Techno Economic Analysis on PV System Based on Localized Load Profile

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Abstract – *Electricity in most developing countries still relies heavily on fossil-fuel generation. Growing concerns about greenhouse-gas emissions and the falling cost of photovoltaic (PV) modules have made grid-connected PV (GCPV) systems an attractive option. This study presents a techno-economic analysis of a localized GCPV system at Universiti Teknikal Malaysia Melaka (UTeM). Using HOMER software, several system configurations were simulated to determine the most cost-effective and technically feasible design. The optimal configuration achieved the lowest Net Present Cost (NPC) while maintaining reliable performance. Results show that the proposed GCPV system is both technically and economically viable for institutional implementation.*

***Keywords**: GCPV, HOMER, Net present cost (NPC), PV system, Techno-economic analysis*

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I. Introduction

Renewable energy sources (RES) such as wind and solar are free, abundant, and naturally available. In 2005, only 43 nations had adopted RES targets; by 2015, more than 160 countries had implemented at least one renewable energy target [1]. Among the RES, solar energy technologies are among the most important. Solar photovoltaic (PV) technology, which directly converts solar irradiance into electrical energy, is one of the most popular and rapidly expanding renewable energy technologies worldwide. The cost of solar PV modules has decreased by nearly 80%, and this downward trend is expected to continue [1].

According to the Malaysian Investment Development Authority (MIDA), the demand for PV systems as electricity generators has increased due to the rapid advancement of solar technology. This development is also influenced by the rising price of fossil fuels and the emission problems associated with conventional electricity generation methods. The combination of renewable sources can also provide an overall system efficiency close to 100%. However, to implement PV systems effectively, detailed technical and economic analyses are required to avoid resource wastage, system oversizing, and, most importantly, unnecessary high construction costs [2] – [3].

Numerous researchers have conducted techno-economic analyses of PV systems for various reasons and purposes. Due to the rapid development of solar technology, there has been a growing interest in the economic analysis of renewable energy systems, particularly PV systems, as they are among the most accessible renewable energy sources for end users [4], [5]. Other studies have been conducted because of the increasing use of renewable energy sources as electricity generators for institutional and industrial facilities, influenced by the rising price of fossil fuels and the depletion of non-renewable energy resources [6] – [7].

Techno-economic analysis of PV systems is essential to reduce costs and improve system efficiency. Several studies have evaluated the technical, financial, and environmental aspects of solar power systems [8] – [9]. The **Hybrid Optimization Model for Electric Renewables (HOMER)** software serves as a practical tool for designing solar PV systems. Using this tool, users can assess a wide range of design configurations based on technological and financial performance indicators. It is commonly employed to evaluate system feasibility under changing conditions or operational instability [10] – [11].

The design and sizing of the PV systems in this study were simulated using HOMER Grid software, which allows users to create customized tariff models. The software incorporates data related to electrical demand, building location, solar resource availability, system components, grid connection, and financial parameters to generate the most suitable output based on techno-economic indicators such as Levelized Cost of Energy (LCOE), Internal Rate of Return (IRR), and Net Present Cost (NPC) [12] – [13]. Since all the buildings in the study scenarios are grid-connected, the system analyzed primarily consists of PV panels and an inverter, without the inclusion of batteries.

II. Research Method

In this study, a grid-connected photovoltaic (GCPV) system was simulated using HOMER software. To achieve precise optimization results, several key parameters were required, including the load profile, ambient temperature, global horizontal irradiance (GHI) data, and the cost of each component used in the simulation [14] – [16]. These parameters directly affect the system's performance, energy yield, and economic feasibility.

A. Load Profile At FTKE, UTeM

The Faculty of Electrical Technology & Engineering (FTKE) at Universiti Teknikal Malaysia Melaka (UTeM) was selected as the research site due to its diverse and dynamic electricity usage patterns. Electricity consumption at FTKE primarily supplies ventilation systems, air-conditioning units, laboratory instruments, computers, and projectors.

The analysis covers the entire faculty building complex (refer Fig.1). The daily load profile, shown in Fig. 2, indicates the highest energy consumption between 8:00 a.m. and 9:00 p.m., corresponding to periods of teaching, laboratory experiments, and administrative activities.

