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Assessing the Impact of Standby Charges on the Financial Viability of Rooftop Solar PV Systems in Malaysia

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Abstract

This study investigates the economic impact of standby charges on a 6.9 MWp commercial rooftop solar photovoltaic (PV) system operating under Malaysia's Self-Consumption (SELCO) regulatory framework. Using actual performance data and a 21-year project horizon, a parametric analysis was performed to evaluate the sensitivity of four key economic indicators: simple payback period, internal rate of return, net present value, and levelized cost of energy to standby charges levels ranging from RM 0.00 to RM 12.00 per kWp per month. Results show that increasing standby charges significantly reduces project feasibility. The SPP extended from 9.84 to 28.07 years, IRR declined from 7.98 % to negative (2.10 %), and NPV shifted from RM 4.47million to negative (RM 8.27million), with the break-even point occurring near RM 4.00 and RM 5.00/kW/month. Similarly, LCOE increased from RM 0.192 to RM 0.334/kWh, exceeding the grid tariff of RM 0.27/kWh at around RM 6.00/kW/month. These trends indicate that standby charges above RM 4.00/kW/month compromise investment viability. The findings highlight the need for balanced regulatory design to ensure grid reliability while sustaining investor confidence. The developed analytical framework and heat-map representation provide a practical reference for policymakers to optimize standby-charge levels and promote sustainable rooftop solar PV deployment in Malaysia.

1. Introduction

The accelerating global shift toward low-carbon energy systems has positioned solar photovoltaic (PV) technology as one of the most rapidly expanding renewable energy solutions worldwide. Among available configurations, rooftop solar PV systems have attracted substantial attention due to their scalability, environmental benefits, and declining costs [1]–[3]. Global PV deployment has been driven not only by technological advancement but also by policy measures aimed at reducing greenhouse gas emissions and enhancing energy security.

In Malaysia, the government has demonstrated a strong commitment to expanding renewable energy generation, targeting 31% of total installed capacity by 2025 and 40% by 2035 [4]. To achieve these objectives, incentive mechanisms such as the Feed-in Tariff (FiT) and Net Energy Metering (NEM) schemes have been introduced to encourage both residential and commercial investments in rooftop PV [5]. These policy tools aim to enhance the financial feasibility of distributed solar generation by providing stable returns to investors while contributing to grid decarbonization. Despite these efforts, the economic viability of rooftop solar PV in Malaysia remains highly sensitive to regulatory frameworks and cost structures imposed by utilities [6], [7].

One key regulatory factor influencing project profitability is the standby charge, which is levied on self-generating consumers connected to the national grid. This charge compensates utilities for maintaining grid readiness and ensuring electricity supply continuity when PV systems underperform or experience downtime [8]. While the rationale for standby charges is grounded in grid reliability and cost recovery, their implementation can substantially affect the financial returns of rooftop PV systems by increasing operational costs and reducing investor margins [9], [10].

Several studies have emphasized that standby charges can significantly alter the Internal Rate of Return (IRR), Net Present Value (NPV), and Simple Payback Period (SPP) of solar investments. For example, Yusof and Zainudin [11] found that under Malaysia's NEM 3.0 regime, a 10% rise in standby tariffs can reduce IRR by as much as 35%. Altaf and Hashim [8] similarly reported that high standby fees (above RM10/kW/month) could render rooftop PV investments financially unattractive for small and medium enterprises. These findings align with regional evidence suggesting that regulatory costs, rather than technical inefficiencies, are the dominant deterrent to distributed generation adoption [12], [13].

To evaluate such financial implications, economic metrics like IRR, NPV, and SPP are extensively used to determine project feasibility and compare renewable projects against conventional investments [14], [15]. However, given the inherent uncertainty in variables such as capital costs, energy output, tariff escalation, and regulatory charges, sensitivity analysis has emerged as a key tool for assessing investment robustness under fluctuating policy and market conditions [16], [17]. Mekhilef et al. [18] highlighted that policy-related cost changes, including standby fees, can alter payback periods by more than 40%, while Razali and Wahid [20] stressed that optimizing such regulatory parameters is essential for achieving long-term investor confidence and grid sustainability.

Therefore, assessing how standby charges influence the financial performance of rooftop PV systems is vital for both policymakers and investors. A quantitative evaluation of their impact on IRR, NPV, and payback period can provide insights into the threshold levels beyond which projects become economically unfeasible. This study focuses on evaluating the economic impact of standby charges on rooftop solar PV investments in Malaysia, emphasizing the sensitivity of the Internal Rate of Return (IRR), Net Present Value (NPV), and Simple Payback Period (SPP) under different regulatory charge scenarios.

2. Methodology

This study employs a quantitative case study approach to evaluate the economic feasibility and investment sensitivity of a grid-connected rooftop solar photovoltaic (PV) system under Malaysia's Supply Agreement for Renewable Energy (SARE) framework. The analysis integrates actual performance data from an existing rooftop PV system with energy yield projection, revenue modelling, and financial performance evaluation.

2.1 Technical & Financial Parameters

The case study system represents a rooftop solar PV installation operating under the self-consumption (SELCO) configuration within Malaysia's SARE regulatory framework. The system supplies power directly to the host facility without exporting excess electricity to the grid. Technical and financial parameters involved in the study are summarized in Table 1.

