EVALUATING THE FINANCIAL AND ENVIRONMENTAL BENEFITS OF SOLAR ENERGY RETROFITTING IN INSTITUTIONAL ELECTRICAL SYSTEMS

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ABSTRACT: *This study evaluated the financial and environmental benefits of solar photovoltaic (PV) retrofitting in institutional electrical systems, focusing on the Central Philippines State University (CPSU) Main Campus. Monthly electricity consumption data from 2019 to 2024 were analyzed to establish baseline demand, and PV system layouts were developed for the College of Engineering (COE) and the Research, Development, and Extension Center (RDEC) buildings. Structural assessments confirmed the feasibility of installing systems with a combined capacity of 145.2 kWp. The total installation cost was estimated at ₱14.52 million, with a projected payback period of 5.07 years. The proposed systems are expected to generate 235.224 MWh annually, offsetting approximately 163.13 t-CO_2e per year, or 4,893.9 t-CO_2e over a 30-year lifespan. The findings demonstrate that solar retrofitting reduces institutional dependence on grid-supplied, fossil fuel–based electricity while providing significant cost savings and measurable environmental benefits. The study highlights solar PV retrofitting as a viable strategy for academic institutions in the Philippines to achieve energy efficiency, ensure cost-effectiveness, and align with global sustainability goals.*

Keywords: Renewable energy; Energy retrofitting; Carbon dioxide (CO_2) reduction, Grid emission factor, Tree carbon density

1 INTRODUCTION

The rising demand for electricity in academic institutions had increased operational costs and intensified dependence on grid-supplied power, which remained predominantly generated from fossil fuels. Globally, the electricity sector accounted for about 40% of CO_2 emissions, underscoring its significant contribution to climate change [1]. In the Philippines, coal continued to dominate the energy mix, supplying roughly 62% of electricity generation in 2024 despite policy initiatives promoting renewable alternatives [2, 3]. This reliance not only escalated institutional expenditures but also exacerbated greenhouse gas emissions, particularly carbon dioxide (CO_2). In line with global and national calls for sustainable energy, there was an urgent need to assess the feasibility of integrating renewable systems such as solar photovoltaics (PV) into institutional electrical infrastructures, a direction strongly aligned with the United Nations' Sustainable Development Goal [4], which advocates for universal access to reliable, sustainable, and modern energy. Among renewable technologies, rooftop solar PV presents a particularly viable solution, as it utilizes existing building structures without competing for land. Studies demonstrated that rooftop PV directly reduces fossil fuel–based electricity use and provides rapid decarbonization benefits [5]. For instance, a 1 kW rooftop PV system in the Philippines offsets about 1,200–1,500 kg of CO_2 annually [6], which is equivalent to the sequestration of 80–100 mahogany trees, since a mahogany tree absorbs only around 15 kg CO_2 per year [7]. This comparison illustrates the relative efficiency of PV systems in delivering measurable emission reductions, while still recognizing that tree planting remains complementary for ecosystem and biodiversity benefits. Although numerous studies had explored the adoption of solar PV systems in various sectors, limited research had been conducted on their feasibility within academic institutions in the Philippines, particularly in provincial state universities such as Central Philippines State University (CPSU). Existing literature had primarily focused on the technical efficiency of PV systems or their contribution to national renewable energy targets, but there remained a lack of comprehensive analysis that integrated financial viability, structural suitability, and environmental impact within the context of institutional retrofitting. Furthermore, while global frameworks such as Sustainable Development Goal 7 emphasized the importance of affordable and clean energy, there was insufficient localized evidence demonstrating how solar retrofitting could contribute to both institutional cost savings and carbon emission reductions in Philippine higher education settings. This gap underscored the need for studies that not only evaluated projected return on investment (ROI) and cost efficiency but also translated environmental benefits, such as CO_2 reduction, into tangible and relatable metrics, thereby providing decision-makers with data-driven insights for sustainable campus energy management.

Statement of the Problem

Retrofitting institutional electrical systems with solar energy offered dual benefits: reducing carbon emissions and providing long-term cost savings despite the high initial investment. Beyond economic and environmental gains, solar integration in academic institutions enhanced educational opportunities through research and training while promoting community awareness and sustainable practices. Focusing on Central Philippines State University (CPSU), this study specifically evaluated the projected costs, return on investment, and potential CO_2 emission reductions of solar energy retrofitting in its identified buildings, thereby contributing to the university's sustainability goals and the global effort toward cleaner and more resilient energy systems.

In this context, the present study sought to address the following research questions:

1. What is the average monthly electricity consumption in kilowatt-hours (kWh) of the CPSU Main Campus?
2. What is the maximum solar panel capacity that can be installed on each identified building for retrofit without compromising structural integrity?
3. What is the estimated installation cost of solar energy systems for the identified buildings?
4. What is the projected payback period after retrofitting?

