Journal of Engineering Science and Technology
Vol. 21, No. 1 (2026) 125 - 153

PATHWAY TOWARDS CARBON NEUTRALITY FOR THE PUBLIC UNIVERSITY IN SARAWAK, BORNEO

MUHAMMAD SYUKRI IMRAN[1,*],
AZHAILI BAHARUN[2], LIDYANA ROSLAN[3]

[1]Civil Engineering Department, Engineering Faculty, Universiti Malaysia Sarawak, Jalan Datuk Mohammad Musa, 94300, Kota Samarahan, Sarawak, Malaysia
[2]Faculty of Built Environment, Universiti Malaysia Sarawak, Jalan Datuk Mohammad Musa, 94300, Kota Samarahan, Sarawak, Malaysia
[3]Mechanical Engineering Department, Engineering Faculty, Universiti Malaysia Sarawak, Jalan Datuk Mohammad Musa, 94300, Kota Samarahan, Sarawak, Malaysia
*Corresponding Author: amsimran@unimas.my

Abstract

The push for sustainability in higher education institutions increasingly focuses on net-zero carbon emission buildings (NZEBs) as a key strategy for reducing carbon footprints. This study evaluates the feasibility of achieving net-zero carbon emissions within the Engineering Faculty at Universiti Malaysia Sarawak (UNIMAS). A digital energy model of the faculty was created using IES-ICD software to simulate baseline performance and assess various retrofit and renewable energy options. The method involved detailed energy modelling, analysis of local climate data, estimation of rooftop solar photovoltaic (PV) generation potential, and projection of grid decarbonization trends through 2050. Energy efficiency measures - such as building envelope insulation, lighting upgrades, and HVAC optimization - were implemented alongside phased solar PV installations under the Net Energy Metering (NEM) scheme. These measures are expected to reduce Building Energy Intensity (BEI) from 146 to 107 kWh/m^2/year and lower site carbon emissions from 1,637 to 711 tons CO_2e annually by 2050. The study also explores the use of Power Purchase Agreements (PPAs) and Renewable Energy Certificates (RECs) to overcome regulatory and technical barriers to self-consumption systems. The results suggest that a combined approach of targeted retrofits, on-site renewable energy, and carbon offsetting offers a technically and financially feasible pathway to net zero emissions, serving as a replicable model for institutional buildings across Malaysia's tropical regions.

Keywords: Emission, Low carbon, Net zero carbon, Renewable energy, Solar PV.

1. Introduction

The built environment significantly contributes to climate change, accounting for about 40% of global energy use and 28% of CO_2 emissions, mainly from operational energy use [1]. In response, net-zero carbon emission buildings (NZEBs) - which offset carbon emissions through efficiency and renewable energy - are increasingly prioritized under global climate goals [2]. Universities are uniquely positioned to lead this shift. As large-scale energy consumers and hubs of innovation, higher education institutions serve as living laboratories for decarbonization. Previous research indicates that retrofitting campus buildings and deploying clean energy can cut operational emissions by up to 50% [3]. Case studies from institutions like Stanford University [4] and the University of British Columbia [5] showcase replicable frameworks for achieving large-scale carbon neutrality.

This study focuses on the Faculty of Engineering (FK) at Universiti Malaysia Sarawak (UNIMAS), selected based on the following considerations:

i. High Operational Energy Intensity: With five major blocks - including Electrical, Mechanical, Civil, and Chemical Engineering Departments - the faculty spans 55,222 m² and records a total estimated annual energy demand of 8.07 GWh, consumed mainly by MVAC systems and artificial lighting. Currently, the faculty has about 3500 students.

ii. Tropical Climate Conditions: Situated in Kota Samarahan, Sarawak, the region features equatorial climatic conditions (24–34°C year-round), with high humidity (up to 90%) and heavy rainfall. These conditions drive cooling demand, which accounts for over 50% of building energy use in tropical regions [6-8].

iii. High Solar Irradiance Potential: The region receives average daily solar radiation of 4.8–5.4 kWh/m²/day, making it well-suited for solar photovoltaic (PV) integration. Sarawak's sunshine index and low latitude provide a strategic advantage for year-round solar harvesting [9-11].

iv. Institutional Strategic Alignment: The study aligns with the broader UNIMAS Low Carbon Campus Roadmap, which aims to reduce institutional greenhouse gas emissions through building energy optimization, renewable energy adoption, and innovative campus integration. The FK is identified as a priority building cluster under this roadmap for demonstrating replicable low-carbon strategies across other faculties and departments [12].