System capacity considered in the study is a 6.9 MWp commercial rooftop solar PV installation evaluated over a 21-year power purchase agreement (PPA) period. The system performance is modeled with a linear degradation rate of 0.5% per year, reflecting gradual efficiency loss over time. The financial assumptions adopt a tariff rate of RM 0.27 per kWh under a self-consumption arrangement, with capital expenditure (CAPEX) taken to be at RM 2,450.00 per kWp and operational expenditure (OPEX) of RM 30.00 per kWp per year. A discount rate of 6% per annum is used to represent the expected return on investment under prevailing Malaysian commercial conditions.

These parameters were selected to represent realistic market values for large-scale rooftop solar PV systems in Malaysia. The present study excludes taxation and depreciation effects to maintain transparency in comparing the pure cash-flow performance of the investment.

Table 1 *Technical and financial parameters of the rooftop solar PV system*

Parameter	Values
System capacity, P_{cap}	6.90 MWp
Power purchase agreement tenure, n_{max}	21 years
System degradation rate, d	0.6% / year
PPA tariff rate, T	RM 0.27 / kWh
Capital expenses rate, C_{CAPEX}	RM 2,450.00 / kWp
Maintenance expenses rate, $F_{maintenance}$	RM 30.00 / kWp / year
Discount rate, r	6.0% / year

2.2 Energy Yield Projection

The energy generation for the first year, E_1, was determined using the actual monthly generation, G_i, data recorded from the system. The available dataset covers a continuous 36-month period, representing measured generation under actual consumption and operating conditions. For systems operating under the Self-Consumption (SELCO) mode, the electricity generated is directly tied to the load profile of the host facility rather than solely to the solar irradiation potential. As such, using instantaneous or single-year generation data could misrepresent the true operational pattern due to variability in the host's demand.

To mitigate this effect, the three-year average generation was adopted to reflect a more representative baseline of the system's annual output. This approach captures how the generation dynamically responds to the facility's consumption pattern and ensures that the estimated first-year energy yield, E_1, reflects a stable long-term performance under typical operational conditions. Since the yield is derived from actual data, no additional performance ratio correction is applied, and the projected annual generation for subsequent years, E_n, is given by Equation (1):

$$E_n = E_1(1-d)^{n-1} \tag{1}$$

The methodology ensures that generation projections account for both operational consumption behavior and the physical degradation of the PV modules over time. The resulting annual generation values are used to compute the system's annual gross revenue, R_{gross} obtained by multiplying the annual generation, E_n with PPA tariff rate, T. These revenue projections form the foundation for the subsequent economic analyses, including annual net revenue, R_{net}, simple payback period, *SPP*, internal rate of return, *IRR* and net present value, *NPV*, as described in the following sections.

2.3 Revenue Model

The annual revenue of a rooftop solar PV system operating under Malaysia's Supply Agreement for Renewable Energy (SARE) framework is affected by both technical generation and regulatory charges. In this study, the revenue model incorporates the SARE service fees, standby charges, and annual maintenance costs (OPEX) to determine the actual net cash inflow of the investment.

2.3.1 SARE Fees

Under the SARE mechanism, service fees are applied according to the installed system capacity. These fees cover administrative, contractual, and metering management costs borne by SEDA Malaysia and the distribution licensee. The charge is calculated monthly and converted to an annual cost based on the system capacity according to Table 2.

For the present case study with an installed capacity of 6.9 MWp, the corresponding SARE service fee is determined through linear interpolation within the capacity range from 2,001 to 10,000 kWp. The resulting value for the SARE fee rate, F_{SARE}, is 0.694 cent/kWh, representing a proportional adjustment between the upper and lower limits of the SARE charge category.

Table 2 *SARE service fee rates by system capacity category*

System capacity	Charges [cent/kWh]
< 500 kWp	2.0
500 – 1,000 kWp	1.5
> 1,000 – 2,000 kWp	1.0
> 2,000 –10,000 kWp	1.0 – 0.5

Accordingly, the total annual SARE fees, C_{SARE} is given by Equation (2),

$$C_{SARE} = E_n \times F_{SARE} \tag{2}$$

2.3.2 Standby Charges

Standby charges are levied by the utility to recover the cost of providing backup power capacity when the self-consumed solar generation does not meet the facility's instantaneous demand. The rate is typically defined by the Energy Commission of Malaysia (Suruhanjaya Tenaga) and varies depending on regulatory approval and consumer category.

In this study, a range of standby charge values is applied to evaluate their influence on project feasibility. The standby charges are expressed in RM/kWp of system capacity. The baseline standby charges rate, $F_{standby,}$ is set at RM 0.00/kWp/month. To evaluate the sensitivity of the project's economic performance to regulatory cost variations, a range of standby charge values is modelled from the baseline rate to RM 12.00/kWp/month. The annual standby charges, $C_{standby}$ is given by Equation (3);

$$C_{standby} = P_{cap} \times F_{standby} \times 12 \text{ months} \tag{3}$$

This parametric variation enables assessment of how incremental increases or decreases in standby cost influence the system's annual net revenue and, consequently, provides quantitative insight into the financial robustness of rooftop solar PV projects under different regulatory charging conditions.

2.3.3 Net Revenue

The net annual revenue, $R_{net,}$ represents the effective income after accounting for all operational and regulatory costs, including operational expenses, SARE fees, and standby charges. The annual operational expenditure, $C_{maintenance,}$ is derived from Table 1, defined as RM 30.00/kWp/year. The annual net revenue, $R_{net,}$ is therefore given by Equation (4):

$$R_{net} = R_{gross} - C_{SARE} - C_{standby} - C_{maintenance} \tag{4}$$

This expression integrates both fixed and variable costs, allowing the evaluation of the project's financial performance under various standby charge conditions.

