# Self-Consumption Optimisation and Energy Yield of a 23.4 kWp Grid-Connected PV-BESS System in a Tropical Commercial Environment

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**Abstract.**The deployment of solar photovoltaic (PV) systems in commercial settings presents distinct technical challenges associated with load profile variability, self-consumption optimisation, and grid interaction dynamics. This study investigates the physical performance and energy yield characteristics of a 23.4 kWp grid-connected PV system with optional battery energy storage system (BESS) integration, installed at a commercial food-service premises in Kuala Lumpur, Malaysia. The system is assessed under the tropical irradiance conditions of peninsular Malaysia, where high solar insolation levels and consistent irradiance patterns create favourable conditions for PV energy generation. Simulation and modelling results indicate an annual energy yield of 28,185 kWh/year (2,317 kWh/month), corresponding to a 19% reduction in grid energy demand at the site. The BESS configuration is evaluated for its capacity to increase self-consumption ratios to 80–90%, reduce grid dependence, and buffer demand-supply mismatches arising from non-coincident solar generation and peak commercial load periods. System degradation modelling over a 30-year operational horizon is incorporated to assess long-term yield stability under fixed Malaysian grid tariff conditions. The findings establish a technical performance baseline for SELCO (Self-Consumption Solar) PV deployments in the tropical commercial sector, contributing empirical energy yield and system behaviour data relevant to Malaysia's 70% renewable energy target by 2050.

**Keywords:**Photovoltaic system performance; energy yield modelling; battery energy storage system (BESS); self-consumption optimisation; tropical irradiance; grid-connected PV; commercial load profile; PV degradation modelling.

## 1 Introduction

The commercial electricity tariffs in Malaysia have continuously been on the rise over the last few years, which has strained the financial capacities of small and medium-sized enterprises (SMEs) such as restaurants [1]. Fridges, cookers, ventilation systems, and lights make restaurants very energy-consuming because they run all the time. This is triggering a surge of renewable option research by many commercial operators, with a focus on solar PV in the Self-Consumption (SELCO) scheme under the Energy Commission (Suruhanjaya Tenaga) regulation [2].Recent studies confirm that rooftop solar PV installations in Malaysian commercial buildings consistently reduce electricity bills by 18–23%, with payback periods well below the project lifetime, reinforcing the financial case for SELCO adoption [5,6,9].

In the SELCO model, no solar energy should be exported to the grid, and it should be used locally; therefore, this aspect is the main difference between this model and Net Energy Metering (NEM). The export of surplus generation is met by the grid in NEM in a feed-in displacement rate and is allocated against the bill of the consumer, but in SELCO, the consumers only get benefits through direct self-consumption, so load-matching is essential. Additionally, SELCO installations above 72 kWp are now required to incorporate BESS under revised 2025 Energy Commission guidelines, adding capital cost but improving self-consumption ratios and grid stability [3,4,25].To commercial organizations with operations that mostly happen during the day like restaurants, a decent opportunity to save the grid dependence and enhance the predictability of costs has been offered by SELCO.

Nevertheless, regardless of its strengths, its adoption is subject to consumer issues such as high start-up capital cost, system reliability, larger installations, battery use, standby fees, and regulatory modifications [4].

In this research study, the experimental 23.4 kWp solar PV system at Kuala Lumpur was considered to determine the financial performance, potential of hybrid optimization, and consumer risk.

## 2. Literature Review

Most recent research has been done in 2023-2026, investigating the hybrid PV-BESS system in commercial buildings in Malaysia [5-7]. Particle Swarm Optimization (PSO) is one of the optimization methods that has shown better self-consumption and minimized Net Present Cost (NPC) [8].

UniversitiTeknikal Malaysia Melaka (UTeM) and other commercial installations give case studies of electricity bill savings of between 18 and 23 percent, according to load matching and system sizing [9], [10]. The result is in line with the commercial ROI estimates in Malaysia that have an average payback period of 4-6 years on a typical SME installation [11-12].

The recent regulatory changes, however, such as the revised standby charge and obligatory BESS to SELCO systems over 72kWp, have added new capital costs [13-14]. Such requirements can add up to 40 to cost of the entire project, and related logistical costs which may put its use off-putting to SMEs.

Moreover, there are other technical considerations brought about by the tropical climate conditions. An increase in ambient temperature increases lithium-ion battery degradation, decreasing the efficiency of the lifecycle. The existing literature indicates the need to introduce the latest trends in managing energy and modelling the flexible tariff to enhance the performance of systems in the long-term [15-16].