The study objectives are:

i. Quantifying Scope 2 operational emissions from electricity consumption (grid emission factor: 0.2 tCO_2e/MWh),

ii. Identifying cost-effective energy efficiency measures suitable for tropical institutional buildings,

iii. Evaluating the technical feasibility of solar PV deployment,

iv. Assessing emission reduction potential and economic viability of decarbonization pathways, and

By examining the relationship between energy demand, climate adaptation, and renewable energy potential, this study enhances understanding of net-zero transitions in tropical institutional buildings - an area lacking sufficient coverage in current research.

This study mainly examines operational carbon emissions (Scope 2) related to electricity use in the FK building, as modelled through digital energy simulation. Scope 1 emissions - such as direct fossil fuel consumption for backup generators or laboratory processes - and Scope 3 emissions, including embodied carbon from construction materials, transportation, and user behaviour, are not included in this evaluation. Therefore, the results focus solely on assessing the building's energy performance and carbon reduction strategies through operational energy efficiency and renewable energy measures.

This study contributes to the growing body of knowledge on institutional decarbonization by providing a practical, data-driven roadmap for achieving net-zero carbon emissions in a higher education setting within the Malaysian tropical climate. By integrating energy modelling using IES-ICD software, evaluating targeted energy efficiency retrofits, and exploring scalable renewable energy deployment through Power Purchase Agreements (PPAs) or Energy Performance Contracts (EPCs), the study offers a replicable framework for similar institutions. It addresses a gap in localized research on operational carbon mitigation strategies in tropical academic campuses. It supports evidence-based decision-making aligned with national policies such as the National Energy Transition Roadmap (NETR), the Climate Change Act (in development), and the Twelfth Malaysia Plan’s Low Carbon Cities Framework.

2. Net zero carbon Emission Building Concepts

Net-zero carbon emission buildings aim to eliminate or neutralize greenhouse gas (GHG) emissions by applying a combination of energy demand reduction, clean energy generation, and offset mechanisms [13]. The process typically begins with energy efficiency measures, such as improved insulation, high-performance HVAC systems, and intelligent controls, which significantly lower the building’s energy requirements. This is followed by the incorporation of renewable energy sources, most commonly solar photovoltaic (PV) systems, which are deployed to meet the remaining energy demand with clean, on-site generation. Together, these strategies form the foundation of carbon abatement, where emissions are minimized at the source by reducing reliance on fossil fuels and enhancing operational sustainability.

After all feasible carbon abatement measures are taken, some residual emissions may still exist due to factors such as embodied carbon in materials, construction processes, or certain ongoing operational activities. To achieve net-zero carbon status, these remaining emissions must be neutralized through carbon offset projects, including reforestation, carbon capture and storage (CCS), or the purchase of renewable energy credits (RECs). These offsets, when correctly verified and transparently reported, ensure that the building’s total emissions are effectively balanced, allowing it to achieve actual net-zero carbon performance [14].

Achieving net zero carbon under the Science Based Targets initiative (SBTi) Net-Zero Standard requires organizations to reduce greenhouse gas (GHG) emissions in line with limiting global warming to 1.5°C, followed by neutralizing any residual emissions [15]. The SBTi framework emphasizes a “reduce first, offset later” hierarchy, where at least 90–95% of emissions across all scopes (1, 2, and relevant scope 3) must be cut through direct mitigation efforts by 2050 or earlier, as shown in Fig. 1. Only after reaching this deep decarbonization threshold can remaining unavoidable emissions be neutralized through permanent carbon removals, such as reforestation or direct air capture. The standard explicitly discourages over-reliance on carbon offsetting instead of real emission reductions and mandates transparent reporting and validation. This approach ensures net zero claims are credible, science-aligned, and contribute meaningfully to global climate goals [16].