Fig 1. FTKE UTeM Map

From the load profile, it can be observed that daytime peaks dominate the overall energy pattern, suggesting that the FTKE load profile is well-suited for a grid-connected PV system without battery storage. This alignment between solar availability and electricity demand increases the system's self-consumption rate and improves its economic viability by reducing the reliance on grid imports during operational hours.

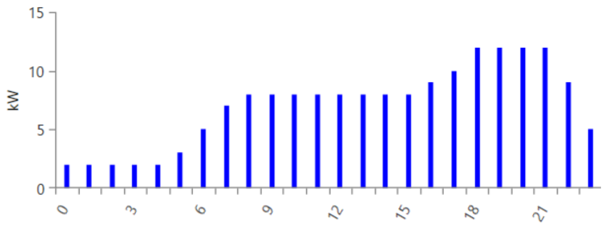

Fig 2. Daily Load Profile

B. Solar Global Horizontal Irradiance (GHI) Data

One year of GHI data (2021) was obtained from the FTKE solar monitoring system. The monthly solar GHI at the study location is presented in Fig. 3. The GHI ranged from 5.379 to 7.811 kWh/m²/day, with an annual average of 6.48 kWh/m²/day.

The analysis shows that solar radiation levels are relatively stable throughout the year, with the highest irradiation recorded during April to August, coinciding with Malaysia's dry season. This consistency in solar energy potential supports sustained PV generation and enhances the reliability of the GCPV system at the site.

Fig 3. Monthly solar GHI data for FTKE, UTeM

III. Economic Parameters

The economic evaluation of the proposed grid-tied PV system was performed to determine its financial viability before deployment. The main performance indicators used are the Net Present Cost (NPC) and Cost of Energy (COE) [17] – [18]. These parameters help assess whether the project represents a sound investment and estimate the expected payback period.

A. Net Present Cost (NPC)

The Net Present Cost (NPC) of a component represents the current worth of all costs incurred for installation and operation throughout the project's lifetime, minus the present worth of all revenues earned during that period [19] – [20].

NPC is a crucial metric because it indicates the total lifetime expenditure of the project in today's monetary value. A lower NPC corresponds to a more cost-efficient system, helping decision-makers select or reject investment proposals. However, NPC calculations do not always account for hidden costs such as maintenance uncertainties or inflation effects during operation [21] – [22].

The NPC is calculated using Equation (1):

$$C_{NPC} = \frac{C_{total,ann}}{CRF(i,R_{proj})} \quad (1)$$

where $C_{total,ann}$ is the total annualized cost (RM/year), CRF is the capital recovery factor, i is the real discount rate, and R_{proj} is the project lifetime (years).

B. Cost of Energy (COE)

The Cost of Energy (COE) represents the average cost per kilowatt-hour (kWh) of useful electricity produced by the system. It reflects variations in energy demand, generation availability, and fossil fuel costs.

COE provides a direct measure of the project's competitiveness compared to grid electricity prices. It is calculated by dividing the total annualized system cost (excluding thermal load costs) by the total electric load served, as expressed in Equation (2) [23] – [25]:

$$\text{COE} = \frac{C_{total,ann}}{E_{primary,AC} + E_{primary,DC} + E_{grid,sales}} \quad (2)$$

A lower COE indicates a more economically viable system, demonstrating the system's ability to generate electricity at a cost lower than or comparable to the grid tariff rate.

IV. System Architecture

The proposed grid-connected photovoltaic (GCPV) system was modelled in HOMER as shown in Fig. 4. The configuration consists of three main elements: the PV array, the power converter, and the faculty building load, which is connected to the utility grid. The system is designed such that the PV array supplies a portion of the faculty's demand during daytime, while any deficit is covered by the grid and any surplus can be exported according to the applicable tariff scheme.

This section describes the components considered in the simulation and their role in determining the technical and economic performance of the system.