Although there is an increasing interest in commercial solar PV adoption, there is a research gap with respect to the restaurant energy profile. The load curve is a unique shape of restaurants with two peaks in the usage (lunch service: 11:0014:00; dinner service: 18:0022:00) and comparatively low consumption in the mid-afternoon daytime, which is very different in comparison with ordinary office or retail buildings and poses unique challenges to SELCO self-consumption optimisation. To date, no published research has measured the financial performance and hybrid BESS returns of an installation of a specific SELCO calibrated to this restaurant load profile in Malaysia. The proposed research provides that gap by examining a real-life 23.4 kWp installation in one of the commercial food-service restaurants in Kuala Lumpur.

Smart systems have been used increasingly in the environmental and infrastructure field: Bai et al. [31] surveyed AI-based waste and environmental management solutions, and Gopinath et al. [32] and Ramani Bai [33] discussed data mining and neural network representations of intelligent reservoir management, setting the stage for smart energy resource planning. In line with this, Yuan and Bai [34] developed a stochastic programming model based on simulation to do cost-effective retrofit of ageing fluid pipelines and provided optimization frameworks that could be used in long-term performance management of solar and hybrid energy systems.

## 3. System Description

The system that was assessed was a 23.4 kWp rooftop solar PV system installed within the SELCO framework. Table 1 shows the available Engineering, Procurement, Construction, and Commissioning (EPCC) scope.Key technical specifications: AIKO Comet 650W ABC modules have a rated efficiency of 22.8% and temperature coefficient of −0.29%/°C; the Solis S5-GR3P17K inverter has a rated AC output of 17 kW with a maximum efficiency of 98.3% and Euro efficiency of 97.5%.Figure 1 depicts the conceptual design of the system.

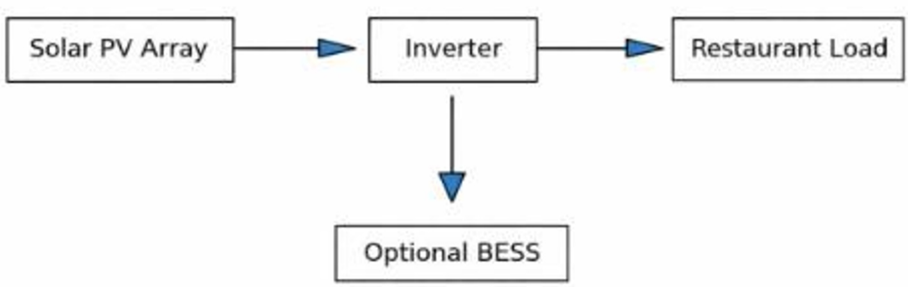


**Fig. 1.** SELCO-Self consumption system flow diagram

Under SELCO set up, solar energy produced during the sun peak hours are initially fed into the restaurant loads. In case of excess generation, when it is combined with BESS, it is stored to be used later. None of the energy is wasted to the grid.

**Table 1.** Solar system requirements

| Component | Quantity | Description |
|---|---|---|
| Solar PV Modules | 36 units | AIKO Comet 650W ABC |
| Inverter | 1 unit | Solis S5-GR3P17K |
| Mounting Structure | 1 lot | Clamps and brackets |
| Electrical Accessories | 1 lot | Cables, Rapid Shutdown Device (RSD), junction box |
| Installation | 1 lot | Design, logistics, testing |

With a total installed output of 23.4 kWp, it is estimated that 28,185 kWh/year of power will be produced, and this is using an average of 3.3 peak sun hours (PSH) per year as in Kuala Lumpur [24]. The total capital cost is RM53,470. There are 15 years product warranty and 30 years performance warranty as the module warranties, and the inverter has a warranty of 10 years. The system is set in such a way that it does not export grids as it is against the SELCO regulations [25]. Elective BESS will enable excess daytime generation to be stored to facilitate evening loads to enhance energy autonomy and self-consumption ratio.

## 4. Methodology

Financial and technical analysis was performed using deterministic solar energy yield modelling based on the PVWatts methodology, with annual generation estimated from system capacity (23.4 kWp), site-specific peak sun hours (PSH = 3.3 h/day, sourced from NASA POWER dataset for Kuala Lumpur), and a system performance ratio of 0.75. The simple payback period (SPP), 30-year cumulative net savings, and Return on Investment (ROI) were calculated in Microsoft Excel and used to calculate the financial projections.