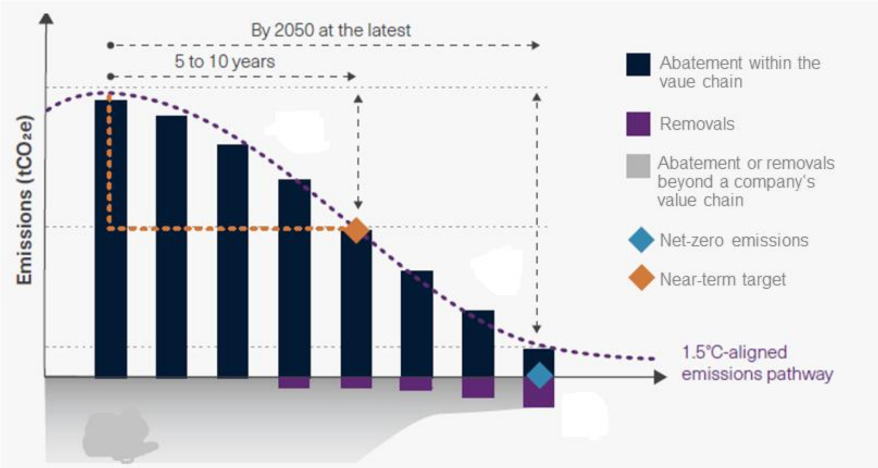


Fig. 1. SBTi Net-Zero Pathway illustrating the required 90–95% emissions reduction by 2050 and the neutralization of residual emissions to achieve net-zero carbon alignment [17].

In the Malaysian context, the pursuit of net-zero carbon buildings is guided by MS1525:2019 – Code of Practice on Energy Efficiency and Use of Renewable Energy for Non-Residential Buildings, which emphasizes minimizing energy demand before integrating renewable sources [18]. The standard outlines key energy efficiency measures such as thermal insulation, daylighting optimization, high-efficiency HVAC systems, and intelligent controls, which collectively reduce baseline energy consumption.

Complementing this, the Building Sector Energy Efficiency Project (BSEEP) provides best practices for retrofitting and performance monitoring, recommending the adoption of energy management systems, efficient lighting (e.g., LED), and chiller system optimization to achieve at least 25–30% energy savings in existing buildings [19-20].

Once demand is reduced, onsite renewable energy, primarily solar PV, is proposed under MS1525 and BSEEP as the preferred method for offsetting residual emissions. This EE+RE approach not only aligns with Malaysia's low-carbon aspirations but also forms a critical two-tier strategy - reduce first, then offset - essential for realizing operational net zero carbon buildings.

Table 1 highlights essential research on the concepts of net zero carbon emission buildings, with an emphasis on energy efficiency, retrofitting, low-carbon technologies, renewable energy integration, and carbon neutralization strategies.

Table 1. Summary of relevant journal papers related to Net Zero Carbon Emission buildings, including carbon abatement and carbon neutralization.