2.4 Economic Indicators

The financial feasibility of the rooftop solar PV investment is evaluated using three widely applied economic indicators: simple payback period, internal rate of return, and net present value. These indicators quantify the project's economic performance over the 21-year assessment horizon by incorporating annual net revenues, upfront capital expenditure, and the system's discount rate.

2.4.1 Simple Payback Period

The simple payback period, *SSP,* measures the time required for the cumulative net revenue generated by the system to recover the initial capital expenditure, C_{CAPEX}. Unlike discounted measures, SPP provides a straightforward indication of liquidity and investment recovery time. In the study, the simple payback period is given by Equation (5):

$$\sum_{n=1}^{n_{max}} R_{net} \geq C_{CAPEX} \tag{5}$$

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The *SPP*, expressed in years, corresponds to the year *n* in which the cumulative annual net revenue equals or exceeds the initial capital expenditure. A shorter SPP indicates faster capital recovery and generally increases the attractiveness of the investment.

2.4.2 Internal Rate of Return

The internal rate of return, *IRR,* represents the discount rate at which the net present value of all future net revenues equals the initial capital investment. The *IRR* value is derived from Equation (6):

$$0 = -C_{CAPEX} + \sum_{n=1}^{n_{max}} \frac{R_{net}}{(1+IRR)^n} \tag{6}$$

IRR is widely accepted in financial analysis as it provides a rate-of-return measure that can be compared directly with alternative investment benchmarks or financing costs. A higher IRR indicates greater profitability relative to the project's risk profile and prevailing market conditions.

2.4.3 Net Present Value

Net present value, *NPV,* quantifies the difference between the present value of future net revenues and the initial capital expenditure. *NPV* incorporates the time value of money using the project's discount rate, *r,* and is therefore considered one of the most robust indicators for investment decision-making. *NPV* is given by Equation (7):

$$NPV = -C_{CAPEX} + \sum_{n=1}^{n_{max}} \frac{R_{net}}{(1+r)^n} \tag{7}$$

A positive *NPV* indicates that the investment generates financial value beyond the required rate of return.

2.4.4 Levelized Cost of Electricity

The levelized cost of energy, *LCOE,* provides the average cost of producing one kilowatt-hour of electricity over the system's entire operational life. *LCOE* is widely used in energy system evaluations because it incorporates capital costs, operational expenditures, discounting, and generation degradation. It enables direct comparison with grid tariffs or other energy technologies and reflects the minimum revenue per kWh required for cost breakeven. *LCOE* is given by Equation (8):

$$LCOE = \frac{C_{CAPEX} + \sum_{n=1}^{n_{max}} \frac{C_{OPEX}}{(1+r)^n}}{\sum_{n=1}^{n_{max}} \frac{E_n}{(1+r)^n}} \tag{8}$$

where C_{OPEX} is a sum of C_{SARE}, $C_{standby}$, and $C_{maintenance}$.

A lower LCOE indicates a more cost-competitive project. Since this case study uses actual generation data and a degradation model, the denominator reflects realistic year-by-year output rather than idealized production.

2.5 Parametric Analysis

A parametric analysis was conducted to evaluate the influence of standby charges on the long-term economic performance of the rooftop solar PV system. This analysis systematically varies the standby charge rate applied to the system while holding all other technical and financial parameters constant, thereby isolating the effect of the standby-charge policy on project feasibility. The standby charge, C_{stanby}, varied across a continuous range from RM 0.00/kW/month to RM 12.00/kW/month, with incremental steps of RM 1.00/kW/month corresponding to Equation (3).

The calculated value of $C_{standby}$ was incorporated into the consolidated operating expenditure, C_{OPEX}, together with the C_{SARE} and $C_{maintenance}$. This allowed the annual net revenue, R_{net}, to be recalculated (Equation (4)) for each standby-charge scenario while maintaining consistency across all other model inputs.

The revised R_{net} profiles were subsequently used to compute the key economic indicators as functions of the standby-charge rate. These indicators will allow assessment of both short-term payback characteristics and long-term discounted financial performance. It also allows for the identification of threshold standby-charge levels at which the project transitions from financially feasible to marginal or infeasible, thereby providing valuable insight for both investors and policymakers.

3. Results and Discussion

3.1 Annual Energy Generation Performance

The updated first-year annual generation, E_1, derived from the average performance of the system over the most recent 24-month dataset, is 7,420.48 MWh. Because the system operates under SELCO mode, this measured generation inherently reflects on-site consumption behavior, offering a more realistic performance baseline compared to theoretical irradiation models.

Table 3 *Annual energy generation projection over 21 years*

Year	Generation (MWh)	Year	Generation (MWh)
1	7,420.48	12	6,956.03
2	7,376.96	13	6,915.35
3	7,333.70	14	6,874.92
4	7,290.70	15	6,834.74
5	7,247.96	16	6,794.82
6	7,205.48	17	6,755.14
7	7,163.26	18	6,715.72
8	7,121.30	19	6,676.54
9	7,079.60	20	6,637.61
10	7,038.15	21	6,598.93
11	6,996.97		

Annual generation for subsequent years was projected using a linear PV degradation rate of 0.6%, consistent with established performance benchmarks for commercial monocrystalline PV systems. As shown in **Table 3**, energy output declines gradually from 7,420.48 MWh in Year 1 to 6,598.93 MWh in Year 21, corresponding to an overall reduction of approximately 11.1% across the lifecycle. The relatively modest decline over two decades indicates stable long-term performance consistent with real-world rooftop PV installations. Importantly, because the system operates under SELCO mode, annual generation reflects both the physical performance of the PV array and the load-matching characteristics of the host facility.