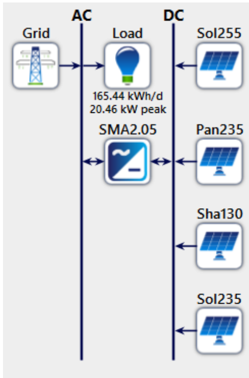

Fig 4. System Architecture

A. Solar Panel

FTKE UTeM was selected as the study site due to its consistent daytime activity and suitability for rooftop PV installation. In this study, four types of commercially available PV modules were considered, with a total installed capacity of 24 kWp to match the faculty's daytime load characteristics. The PV array is assumed to supply electricity directly to the faculty building, with excess energy transferred to the grid.

All PV modules were modeled with a lifetime of 25 years, while their initial investment costs differ according to technology and rated capacity. The PV system configurations are summarized in Table I.

TABLE I
PV PANEL INFORMATION

PV System No	PV Panel	Total Capacity (kW)	Power Rated (W)	Initial Cost (RM)
1	Sol255	6.12	255	10320
2	Pan235	5.64	235	5076
3	Sha130	6.24	130	10522
4	Sol235	5.88	235	9600

The use of multiple PV module options allows HOMER to evaluate different cost–performance combinations. Higher wattage modules may reduce required installation area, while lower-cost modules may reduce capital expenditure but require a larger surface. By including these alternatives, the optimization process can identify the configuration that minimizes Net Present Cost (NPC) while adequately following the faculty's load profile.

From an analytical perspective, the chosen total capacity (24 kWp as the design basis and up to ~31 kWp in the optimized case) is aligned with the daytime-dominant load discussed earlier. This reduces the risk of oversizing (which would increase NPC without proportional benefits) and enhances self-consumption, thereby improving project economics.

B. Converter

A bidirectional converter (inverter/rectifier) is included to interface the DC output of the PV array with the AC grid and building load. Since the system requires both DC–AC conversion (PV to grid/load) and, potentially, AC–DC operation for certain conditions, the converter is modeled as a key power-conditioning unit.

The inverter is specified with:

- **Efficiency:** 97%
- **Lifespan:** 15 years
- **Replacement interval:** once during the 25-year project period
- **Initial/replacement cost:** RM 6060
- **O&M cost:** assumed negligible

Converter efficiency directly affects the usable PV energy delivered to the load and thus influences both COE and NPC. A high-efficiency inverter reduces conversion losses and improves overall system performance, while its replacement cost is fully accounted for in the life-cycle economic analysis. The selected converter rating (34 kW in the optimal configuration) is sufficiently sized to handle the maximum expected PV output and ensure reliable operation under peak conditions without significant derating.

By explicitly modelling converter lifespan, replacement, and efficiency in HOMER, the study captures their contribution to long-term system cost and confirms that the selected configuration is not only technically adequate but also economically robust over the project horizon.

V. Results and Discussion

The optimization results generated by HOMER for the grid-connected PV system are summarized in Table II. The simulation evaluated several system architectures that varied slightly in PV capacity, converter size, and operating dispatch. The objective of the optimization was to minimize the Net Present Cost (NPC) and Cost of Energy (COE) while maintaining reliable power supply to the load.

TABLE II
OPTIMIZATION RESULT

Architecture				System				
PV (kW)	Grid (unit)	Conv (kW)	Dispatch	NPC (RM)	COE (RM/kWh)	Operating Cost (RM/year)	Initial Capital (RM)	RF ((%)
31.1	1	34	CC	480045	0.287	12342	138314	48
31.375	1	34	CC	480263	0.287	12335	138739	48
32.68	1	34	CC	480344	0.287	12300	139766	48

A. Technical Performance

The simulation shows that all three configurations achieve nearly identical technical performance, with renewable fractions (RF) of approximately 48 %. This indicates that almost half of the annual energy demand is met directly by PV generation, while the remainder is imported from the grid. The slight variation in PV capacity (31–33 kW) does not significantly alter the total energy output or system efficiency because the load profile is highly correlated with solar irradiance—most of the demand occurs during daylight hours.

The optimal configuration was found to include 31.1 kW of PV capacity and a 34 kW converter, yielding an NPC of RM 480 045, COE of RM 0.287/kWh, and annual operating cost of RM 12 342. The low COE compared with Malaysia's commercial electricity tariff (approximately RM 0.40/kWh) confirms the system's technical feasibility and competitiveness.