No.	Authors	Year	Key Concept
1	Brown et al. [21]	2019	Emphasizes retrofitting residential buildings as a critical strategy for energy efficiency and carbon reduction, exploring alternative financing mechanisms.
2	Pomponi and Moncaster [22]	2016	Highlights strategies for mitigating embodied carbon in the built environment, stressing comprehensive implementation for significant impact.
3	Prasad et al. [23]	2023	Advocates are measuring and benchmarking operational carbon in the built environment to achieve net-zero through effective strategies.
4	Borghi et al. [24]	2021	Compares design vs. retrofitting approaches for carbon-neutral campus buildings in Europe and the U.S., analysing their effectiveness .
5	Goldstein et al. [25]	2020	Explores pathways to net-zero in commercial buildings by integrating energy efficiency and renewable energy solutions.
6	Filho et al. [26]	2019	Discusses universities' leadership in climate action by implementing carbon neutrality initiatives and promoting sustainability.
7	Voytenko et al. [27]	2018	Introduces urban living labs as experimental platforms for advancing low-carbon initiatives in European cities.
8	Udas et al. [28]	2020	Reviews strategies and challenges for achieving a carbon-neutral university in Germany, focusing on higher education's role in emission reduction.
9	Kourgiozou et al. [29]	2021	Examines scalable pathways to net-zero in UK universities, emphasizing innovative energy systems' transformative potential.
10	Aghamolaei and Fallahpour [30]	2023	Provides a comprehensive review of decarbonization strategies for university campuses across climates, highlighting smart technologies and policy integration.
11	O'Flynn et al. [31]	2021	Demonstrates the role of Science-Based Targets Initiative (SBTi) in achieving net-zero, using a UK university case study as a model.
12	Ürge-Vorsatz et al. [32]	2020	Highlights advance in net-zero energy buildings, emphasizing technology and policy potential while addressing embodied carbon challenges.

Net-zero carbon emission buildings aim to eliminate as much carbon footprint as possible through direct measures like energy efficiency and renewable energy integration. Carbon offsetting complements these efforts by addressing any remaining emissions that cannot be fully reduced on-site. Effective offsetting involves investing in high-quality, additional, and verifiable projects that genuinely contribute to emission reductions. Together, direct reduction strategies and credible carbon offsetting work in tandem to achieve and maintain a net-zero carbon status, ensuring that all aspects of carbon management are comprehensively addressed.

2.1. Carbon abatement in institutions of higher education

The main goal that universities are striving to achieve concerning global climate goals is to decarbonize campus operations and achieve net-zero greenhouse gas emissions, aligning with international commitments such as the Paris Agreement and the United Nations Sustainable Development Goals (SDGs). This involves reducing energy consumption, integrating renewable energy, promoting sustainable practices in research, education, and infrastructure, and serving as living laboratories for climate solutions. As institutions of higher education strive to contribute to global climate goals, many universities have developed comprehensive strategies to achieve net-zero carbon emissions. The following Table 2 summarizes the current carbon footprint baselines, key initiatives, and target years for several universities across different regions. These case studies highlight the diverse approaches and commitment levels of universities towards sustainability and carbon neutrality.

Table 2. Summary of net-zero carbon efforts at selected universities.

University	Baseline tCO_2e (Annual)	Target Year	Key Initiatives
University of Leeds [33]	69,000 (2019)	2030	Solar farm installation, heating system upgrades, improved insulation, energy reduction strategies.
University of Worcester	8,000 (2018)	2030	Energy-efficient buildings, solar PV panels, sustainable transport options.
University of Oxford [35]	37,450 (2016)	2035	Investing in renewable energy, energy efficiency in buildings, sustainable transportation, and carbon offset projects.
Universiti Teknologi Malaysia (UTM) [36]	57,576 (2011)	2050	Green campus initiatives, energy-efficient projects, solar PV installations, subscribe to green electricity tariff (GET RE).
University Malaya [37, 38]	82,500 (2016)	2050	Energy management, waste and water management, green transport and procurement, subscribe to green electricity tariff (GET RE).

Universities worldwide are adopting diverse strategies to achieve net-zero carbon emissions, each focusing on integrating renewable energy, enhancing energy efficiency, and reducing overall carbon footprints. Institutions such as the University of Leeds and the University of Worcester emphasize significant investments in solar photovoltaic (PV) technology and upgrades to energy-efficient systems, alongside initiatives to improve building insulation and energy management. Universiti Teknologi Malaysia (UTM) and University Malaya are similarly focusing on green campus initiatives, incorporating energy-efficient technologies and subscription to green electricity tariff (GET) [39]. Collectively, these universities aim to reduce reliance on non-renewable energy sources, optimize energy use, and achieve carbon neutrality through a combination of technological advancements and sustainable practices.

