, 2019; Garg & Shukla, 2020). Benchmarking suggests that the University's financial performance is consistent with other institutional systems, which typically achieve 50–70 percent annual bill savings and payback periods of 3–5 years (Kulkarni *et al.*, 2020; Sharma *et al.*, 2021; Aggarwal & Parmar, 2023). International evidence from Southeast Asia also confirms strong internal rates of return for campus-scale rooftop PV (Yusri *et al.*, 2023; Gao *et al.*, 2024; Leeabai *et al.*, 2025). These comparisons underscore that the University's savings are not anomalous but part of a broader trend establishing rooftop PV as a financially viable energy solution for educational institutions.

Reduction in Grid Dependency

Subtracting solar generation from total grid consumption shows a structural decline in net grid demand from 250,000–350,000 kWh per month in the pre-solar period to 150,000–220,000 kWh thereafter. This represents a sustained reduction of approximately one-third in reliance on grid-supplied electricity. Comparable reductions have been reported at other campuses: a 76 percent cut in Karnataka (Kulkarni *et al.*, 2020) and 30–50 percent at institutions in eastern and western India (Sharma *et al.*, 2023; Yadav *et al.*, 2025). Such outcomes confirm that rooftop solar systems not only mitigate emissions but also enhance institutional energy security by lowering exposure to fluctuating grid tariffs and supply constraints.

Integrated Implications

The evidence across these dimensions highlights the multiple co-benefits of rooftop solar for academic institutions. Environmentally, the project has avoided nearly one million kilograms of CO₂ annually while simultaneously displacing fossil-fuel generation. Economically, savings of nearly ₹5 crore demonstrate long-term viability even without factoring in externalities such as avoided pollution costs. Operationally, reduced diesel and grid reliance indicate greater resilience and independence. At a policy level, these findings reinforce the suitability of the RESCO model for scaling rooftop solar in the education sector, particularly where upfront capital costs are a barrier. The University's experience parallels results across India, demonstrating that when institutional rooftops are leveraged for distributed solar, they can generate measurable climate and financial benefits while easing grid stress. This dual impact validates ongoing government initiatives that target rooftop adoption in non-residential segments (CEA, 2023; Kumar *et al.*, 2024).

CONCLUSION

This study assessed the financial and environmental impacts of the University's rooftop solar photovoltaic (RSPV) plant installed under the RESCO model. Drawing on operational data from 2016 to 2025, the analysis confirmed that solar adoption produced tangible benefits across multiple dimensions. First, diesel generator reliance declined by more than half, reducing both operational costs and local emissions. Second, avoided carbon dioxide emissions consistently exceeded one million kilograms annually, aligning with benchmarks reported for comparable institutional projects across India. Third, the plant's average PLF of 13.14 percent fell within the expected range for north-central India, demonstrating stable performance despite seasonal variability and the disruptions of the COVID-19 period. Notably, when taken together, PLF shows a strong correlation with both financial savings and environmental benefits, indicating that higher plant efficiency directly enhances sustainability outcomes. Fourth, cumulative financial savings reached nearly ₹5 crore by 2025 under conservative estimation, reinforcing the economic viability of campus-scale rooftop solar under RESCO arrangements. Finally, grid dependency fell by roughly one-third, underscoring the role of distributed generation in enhancing institutional energy security. The decline in generator dependency further suggests that investment in battery infrastructure could reduce this reliance even more, amplifying both the financial and environmental advantages of the system. Taken together, these outcomes provide robust evidence that non-residential rooftop solar can simultaneously achieve environmental mitigation, cost savings, and resilience objectives. The University's experience illustrates the suitability of the RESCO model for institutions that may not have the resources for upfront investment but seek to benefit from renewable energy integration. The findings also highlight broader implications for policy and practice. Leveraging institutional rooftops can meaningfully contribute to India's renewable energy targets and climate commitments while reducing stress on state-level distribution networks. With supportive regulatory frameworks, streamlined net-metering, and standardized RESCO contracts, the education sector could emerge as a key driver of decentralized solar expansion. Future research should extend this analysis through life-cycle costing, inclusion of storage integration, and multi-campus comparisons across climatic zones. Nevertheless, the evidence from this case confirms that rooftop solar adoption in academic institutions is not only technically feasible but also financially prudent and environmentally necessary.

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SECTION IV

Indigenous Knowledge, Culture, Education and Sustainable Futures