The converter sizing also proves adequate, maintaining safe operational margins under maximum solar output without significant derating losses. A higher PV capacity (e.g., 32.7 kW) only marginally improves energy generation but increases capital investment and replacement cost, leading to negligible improvement in COE. Thus, the 31.1 kW configuration represents the best trade-off between cost and performance.

B. Economic Analysis

From an economic standpoint, the optimized GCPV system yields the lowest NPC among all tested configurations. The results show that increasing PV size beyond the optimal point raises the capital cost faster than it reduces grid electricity consumption, leading to diminishing returns.

The optimal system's COE of RM 0.287/kWh positions it below the national grid tariff, demonstrating its capability to deliver cheaper renewable electricity over its 25-year lifetime. The initial investment of RM 138 314 is recovered within a simple payback period of 5.02 years, while the Internal Rate of Return (IRR) of 15.9 % confirms strong profitability under current economic assumptions.

Compared with the base-case grid-only scenario, the GCPV system reduces dependency on grid imports by nearly half, lowering both operational expenses and carbon emissions. In long-term projections, such systems contribute to grid stability and energy diversification for institutional facilities.

C. Economic Performance Analysis

The economic indicators of the optimized grid-tied PV system are summarized in Table III. The system achieved an Internal Rate of Return (IRR) of 15.9%, a Return on Investment (ROI) of 19.7%, and a Simple Payback Period of 5.02 years. These parameters demonstrate that the investment in a grid-connected PV system at FTKE, UTeM is both financially feasible and economically sound under current energy market conditions.

TABLE III
ECONOMIC COMPARISON

Metric	Value
Internal rate of return, IRR (%)	15.9
Return on investment, ROI (%)	19.7
Simple Payback (Year)	5.02

From the results, an IRR of 15.9% exceeds the typical discount rate for renewable energy investments (usually between 6–10%), confirming the system's strong profitability. A ROI of 19.7% indicates that the total gain over the project's lifetime significantly surpasses the initial investment. Furthermore, the payback period of approximately five years shows that the capital cost can be recovered within a relatively short timeframe compared to the 25-year project lifetime. This economic outcome can be attributed to several factors. High solar irradiance levels at the research location ensure consistent power generation throughout the year. Load profile alignment with daylight hours increases self-consumption, minimizing grid dependency. Declining PV module costs improve investment performance without compromising technical reliability. Overall, the economic evaluation confirms that the proposed GCPV system not only provides long-term cost savings and energy security for the faculty but also supports Malaysia's goal of increasing renewable energy penetration within institutional facilities.

VI. Conclusion

This study presented a techno-economic analysis of a grid-connected photovoltaic (GCPV) system designed for the Faculty of Electrical Engineering (FTKE), Universiti Teknikal Malaysia Melaka (UTeM), using HOMER software. The system was modeled based on real load profiles and one year of solar irradiance data. Optimization results identified the most feasible configuration comprising a 31.1 kW PV array and a 34 kW converter, yielding a Net Present Cost (NPC) of RM 480,045 and a Cost of Energy (COE) of RM 0.287/kWh.

The system achieved a renewable fraction of 48%, indicating that nearly half of the total annual energy demand can be supplied by solar energy. Economic evaluation produced an Internal Rate of Return (IRR) of 15.9%, Return on Investment (ROI) of 19.7%, and a payback period of approximately 5 years, demonstrating strong financial viability. The optimized design also contributes to a notable reduction in carbon emissions while maintaining grid stability and supply reliability.

Overall, the findings confirm that grid-tied PV systems without battery storage are technically and economically feasible for institutional applications in Malaysia's tropical climate. The integration of renewable energy at the faculty level not only reduces operational costs but also supports the country's commitment to sustainable energy development and carbon reduction targets.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships

Author Contributions

Author 1 designed and simulated the whole data in HOMER and wrote the methodology and results sections. Author 2 checks the whole concept and approved the basic ideas of this project and also contributed to control strategies and the discussion and conclusion sections. Author 3 oversaw the project, ensured project are in order, and reviewed the manuscript, providing feedback and final approval for submission.

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