The University of Oxford exemplifies institutional leadership in the adoption of the Oxford Principles for Net Zero Aligned Carbon Offsetting; a framework it helped establish to promote credible and science-aligned offsetting practices. In its 2021 Sustainability Strategy, Oxford outlines a phased approach to reach net zero carbon emissions by 2035, focusing first on direct emission reductions through energy-efficient buildings, low-carbon transport, and the decarbonization of electricity supply across its estate. Residual emissions will only be addressed using high-quality carbon removals, such as afforestation and long-lived storage, in strict accordance with the Oxford Principles [40] . The university also commits to annual carbon accounting and progress reporting, ensuring transparency and alignment with best practices in carbon management. Oxford's leadership serves as a model for other institutions aiming to meet net-zero targets through a rigorous combination of internal reductions and verifiable offsetting.

3. Methodology

3.1. Digital modelling and simulation

The University Malaysia Sarawak (UNIMAS) campus features a wide range of buildings housing various faculties, colleges, and institutes. For this study, the focus is specifically on FK buildings. To ensure a thorough and accurate assessment of carbon emissions and energy performance, this study employed a systematic methodology involving data collection, modelling, and analysis stages. The process started with selecting FK buildings at Universiti Malaysia Sarawak (UNIMAS), followed by categorizing functional spaces and conducting extensive energy profiling over several months. Design and system specifications were collected to support the development of a detailed energy model using IES-ICD software.

The IES-VE ICD software is a powerful and comprehensive building performance simulation tool that plays a critical role in achieving Net Zero Energy Building (NZEB) goals, optimizing HVAC and control strategies, and supporting green certifications such as GBI and LEED. Its ability to model dynamic energy use and detailed analysis of passive and active design strategies make it highly valuable for energy consultants, ESCOs, and institutions aiming for carbon reduction, energy performance contracting, and ESG reporting. In Malaysia's context, it aligns well with MS1525, BSEEP, and national decarbonization targets.

Simulation outputs were then used to evaluate the impact of proposed energy efficiency interventions on operational CO_2 emissions. The overall methodology is summarized in Fig. 2.

To establish a reliable energy performance baseline for the FK buildings, this study used the IES-ICD (Integrated Environmental Solutions – Integrated Construction and Design) software, which functions as a plugin within the SketchUp Pro environment. This integration enables direct modelling of building geometry and spatial zoning in 3D, making the process of preparing a simulation-ready model more efficient.

The geographical context of the study is shown in Fig. 3, which displays the FK complex at Universiti Malaysia Sarawak (UNIMAS) using a Google Maps satellite view, while Fig. 4 presents the visual context of the building used for modelling. The faculty includes several interconnected buildings with different orientations and exposures, which were used to develop the simulation model geometry. The modelling process in IES-ICD also allows for OpenStreetMap (OSM) data to be imported directly into the interface, enabling users to easily overlay and trace digital energy models onto real-world building footprints. This feature improves accuracy in representing spatial layout and enhances alignment with actual site conditions during energy analysis.

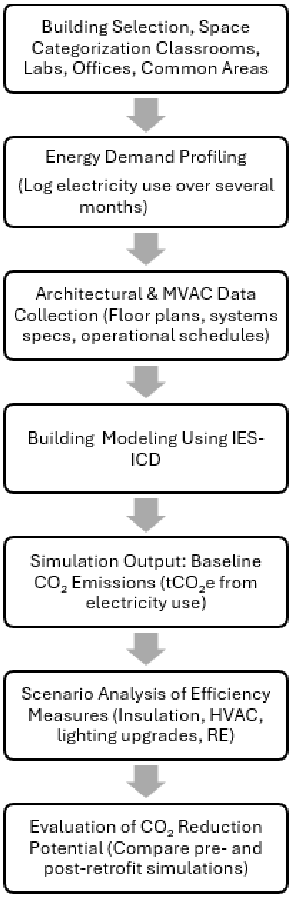


Fig. 2. Methodological flow chart for evaluating energy performance and CO_2 reduction strategies in UNIMAS FK buildings.