### 4.1 Assumptions

The data that was going to be used in the determination of the energy consumption and financial performance of the solar installation system in the chosen restaurant outlet in Malaysia was assumed in the following way.

- Annual generation: 28,185 kWh
- Monthly generation: 2,317 kWh (based on PSH = 3.3 h/day for Kuala Lumpur from NASA POWER long-term average solar resource data [24].
- Electricity tariff: RM0.5068/kWh
- Annual degradation: 0.99% (According to the datasheet warranty specification of AIKO manufacturer; same as other reported crystalline silicon degradation rates of 0.5-1.0%/yr in tropical climates [15,16]).
- The formulae used to compute the calculations particularly Return On Investment (RoI) are as shown below.

- Annual O&M cost: RM936
- Project lifetime: 30 years

**4.2 Financial Metrics:**

The formulae used to compute the calculations particularly Return On Investment (RoI) are as shown below.

- Annual savings = annual generation (kWh) multiplied by electricity tariff (RM/kWh)
- Simple Payback Period (years) = Capital Cost (RM)/ Annual Savings (RM/year)
- Where Gross Annual Savings (RM) = net annual savings (RM) = Gross Annual Savings (RM) -Annual O&M Cost (RM) = Gross Savings- O&M.
- Cumulative Savings in 30 years.

ROI was calculated based on initial investment; Net Present Value (NPV) based on a 5% discount rate over 30 years; Internal Rate of Return (IRR) computed as the discount rate that makes NPV =0.It was compared to the commercial savings of 1823 in solar reported in Malaysia [26].

# 5. Results

## 5.1 Energy and Cost Savings

The system produces an average of 2,317 kWh per month that will save RM1,174 per month in electricity bills. Annual savings would be RM14,284 which is a reduction of 19 percent on the original monthly bill of the restaurant which was RM6,082.

## 5.2 Payback and ROI

The estimated payback and ROI are presented as follows.

- Capital cost: RM53,470
- Simple payback: 2.98 years
- Initial ROI: 26%
- NPV (5% discount rate, 30 years): RM 198,450
- IRR: 34.2%

This is a short payback compared to the average payback period of 4-6 years as it is exhibited in Malaysian commercial installations [27].For context, comparable rooftop solar PV studies in Southeast Asia report payback periods of 4.2 years for office buildings in Thailand, 5.1 years for industrial facilities in Vietnam, and 4.8 years for commercial premises in Singapore [9,11,12]. The 2.98-year payback achieved in this study is thus substantially better than the regional commercial average, attributable to the favourable Kuala Lumpur, competitive EPCC costs, and a well-matched daytime load profile

## 5.3 Long-Term Financial Performance

The financial performance of the organization has been falling over the past five years. Table 2 summarizes the annual projection of system performance in 30 years.The total generation in 30 years is scheduled to be 797,334 kWh. Cumulative net savings become about RM383,946 after taking into consideration the degradation and the O&M.

**Table 2**. 30-Year Financial Projections (selected years)

| Years | Degradation (%) | Generation (kWh) | Gross Savings (RM) | Net Savings (RM) | Cumulative (RM) |
|---|---|---|---|---|---|
| 1 | 100.00 | 28,185 | 14,284 | 18,211 | 35,259 |
| 5 | 97.95 | 27,608 | 13,991 | 14,672 | 23,730 |
| 10 | 96.20 | 27,114 | 13,742 | 12,806 | 89,413 |
| 20 | 92.70 | 26,128 | 13,242 | 12,109 | 213,267 |
| 30 | 89.20 | 25,141 | 12,742 | 11,496 | 330,475 |

### 5.4 Hybrid Performance with BESS

Integrating a Battery Energy Storage System (BESS) with the 23.4 kWp solar installation enables surplus daytime generation to be stored for dispatch during evening peak hours. Published studies report that BESS integration can raise self-consumption ratios from approximately 40–55% (PV-only) to 80–90% in commercial buildings with evening-dominated loads [5,6,7].In restaurants that are evening loaded the battery storage helps to reduce the dependence on grid electricity during the peak tariff hours and increases supply levels.

Figure 2 shows the intersection of daytime production and restaurant consumption of the sun. Comparing the peak sun hours (3.3 PSH) to the working load is a major boost in self-consumption efficiency on the conditions of SELCO regulations [3].