5. What is the potential CO_2 emission reduction that can be achieved through solar energy retrofitting compared to conventional grid-powered systems?

By answering these questions, the study aimed to determine the economic viability and environmental sustainability of retrofitting institutional electrical systems with solar energy, thereby providing a framework for informed decision-making and long-term planning.

1 MATERIALS AND METHODS

This study utilized a quantitative descriptive research design to assess the feasibility of retrofitting the Research, Development, and Extension Center (RDEC) and the College of Engineering (COE) buildings at CPSU Main Campus with solar photovoltaic (PV) systems. Monthly electricity consumption records from January 2019 to June 2024, together with the buildings' energy demand for the first half of 2024, were obtained from utility records and analyzed using Microsoft Excel to determine average monthly energy consumption. Based on the available roof area, PV system layouts were prepared using CAD software, ensuring that the installed capacity did not exceed the 100-kW limit under the Philippine net metering program [8, 9, 10]. The proposed designs were validated by a licensed civil engineer to verify the structural suitability of the buildings.

Installation costs were estimated through consultations with solar energy providers using a benchmark cost of ₱100 per watt. The return on investment (ROI) was determined by calculating the expected payback period using the Philippine average of 4.5 peak sun hours per day to estimate annual electricity generation and potential savings. Environmental benefits were evaluated by estimating the reduction in CO_2 emissions based on the Luzon–Visayas grid emission factor [11], and the avoided emissions were expressed as the equivalent number of trees planted using the U.S. Department of Agriculture's standard carbon absorption rate for a mature tree [12].

2 RESULTS

2.1 The average monthly electricity consumption in kilowatt-hours (kWh) of the CPSU Main Campus.

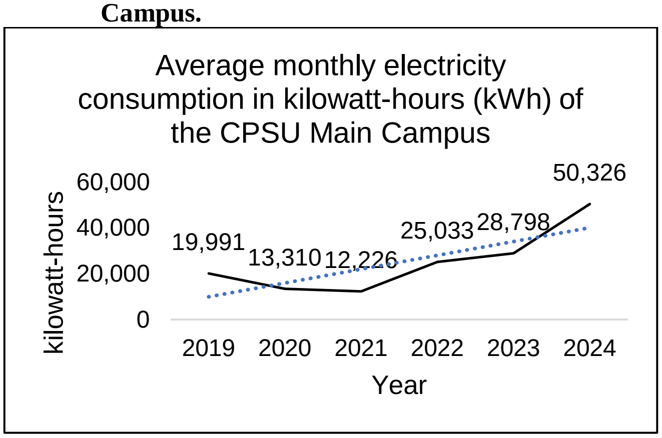

Figure 1. Average monthly electricity consumption for the year 2019 to 2024

The CPSU Main Campus recorded an electricity consumption of 19,991 kWh in 2019. A sharp decline occurred in 2020 (13,310 kWh) due to pandemic-related restrictions, reaching the lowest value in 2021 (12,226 kWh). As on-site operations resumed, consumption increased to 25,033 kWh in 2022 and 28,799 kWh in 2023. For 2024 (January–July), the total consumption reached 50,326 kWh. The trendline showed an overall upward pattern after the pandemic years.

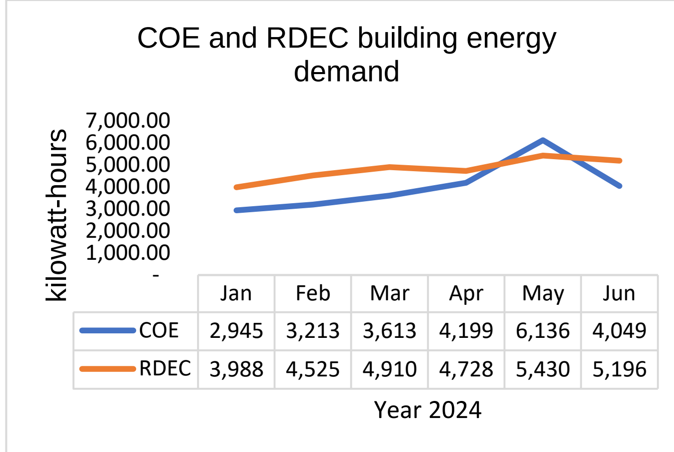

Figure 3. COE and RDEC building energy demand

The COE building's consumption rose from 2,945.90 kWh in January to 6,136.33 kWh in May before decreasing to 4,049.18 kWh in June. RDEC recorded higher values in early months, peaking at 5,430.77 kWh in May and slightly dropping to 5,196.89 kWh in June. RDEC showed relatively stable demand, while COE presented higher variability.