Once the building form is created in SketchUp as shown in Fig. 5, the ICD plugin a user's to assign building materials, occupancy profiles, system types, and schedules using the Edit Object dialog boxes within the ICD interface. These inputs include data on thermal envelope characteristics, lighting power density, cooling system specifications, and equipment loads, as illustrated in the screenshots in Fig. 6.

Fig. 3. Google Maps satellite view of the Engineering Faculty, Universiti Malaysia Sarawak (UNIMAS), showing the overall building layout (highlighted in red box) and orientation used in simulation modelling.

(a) Street view of civil engineering lab

(b) Street view of the admin block

(c) Street view of the Mechanical Department block

(d) Street view of Electrical Department Block

Fig. 4. Street view images of FK provide visual context for the energy modelling study.

Crucially, the model incorporates Kuching's Typical Meteorological Year (TMY) weather data to accurately reflect the local climate, including high humidity, solar radiation, and temperature variations typical of equatorial regions. This ensures the simulation results precisely represent the cooling demand and energy consumption patterns. The software then calculates the Building Energy Intensity (BEI) in kWh/m^2/year, along with annual carbon emissions (tCO_2e) based on grid emission factors. To validate the model, the predicted BEI is compared with measured electrical energy data collected from the building over several operational months. This process verifies the baseline accuracy before evaluating any proposed energy efficiency measures.

To evaluate retrofit scenarios, the Edit Objects function within the ICD plugin is further used to modify baseline inputs and simulate performance improvements aligned with MS 1525 recommendations. Key enhancements include lowering the U-value of external walls and roofs to strengthen the building envelope, reducing the solar heat gain coefficient (SHGC) of glazing to decrease solar heat gain, and upgrading the HVAC system by adding variable air volume (VAV) control and improving the seasonal energy efficiency ratio (SEER) of cooling equipment. Additionally, the lighting power density (LPD) is decreased to reflect the use of high-efficiency lighting systems. These changes enable a comparative assessment of energy savings and reductions in Building Energy Intensity (BEI), providing a basis for prioritizing cost-effective and standards-compliant retrofit strategies.

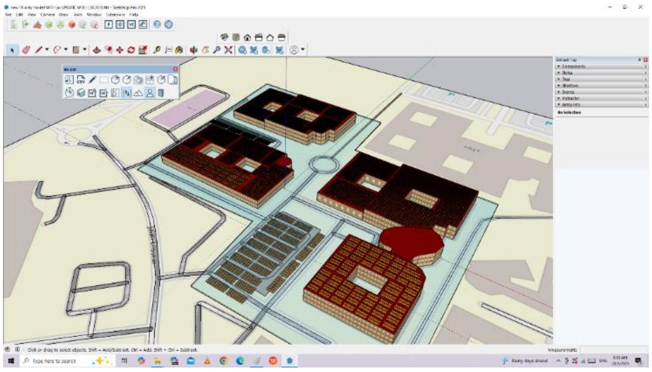
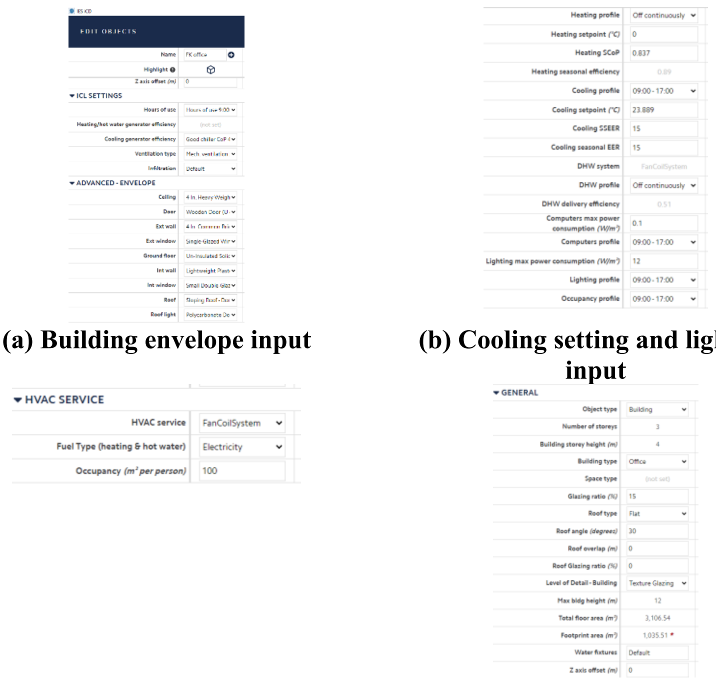