## 6. Discussion

The payback of 2.98 years is much higher than the national commercial averages, which presents a good financial feasibility of restaurants operating with day time loads. This directly responds to the concerns of the primary consumers in relation to long-term returns and the risk of capital recovery.

Policy risk represents a material consideration for long-term ROI. The 2025 revision to SELCO standby charges increased fixed monthly costs for grid-connected solar consumers, reducing net savings by an estimated 5–8% depending on system size [4,28]. Electricity tariff adjustments under the Imbalance Cost Pass-Through (ICPT) mechanism introduce six-monthly tariff volatility. Sensitivity analysis shows that a 10% tariff reduction extends the payback from 2.98 to ~3.3 years, while a 10% increase reduces it to ~2.7 years — both well within the 15-year warranty period. The fixed-tariff base-case assumption is thus conservative but reasonable.

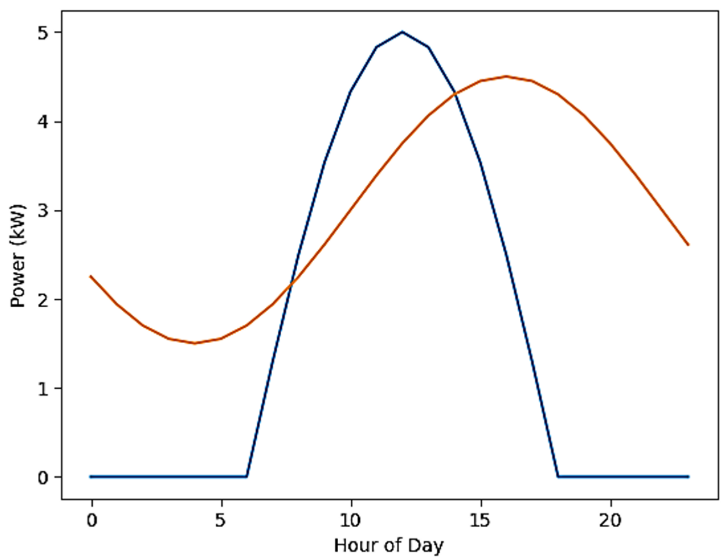


**Fig. 2**. Daily Generation vs. Consumption

The combination of batteries also reduces intermittency and further improves energy security, but the costs in terms of capital should be carefully considered in the present regulations of SELCO [28]. Although the current economics can be affected by standby charges and changing policies, the conservative modelling assumptions (degradation and fixed tariffs) indicate strong profitability in the long-term.

The capacity of urban rooftops is limited by constraints. Some improvements to the policy, especially in dynamic tariffs and ESG incentives, can speed up the uptake of the policy by more SMEs [29-30]. BESS integration improves self-consumption ratios and reduces the problems of intermittency, especially evening load demand.

All in all, the hybrid solar-grid is a viable solution to this, given that it offers a viable roadmap to the 70 percent renewable energy target of Malaysia by the year 2050.

## 7. Conclusion

This study has characterised the physical performance and energy yield behaviour of a 23.4 kWp grid-connected SELCO PV system operating under the tropical irradiance conditions of Kuala Lumpur, Malaysia, in a commercial food-service load environment. Simulation results confirm an annual energy yield of 28,185 kWh, delivering a 19% reduction in site grid energy consumption. Long-term degradation modelling over a 30-year operational period validates the sustained generation capacity of the system under conservative performance ratio assumptions and fixed-tariff grid conditions.

The integration of BESS is shown to elevate self-consumption ratios to the 80–90% range, effectively decoupling peak solar generation periods from commercial load demand cycles and reducing net grid import. This hybrid PV-BESS configuration offers a technically replicable model for commercial premises operating under similar tropical irradiance profiles, where non-coincident generation and consumption peaks are a primary constraint on self-consumption efficiency.

From a systems physics perspective, the principal contribution of this work is a calibrated energy yield and performance characterisation of a PV installation specifically modelled against a real commercial load profile in a tropical climate — a dataset that remains underrepresented in the published literature. The 34.2% internal rate of return and 2.98-year simple payback period further validate the technical sizing methodology employed, affirming that system parameters were optimised for the measured consumption profile rather than generic load assumptions. These results provide an empirical foundation for scaling SELCO PV-BESS deployments in the Malaysian commercial sector, in support of the national 70% renewable energy target by 2050.

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