2.2 Maximum Solar Panel Capacity for COE and RDEC

Table 1. Building profile of the buildings designated for the solar retrofit.

Name of Building	Location	Length (meters)	Width (meters)	Provision for stairway (roof access)	Area for the solar modules (m^2)
COE	Roof top (S & N)	69	21	none	1,449
RDEC	Roof top	42.98	10.67	none	458.59

The COE building had a usable rooftop area of 1,449 m^2, while RDEC had 458.59 m^2. Both structures lacked stairway roof access. These area measurements determined the maximum panel installations for each building.

Table 2. Design specifications of the solar energy systems retrofit for each designated building of the CPSU campuses.

Building Name	Solar panel size (m^2)	No. of Inverters (10kW)	Wattage per Panel	Quantity (Unit)	Total power (kW)	kWh per day	kWh per Month
COE	2.64	12	550	180	99	445.5	13,365
RDEC	2.64	6	550	84	46.2	207.9	6,237
Total	**2.64**	**18**	**550**	**264**	**145.2**	**653.4**	**19,602**

The COE building accommodated 180 panels (99 kW total capacity) producing 13,365 kWh per month. RDEC supported 84 panels (46.2 kW) producing 6,237 kWh per month. Combined, both systems produced 19,602 kWh monthly at a total installed capacity of 145.2 kW.

2.3 Estimated Installation Cost and Payback Period

For the estimated cost of installation, the following formula were used:

Cost of Installation in Philippine Peso **(ECI)** = Solar Panel Rating in Watts **(SPR)** x Number of Panels **(NP)** x Cost of Installation per Watt **(COI)**

For the COE:

ECI = SPR x NP x COI

ECI = 550 W x 180 x ₱100

ECI = ₱ 9,900,000.00

For the RDEC:

ECI = SPR x NP x COI

ECI = 550 W x 84 x ₱100

ECI = ₱4,620,000.00

For the projected payback period the following formula were used:

Payback Period **(PP)** = Estimated Cost of Installation **(ECI)** ÷ Cost of Energy Produced **(CEP)**

Where:

Cost of Energy Produced **(CEP)** = {[SPR x NP x sun-hour/day x 365 days] ÷ 1000} x Price of grid electricity per kW-hr.

For the COE:

CEP = {[550W x 180 x 4.5 sun-hour x 365] ÷ 1000} x ₱12

CEP = ₱1,952,290.00

Therefore:

PP = ECI ÷ CEP

PP = ₱ 9,900,000.00 ÷ ₱1,952,290.00

PP = 5.07 years

For the RDEC:

CEP = {[550W x 84 x 4.5 sun-hour x 365] ÷ 1000} x ₱12

CEP = ₱910,602.00

Therefore:

PP = ECI ÷ CEP

PP = *₱4,620,000.00* ÷ ₱910,602.00

PP = 5.07 years

Using ₱100 per watt installation cost, the COE system required ₱9,900,000.00, while RDEC required ₱4,620,000.00. Both buildings showed an identical payback period of 5.07 years.

Table 3. Estimated cost of installation and ROI/payback period

Building	Estimated Cost of Installation	Return on Investment (ROI) / Payback Period
COE	₱9,900,000.00	5.07 years
RDEC	₱4,620,000.00	5.07 years
Total	**₱14,520,000.00**	**5.07 ears**

The total investment required for the solar energy retrofit of both the COE and RDEC buildings amounted to ₱14,520,000.00. Based on the projected annual energy savings generated by the installed systems, the combined retrofitting is expected to achieve a payback period of 5.07 years, after which the installations will begin providing net financial returns for the institution.

2.4 Potential CO_2 Emission Reduction

Given the 2024 average monthly energy demand of 50,326 kWh for the campus, the annual consumption amounts to 603,912 kWh. The equivalent CO_2 emission is

Equivalent CO_2 Emission **(CO_2e)** = Yearly Energy Demand (YED) x Grid Emission Factor (GIF)

(CO_2e) = 603.912 MWh x 0.6935 t-CO2/MWh

(CO_2e) = 418.813 tons of CO_2

Therefore, CO_2e = 418.813 tons of CO_2 equivalent using only grid power

Given the total panel capacity of 145.2 kW, which has a potential to generate 235.224 MWh annually the potential CO_2 emission reduction is

Potential CO_2 emission reduction **(CO_2R)** = 235.224 MWh x 0.6935 t-CO2/MWh

(CO_2R) = 163.13 tons of CO_2 equivalent

The percent reduction in CO_2 emission of the campus was calculated using the formula,