Fig. 5. IES-ICD plugin integrated with SketchUp Pro interface, showing the modelling of the FK buildings geometry prior to simulation.



(a) Building envelope input

(b) Cooling setting and lighting input

(c) HVAC setting input

(d) general building info input

Fig. 6. IES-ICD Edit Object dialog interface used to define thermal properties, HVAC systems, occupancy, and operation schedules for simulation.

In IES-ICD, solar photovoltaic (PV) systems are incorporated into the model using the renewable energy module, which enables users to specify PV system parameters such as panel area, efficiency, orientation, and tilt angle. The system calculates onsite electricity production based on local solar irradiance data from Kuching's TMY file. The produced energy is then offset against the building's total energy demand, allowing the model to determine the net energy consumption and its influence on Building Energy Intensity (BEI) and annual carbon emissions. This feature supports scenario analysis for grid-tied PV systems, providing insights into how solar PV helps achieve net zero energy goals. Figure 5 also shows the digital building model created in SketchUp and integrated with solar PV panels through the IES-ICD platform. The PV system is assigned based on available rooftop area, orientation, and tilt, enabling the simulation to consider onsite renewable energy generation and its role in reducing the building's net energy use and carbon emissions.

4. Results and Discussion

The simulated baseline energy analysis of the FK buildings showed a total annual site energy use of 8.07 GWh, with a Site Energy Use Intensity (EUI) of 146 kWh/m²/year over the combined gross floor area of 55,222 m². This EUI reflects the high operational demand typical of academic buildings with mixed-use functions, including laboratories, classrooms, and administrative spaces. Using a grid emission factor of 0.20 tCO_2e/MWh, the estimated annual operational carbon emissions amount to 1,637 tCO_2e. As shown in Fig. 7, the energy end-use breakdown indicates that cooling systems and lighting account for the majority of energy use, followed by plug loads and miscellaneous equipment. This distribution highlights the potential of targeted retrofitting strategies, especially in HVAC optimization and lighting upgrades, for effective energy and emissions reduction.

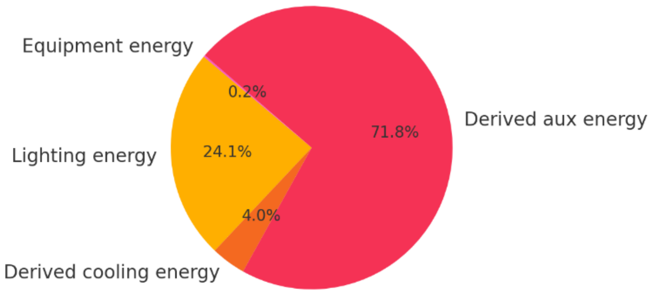


Fig. 7. Energy end-use breakdown for the FK buildings.

The BEI result generated from the simulation for the baseline building falls within the typical range as outlined in Table 2, which summarizes Energy Use Intensity (EUI) or Building Energy Intensity (BEI) values for similar building types across Malaysia, ASEAN, and global benchmarks. This shows that the baseline model is reasonably validated and reflects realistic energy consumption patterns consistent with regional norms. Table 3 summarizes the typical Energy Use Intensity (EUI) or Building Energy Intensity (BEI) values for various building types within Malaysia, ASEAN, and in general.

Table 3. Typical EUI or BEI values for various building types from the referenced sources.