3.2 Net Revenue Projection

Table 4 presents the net revenue over the 21-year project duration. Net revenue in this study is derived by consolidating all recurring cost components into a single operating expenditure term, $C_{OPEX,}$ which comprises the SARE charges, C_{SARE}, maintenance expenses, $C_{maintenance,}$ and standby charges, $C_{standby}$. These components are deducted from the annual gross revenue, $R_{gross,}$ to determine the effective net cash inflow for each year of operation. For the reference case presented in this section, the standby charge is set to RM 0.0/kW/month to reflect the financial performance of the system under pre-policy conditions and to serve as a benchmark for subsequent comparisons.

In the first year of operation, the system produced 7,420.48 MWh, resulting in a gross revenue of approximately RM 1.84 million. After accounting for the SARE charge and annual maintenance expenditure included in C_{OPEX}, the first-year net revenue stands at RM 1.59 million. Over the 21-year analysis period, the net revenue exhibits a gradual downward trend, reaching RM 1.38 million in Year 21. This decline is primarily attributed to the annual 0.6% degradation in system output, which reduces the available revenue pool while the fixed OPEX component remains unchanged.

Despite this reduction, the net-revenue trajectory remains stable and predictable, reflecting the intrinsic characteristics of SELCO-based commercial rooftop PV systems. Because all electricity is consumed on site, the revenue stream is shielded from external uncertainties such as export-tariff fluctuations or curtailment risks. As such, the baseline net-revenue profile offers a reliable representation of long-term cashflow performance and establishes a clear foundation for assessing the impact of newly introduced standby charges in subsequent analysis.

Table 4 *Net revenue projection for rooftop solar PV system*

Year	E_n [MWh]	R_{gross} [RM] (A)	C_{SARE} [RM] (B)	$C_{maintenance}$ [RM] (C)	R_{net} [RM] (A–B–C)
1	7,420.48	2,003,529	51,402	207,000	1,745,127
2	7,376.96	1,992,779	51,242	207,000	1,734,537
3	7,333.70	1,982,099	51,082	207,000	1,724,017
4	7,290.70	1,971,490	50,923	207,000	1,713,567
5	7,247.96	1,960,949	50,764	207,000	1,703,185
6	7,205.48	1,950,481	50,605	207,000	1,692,876
7	7,163.26	1,940,091	50,446	207,000	1,682,645
8	7,121.30	1,929,751	50,289	207,000	1,672,462
9	7,079.60	1,919,492	50,132	207,000	1,662,360
10	7,038.15	1,909,301	49,975	207,000	1,652,326
11	6,996.97	1,899,182	49,820	207,000	1,642,362
12	6,956.03	1,889,129	49,665	207,000	1,632,464
13	6,915.35	1,879,144	49,510	207,000	1,622,634
14	6,874.92	1,869,228	49,356	207,000	1,612,872
15	6,834.74	1,859,370	49,203	207,000	1,603,167
16	6,794.82	1,849,601	49,049	207,000	1,593,552
17	6,755.14	1,839,888	48,897	207,000	1,583,991
18	6,715.72	1,830,244	48,745	207,000	1,574,499
19	6,676.54	1,820,666	48,593	207,000	1,565,073
20	6,637.61	1,811,155	48,442	207,000	1,555,713
21	6,598.93	1,801,711	48,292	207,000	1,546,419

3.3 Standby Charges Effect

The introduction of standby charges for SELCO-operated rooftop solar PV systems represents a major regulatory shift within Malaysia's distributed generation framework. Under the proposed policy structure, a standby fee of RM 12.00/kW/month is imposed based on the installed capacity of the system. For the 6.9 MWp installation evaluated in this study, this translates into a fixed annual standby cost of RM 993,600, which is incorporated into the consolidated operating expenditure term, C_{OPEX}. This section evaluates the impact of the proposed standby charge on the project's annual net revenue and compares it against the baseline case in which standby charges are not applied.

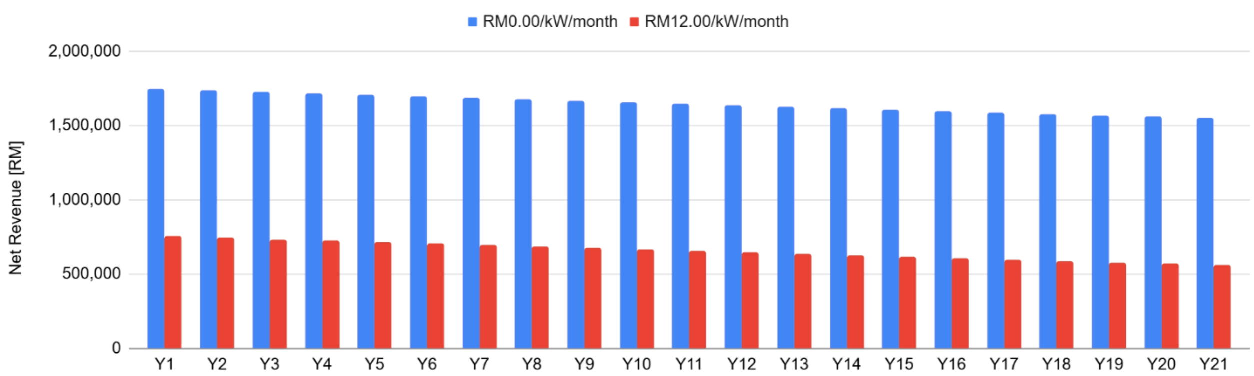

Fig. 1 *Comparison of annual net revenue with and without standby charges (RM 0.00 vs RM 12.00/kWp/month)*

Figure 1 summarizes the annual net revenue comparison between RM 0.00/kW/month under the RM 12.00/kW/month standby charges regime. In the first year of operation, the system generated 7,420.48 MWh of electricity, yielding a gross revenue of RM 2.00 million. After deducting the SARE service fee of RM 51,402, the maintenance expenses of RM 207,000, and the newly introduced standby charge of RM 993,600, the resulting net revenue falls to RM 751,528. This represents a 52.1% reduction compared to the baseline first-year net revenue of RM 1.57 million. The magnitude of this reduction clearly demonstrates that the standby charge is the dominant component of operating expenditure, constituting over 82% of total C_{OPEX} in the first year.