Percent CO_2 emission Reduction = (CO_2e ÷ CO_2R) x 100

Percent CO_2 emission Reduction = (418.813 t-CO_2e ÷ 163.13 t-CO_2R) x 100

Percent CO_2 emission Reduction = 38.95 %

To compute for the equivalent number of trees planted the following formula was used:

NTPe = CO_2R ÷ CO_2S

Where:

NTPe = equivalent number of trees planted

CO_2R = equivalent CO_2 reduction in (t-CO_2)

CO_2S = equivalent tree sequestration in (t-CO_2)

Hence,

NTPe = CO_2R ÷ CO_2S

NTPe = 163.13 t-CO2e ÷ 0.0218 t-CO2e

NTPe = 7,483 equivalent number of trees

The total investment for the solar energy retrofit of the COE and RDEC buildings amounted to ₱14,520,000.00. Based on the projected annual energy savings, both systems are expected to achieve a payback period of 5.07 years, indicating that the institution will begin to realize net financial benefits after this period.

Table 4. Projected CO_2 emission reduction over the lifespan of solar panels.

Parameter	Value	Source/Note
Visayas Grid Emission factor	0.6935 t-CO2/MWhr	[12]
Solar panel lifespan	30 years	[13]
Total Solar panel capacity	145.2 kWp	Computed
Monthly Energy Generation	19.602 MWhr	Computed
Annual Energy Generation	235.224 MWhr	Computed
Yearly Carbon Footprint	163.13 t-CO2e	Computed
Total Carbon footprint	4,893.9 t-CO2e	Computed

The solar energy retrofit is projected to reduce carbon emissions by 163.13 t-CO_2e annually. Over the 30-year lifespan of the solar panels, this reduction amounts to approximately 4,893.9 t-CO_2e. When translated into ecological impact, the total reduction is equivalent to planting about 224,658 trees over the same period, demonstrating the significant environmental benefit of the proposed system.

2.5 The potential CO_2 emission reduction

The proposed 145.2 kWp solar PV system is projected to generate **235.224 MWh of clean electricity annually**, reducing carbon emissions by approximately **163.13 t-CO_2e per year** compared with conventional grid-powered electricity. This represents a **38.95% reduction** in the campus's electricity-related carbon footprint. Over a 30-year system lifespan, the cumulative emission reduction is estimated at **4,893.9 t-CO_2e**, equivalent to the carbon sequestration capacity of approximately **224,658 trees**. These findings demonstrate the significant environmental benefits of solar PV retrofitting in reducing greenhouse gas emissions and supporting institutional sustainability goals.

3 DISCUSSION

The results revealed a consistent increase in electricity consumption at CPSU following the easing of pandemic restrictions. This rise reflected the return of face-to-face classes, operational expansion, and greater utilization of campus facilities. The growing demand reinforced the need for alternative energy solutions.

Analysis of the COE and RDEC building profiles confirmed that both structures were viable for solar retrofitting, with the COE offering a significantly larger area for PV installation. The calculated system capacities demonstrated that both buildings could collectively generate 19,602 kWh monthly, contributing substantially to the campus's energy needs. These outputs aligned with the objective of maximizing rooftop potential while remaining within the government's 100 kW net metering limitation.

The financial assessment showed that although the initial installation costs were considerable, the payback period of 5.07 years indicated strong long-term financial viability. This ROI is consistent with typical solar industry benchmarks [14] in the Philippines, where payback periods generally range from 4 to 7 years depending on system size and electricity rates.

Evironmental impact calculations further strengthened the case for solar retrofitting. Offsetting 163.13 t-CO_2e annually positioned the system as a meaningful contributor to CPSU's sustainability goals. The equivalent of planting 7,483 trees per year illustrated the long-term ecological benefit, especially when projected over the 30-year lifespan of solar panels.

Overall, the findings highlighted the technical feasibility, economic advantage, and environmental significance of solar energy adoption at CPSU. The retrofitting initiative effectively supports the institution's goals toward energy efficiency, financial sustainability, and reduced carbon footprint.

5 CONCLUSIONs

The findings of this study clearly demonstrate that solar energy retrofitting is both financially viable and environmentally impactful for institutional buildings such as the RDEC and COE facilities of CPSU. With an installed capacity of 145.2 kW and a projected energy generation of 235.224 MWh annually, the solar PV systems can offset an estimated 163.13 t-CO_2e per year, equivalent to planting approximately 7,483 trees annually or over 224,000 trees across the panel lifespan. The computed payback period of 5.07 years signifies that the initial investment of ₱14.52 million can be fully recovered within a reasonable timeframe, after which the system continues to generate savings and environmental benefits. Overall, solar retrofitting significantly reduces dependence on fossil fuel–based grid electricity while aligning with national sustainability directives and global climate targets, proving it to be a strategic and forward-looking solution for academic institutions.

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