As the system degrades at a rate of 0.6% annually, the impact of the standby charge becomes even more pronounced over time. In Year 21, the system projected to generate 6,598.93 MWh, resulting in a gross revenue of RM 1.80 million. After applying all operational expenses components, the Year-21 net revenue is RM 555,280, compared to RM 1.55 million under baseline reference conditions; standby charges at RM0.00/kW/month. This corresponds to a 64.2% reduction in the final year's net revenue due solely to the inclusion of standby charges. Because the standby charge remains constant while gross revenue gradually decreases, its relative financial burden increases each year, rising from 49.6% of gross revenue in Year 1 to 55.1% in Year 21.

Over the full 21-year period, the cumulative reduction in net revenue attributable to standby charges exceeds RM 21 million, highlighting the substantial long-term financial implications of the proposed standby-charge structure. The persistent and heavy cost burden imposed by the standby fee significantly suppresses annual profitability and is expected to materially deteriorate key economic indicators. The economic assessment of solar PV systems requires a comprehensive analysis of all recurring costs that impact revenue. Table 3 below shows the impact of RM12/kWp/month standby charges on annual revenue for a duration of 21 years.

3.4 Economic Evaluation

The economic performance of the rooftop solar PV system is highly dependent on the level of standby charges imposed under the SELCO regulatory framework. To examine how different standby-charge magnitudes influence project feasibility, the key economic indicators, simple payback period, internal rate of return, net present value, and levelized cost of energy were evaluated across a standby-charge range of RM 0.00 to RM 12.00/kWp/month.

For each charge level, the annual net-revenue profile was recalculated based on the parametric framework outlined in Section 2.5, and the corresponding economic metrics were derived. This approach enables a clear visualization of the sensitivity of each financial indicator to standby charges increments and allows identification of critical threshold levels at which the project transitions from financially attractive to marginal or infeasible. The following subsections discuss the individual responses of SPP, IRR, NPV, and LCOE to the varying standby-charge conditions.

3.4.1 Simple Payback Period

Figure **2** illustrates the sensitivity of the simple payback period, *SSP*, to incremental increases in standby charges from RM 0.00 to RM 12.00/kW/month. The SPP exhibits a strongly increasing trend with respect to standby-charge magnitude, reflecting the direct reduction in annual net revenue as standby cost is added to the project's operating expenditure. In the absence of standby charges, the system records a payback period of 9.84 years, which is consistent with typical commercial rooftop PV performance under Malaysia's SELCO configuration. This value represents the financial baseline against which all subsequent standby-charge conditions are evaluated.

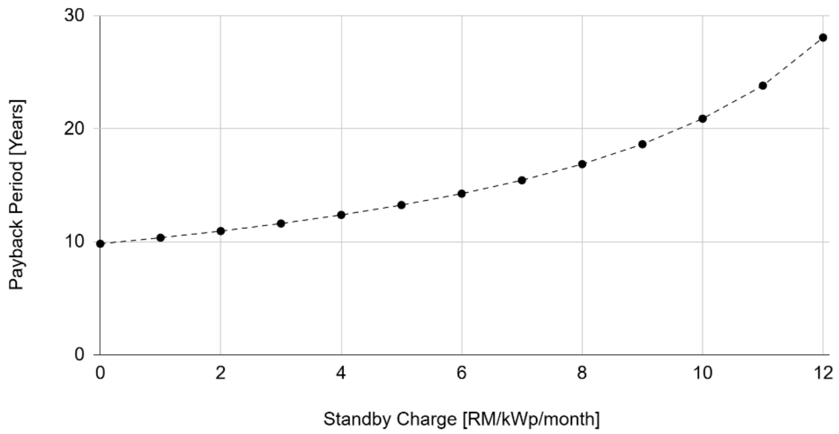

Fig. 2 *Sensitivity of simple payback period (SPP) to varying standby charge levels*

As standby charges increase, the *SPP* lengthens at an accelerating rate. A modest standby charge of RM 1.00/kW/month increases the *SPP* to 10.37 years, while a charge of RM 3.00/kW/month pushes the SPP above 11.6 years, indicating a noticeable erosion of early-stage cost recovery. Beyond RM 6.00/kW/month, the effect becomes more pronounced, where the *SPP* rises above 14 years, and by RM 8.00/kW/month, it reaches 16.88 years, reflecting a substantial delay in investment payback. The threshold at which the project becomes marginal for many commercial investors typically lies between 12 and 15 years, depending on internal financing criteria; this range is crossed between standby charges of RM 4.00 and RM 7.00/kW/month, suggesting a critical economic transition zone.

At the upper end of the parametric range, the project's financial attractiveness deteriorates sharply. A standby charge of RM 10.00/kW/month results in an SPP of 20.90 years, and the highest evaluated charge of RM 12.00/kW/month yields an SPP of 28.07 years, approaching or exceeding the practical investment horizon for most commercial rooftop PV adopters. This steep escalation highlights the high sensitivity of SPP to standby charges and indicates that even moderate standby-charge levels can significantly impair project feasibility.

From an investor's perspective, the SPP is a straightforward and intuitive metric, and its strong sensitivity to standby-charge increments underscores the importance of regulatory stability and cost predictability. For policymakers, these results demonstrate that imposing standby charges at the upper end of the evaluated range would substantially slow capital recovery, reduce investor participation, and weaken the financial competitiveness of SELCO-based rooftop PV systems.

3.4.2 Internal Rate of Return

Figure **3** presents the relationship between the Internal Rate of Return (IRR) and the applied standby charges, showing a clear and continuous decline in investment profitability as the standby charge increases. The IRR, which reflects the project's discounted cash-flow performance over its 21-year lifetime, starts at 7.98 % under the baseline condition of RM 0.00 /kW/month, indicating a financially attractive return typical of commercial rooftop PV projects operating under Malaysia's SELCO framework.

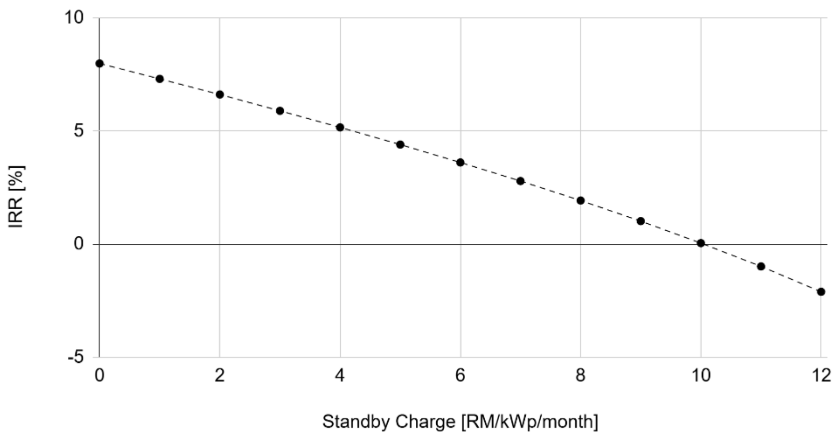

Fig. 3 *Sensitivity of Internal Rate of Return (IRR) to varying standby charge levels*

A gradual erosion in *IRR* is observed as standby charges are introduced. With a standby fee of RM 1.00/kW/month, the *IRR* falls to 7.30 %, still within the viable range for most commercial investors. At RM 2.00 /kW/month, the *IRR* declines to 6.61 %, approaching the lower limit of the generally accepted viability threshold of 6.0 %. Beyond this point, the reduction becomes more rapid; at RM 3.00 /kW/month, the *IRR* drops below the 6.0 % threshold to 5.89 %, marking the transition from economically viable to marginal project performance.

As standby charges continue to rise, the project's financial feasibility deteriorates sharply. At RM 5.00/kW/month, the *IRR* decreases to 4.40 %, while at RM 7.00/kW/month, it falls further to 2.79 %. These levels of *IRR* value are insufficient to offset financing costs or meet internal investment benchmarks. At the highest evaluated standby charge of RM 12.00 /kW/month, the IRR becomes negative (2.10 %), signifying that the project would no longer recover its initial capital investment over its lifetime.

The IRR trend demonstrates that every incremental RM 1.00/kW/month in standby charges reduces the project's return by approximately 0.6 % to 0.8 % percentage points, underscoring the strong sensitivity of internal profitability to regulatory cost additions. The critical standby charges threshold for maintaining minimum investment attractiveness (*IRR* ≥ 6.0 %) occurs near RM 2.50/kW/month. Above this level, the project would likely fail to secure private financing without additional policy incentives or tariff adjustments.

From an investment perspective, maintaining the *IRR* above the 6.0 % benchmark is essential to ensure that rooftop solar PV remains competitive relative to other commercial ventures or low-risk financial instruments. For policymakers, the observed *IRR* decline highlights the potential unintended consequence of excessive standby charges implementation.

3.4.3 Net Present Value

Figure 4 shows the variation of the project's net present value (*NPV)* as a function of standby-charge magnitude, illustrating the cumulative long-term financial impact of increasing standby costs. Under the baseline condition of RM 0.00/kW/month, the system achieves a positive *NPV* of RM 4.47 million, confirming that the project is financially feasible and capable of generating returns exceeding the assumed 6.0% discount rate. This baseline value is typical of large commercial rooftop PV systems operating under stable tariff and cost structures within Malaysia's SELCO framework.

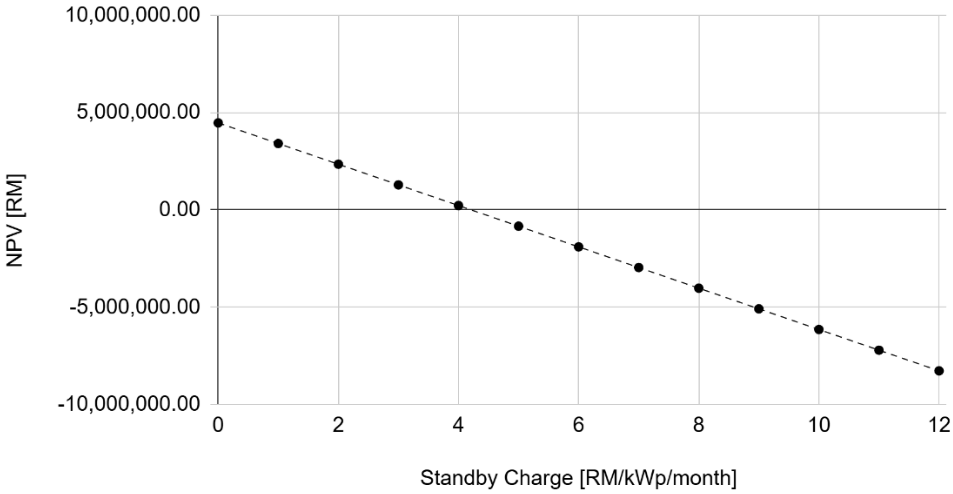

Fig. 4 *Sensitivity of Net Present Value (NPV) to varying standby charge levels*

As standby charges are introduced, the *NPV* declines almost linearly, reflecting the direct reduction in annual net revenue and, consequently, in the discounted cash inflows over the project lifetime. At a standby charge of RM 1.00/kW/month, the *NPV* falls to RM 3.41million, representing a 24.0% reduction relative to the baseline. By RM 3.00/kW/month, the *NPV* has decreased to RM 1.29million, showing that a relatively modest regulatory cost increment can erode down to 75.0% of the project's long-term value.

The breakeven points occur between RM 4.00 and RM 5.00/kW/month. At RM 4.00/kW/month, the project's *NPV* remains marginally positive at RM 224,224.00, while at RM 5.00/kW/month, the *NPV* becomes negative (RM 837,414), indicating that the project would fail to recover its initial investment cost over the analysis period. Beyond this threshold, the *NPV* continues to deteriorate rapidly, reaching negative (RM 4.02million) at RM 8.00/kW/month, and plunging to negative (RM 8.27million) at RM 12.00/kW/month, effectively eliminating the project's economic justification.

The observed *NPV* trend reinforces the results obtained from the *IRR* sensitivity analysis, demonstrating that standby charges above approximately RM 4.50/kW/month render the system financially non-viable. The near-linear decline in *NPV* with increasing standby charges also provides a useful quantitative indicator of sensitivity, with each RM 1.00/kW/month increment reducing the project's *NPV* by approximately RM 0.83 million on average.

From an investor's standpoint, maintaining a positive *NPV* is fundamental to justify capital commitment, as it signifies that the project's discounted cash inflows exceed total costs over its operational lifespan. For policymakers, this behaviour highlights the delicate balance between implementing standby charges to ensure grid reliability and maintaining sufficient financial incentives for private investment in rooftop solar PV.

3.4.4 Levelized Cost of Energy

Figure 5 depicts the variation of the *levelized cost of energy* (*LCOE)* as a function of standby-charge magnitude, highlighting the effect of regulatory cost additions on the overall cost competitiveness of the rooftop solar PV system. At the baseline condition with RM 0.00/kW/month standby charge, the system records an *LCOE* of RM

0.192/kWh, which aligns with reported cost ranges for commercial rooftop PV installations in Malaysia under current capital and operating cost conditions. This baseline represents a highly competitive energy cost relative to prevailing grid tariffs, thus providing a strong economic justification for investment under the SELCO operational model.

As standby charges are introduced, the *LCOE* increases progressively and nearly linearly with each incremental cost step. At a standby charge of RM 3.00/kW/month, the *LCOE* rises to RM 0.228/kWh, representing an approximate 18.0% increase from the baseline value. By RM 6.00/kW/month, the *LCOE* reaches RM 0.263/kWh, approaching parity with the grid electricity tariff of RM 0.27/kWh assumed in this study. This parity point signifies the threshold at which self-generation under SELCO mode ceases to offer clear cost savings to the host facility, thereby undermining the fundamental economic rationale of rooftop PV adoption.

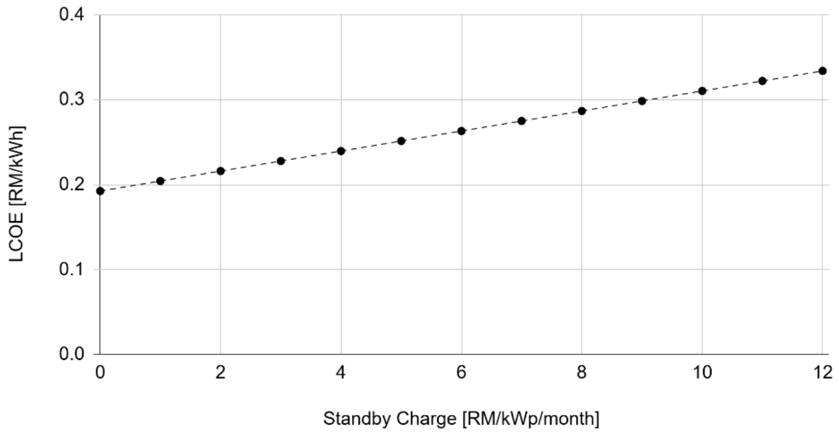

Fig. 5 *Sensitivity of Levelized Cost of Energy (LCOE) to varying standby charge levels*

Beyond this threshold, the cost of energy produced by the system surpasses that of grid electricity. At RM 8.00/kW/month, the *LCOE* increases to RM 0.287/kWh, and at the maximum standby-charge level of RM 12.00/kW/month, it reaches RM 0.334/kWh, exceeding the grid tariff by over 15 %. This escalation illustrates that standby charges exert a compounding effect on *LCOE*, as they represent a fixed cost addition distributed over a gradually declining annual energy output due to PV degradation. Consequently, higher standby charges disproportionately inflate the cost per unit of generated energy over time.

From an investor's viewpoint, maintaining the *LCOE* below the prevailing grid tariff is crucial for ensuring that self-generation remains economically advantageous. Once standby charges raise the *LCOE* above the grid rate, the investment loses its cost-competitiveness, discouraging commercial adoption.

3.4.5 Sensitivity Analysis

To provide a holistic assessment of project feasibility under varying standby-charge conditions, the results of all four economic indicators, simple payback period, internal rate of return, net present value, and levelized cost of energy are consolidated in Table 5. The table is presented as a heat map, where color shading is used to visualize the relative magnitude and transition of economic viability. Favorable or "financially attractive" conditions are represented in green, while marginal zones transition through yellow to orange, and financially unattractive conditions appear in red. This color gradation allows immediate recognition of the threshold standby-charge region where the system's economic performance shifts from viable to non-viable.

The heat map shows a consistent and progressive degradation in all economic indicators as standby charges increase from RM 0.00 to RM 12.00/kW/month. The SPP extends from 9.84 years under baseline conditions to 28.07 years at the upper limit, indicating a threefold lengthening of payback duration. In parallel, the IRR declines from 7.98% to negative (2.10%), with the 6.00% viability threshold crossed between RM 2.00 and RM 3.00/kW/month. The NPV follows a nearly linear downward trend, falling from RM 4.47million to negative (RM 8.27million), and turning negative between RM 4.00 and RM 5.00/kW/month, marking the loss of long-term profitability. Similarly, the LCOE increases from RM 0.192/kWh to RM 0.334/kWh, surpassing the grid electricity tariff of RM 0.27/kWh at approximately RM 6.00/kW/month, where self-generation ceases to offer economic advantage.

The colour transitions in the heat map reinforce this collective trend, visually delineating three distinct regions of economic performance. The green zone (≤ RM 2.00/kW/month) represents the range where all indicators remain within favourable limits, and investment remains robust. The yellow-to-orange transition zone (RM 3.00–5.00/kW/month) corresponds to the onset of financial stress, characterized by IRR values near or below the 6.0% benchmark and *NPVs* approaching zero. Beyond RM 6.00/kW/month, the red zone dominates, where extended payback periods, sub-zero NPVs, and elevated LCOE values collectively signify financial infeasibility.

Among the four indicators, *IRR* and *NPV* are the most informative for evaluating long-term investment potential, as they capture discounted cash-flow effects and investor-required returns. In contrast, SPP and LCOE, while useful for comparative screening, provide less comprehensive measures of economic sustainability. From an investment perspective, maintaining an *IRR* above 6.0 % and ensuring positive *NPV* are the key benchmarks for financial viability. From a policy standpoint, the results suggest that standby charges should not exceed RM 4.00–5.00/kW/month to preserve project attractiveness and sustain private-sector participation in Malaysia's rooftop solar PV market.

Table 5 *Impact of standby charges on economic indicators of the rooftop solar PV system*

Standby Charge [RM/kWp/month]	*SPP* [Years]	*IRR* [%]	*NPV* [RM]	*LCOE* [RM/kWh]
0.00	9.84	7.98	4,470,774.00	0.192
1.00	10.37	7.30	3,409,137.00	0.204
2.00	10.96	6.61	2,347,499.00	0.216
3.00	11.63	5.89	1,285,862.00	0.228
4.00	12.39	5.16	224,224.00	0.24
5.00	13.26	4.40	-837,414.00	0.251
6.00	14.27	3.61	-1,899,051.00	0.263
7.00	15.45	2.79	-2,960,689.00	0.275
8.00	16.88	1.93	-4,022,326.00	0.287
9.00	18.64	1.02	-5,083,964.00	0.298
10.00	20.9	0.05	-6,145,602.00	0.31
11.00	23.82	-0.98	-7,207,239.00	0.322
12.00	28.07	-2.10	-8,268,877.00	0.334

4. Conclusion

This study assessed the economic impact of standby charges on a 6.9 MWp commercial rooftop solar PV system under Malaysia's Self-Consumption (SELCO) framework. Using a 21-year analysis period, the effects of standby-charge levels from RM 0.00 to RM 12.00/kW/month were evaluated through four economic indicators: simple payback period, internal rate of return, net present value, and levelized cost of energy.

Results show a clear deterioration in project feasibility with increasing standby charges. The *SPP* lengthened from 9.84 to 28.07 years, while *IRR* declined from 7.98 % to negative (2.10 %), crossing the 6.0 % viability threshold at around RM 3.00/kW/month. The *NPV* turned negative in the range of RM 4.00 to RM 5.00/kW/month, and *LCOE* rose from RM 0.192 to 0.334/kWh, surpassing the grid tariff of RM 0.27/kWh at approximately RM 6.00/kW/month. These findings indicate that standby charges above RM 4.00/kW/month substantially erode investment returns and threaten project viability.

The analysis underscores the need for balanced regulation that safeguards grid reliability without discouraging private solar investment. Capping standby charges below RM 4.00/kW/month or adopting a tiered structure could maintain positive investor returns while ensuring equitable cost recovery for utilities. Although the study excludes taxation and inflation for clarity, the framework provides a practical basis for future policy evaluation and extension to other PV business models.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Shahrulnizam Siran;* ***data collection:*** *Khazaren Kusaini;* ***analysis and interpretation of results:*** *Shuhaimi Ismail;* ***draft manuscript preparation:*** *Kamil Abdullah. All authors reviewed and approved the final version of this work.*

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