Building Type	Typical EUI or BEI Value ($kWh/m^2/year$)	Source
University Campus Buildings (General)	100–250 $kWh/m^2/year$	[41-46]
Student Hostels	150–300 $kWh/m^2/year$	[47-50]
University Buildings (Southeast Asia)	100–300 $kWh/m^2/year$	[51-54]
Malaysian Public Buildings (General)	120–250 $kWh/m^2/year$	[55-59]

Power logging was carried out over an average of three months during a typical academic semester to capture representative building operational conditions. The logged data closely matches the IES-VE ICD simulation period, allowing for validation of the model's energy use predictions under normal occupancy and system usage patterns. The IES model estimated an average monthly power consumption of 671,867 kWh, while the logged data recorded an average of 580,000 kWh per month, which is within 15% of the simulated value.

4.1. Potential energy savings predicted from energy model

The baseline energy consumption of the university building, mainly consisting of office spaces, provides a reference for assessing the impact of various retrofit strategies aimed at achieving net-zero carbon emissions. The first phase of retrofitting involves lowering the maximum power demand for lighting by installing energy-efficient fixtures and enhancing daylighting. This is followed by improving the building envelope's thermal performance by reducing the U-value of materials and installing low-emissivity (Low-E) double glazing, which decreases heat transfer and enhances insulation. Further retrofits include upgrading the cooling system to a Seasonal Energy Efficiency Ratio (SEER) of 20, implementing a complete water recycling system, increasing solar PV efficiency, and using greener energy sources from the SEB grid. Additional high-efficiency solar PV installations also help reduce reliance on grid power. Finally, natural-based CO_2e offset methods or Renewable Energy Credits can be employed to neutralize any remaining carbon emissions, bringing the building closer to achieving a carbon-neutral or net-zero status. Table 4 summarizes the CO_2e abatement options proposed for the FK building.

Table 4. Proposed deep cuts options to achieve the 2050 building.

Year	Status	CO_2e abatement activities
2024	baseline	Gap analysis
2030	EE retrofit	Reduced lighting max power and provide daylighting
2040	EE retrofit	Reduced U value of material, Low E double glazing
2045	EE retrofit	Cooling SEER 20/ full water recycle/ higher Solar PV efficiency/ greener SEB grid/add more high efficiency solar PV
2050	net zero building	Solar PV phase installation to achieve net positive emission

By combining these energy efficiency measures, the FK building can achieve significant reductions in site energy use, moving closer to its goal of reaching net-zero carbon emissions. These simulations emphasize the importance of taking a comprehensive approach to energy management, combining both passive and active strategies to improve building performance. Table 5 offers a detailed overview of the energy efficiency measures implemented and their target completion year for the FK building.

Table 5. Summary of various building components retrofits and target completion year.

Component	Measures	Retrofit completion target year				
		2024	**2030**	**2040**	**2045**	**2050**
Roof U value W/m²K	Insulation and envelope improvement	3.38	3.38	0.23	0.23	0.23
Ext wall U value W/m²K	4inch brick with 2inch insulation	2.15	2.15	0.53	0.53	0.53
Ext window U value W/m²K	Double glazing	4.83	4.83	2.07	2.07	2.07
Ext window SHGC	Double glazing	0.82	0.82	0.5	0.5	0.5
HVAC service	VAV indoor package cabinet	FCU	FCU	FCU	VAV	VAV
Cooling SEER	Upgrading to high efficiency equipment	15	15	15	20	20
Lighting Max power W/m²	Daylighting at least 50% of floor area (1-3.5% DF)	12	8	8	8	8

It is possible to improve the Seasonal Energy Efficiency Ratio (SEER) of a cooling system through different strategies that focus on both system design and operational efficiency. These improvements include upgrading to high-efficiency equipment with inverter technology and variable-speed compressors, optimizing refrigerant use, and enhancing system design with well-sealed ductwork and zoning systems. Regular maintenance, such as cleaning coils and filters and checking airflow, is crucial. Implementing energy recovery ventilation, smart thermostats, and nighttime setbacks can further increase cooling efficiency. Additionally, enhancing insulation and using high-performance windows can lower the cooling load, collectively boost SEER and reducing energy consumption. By adopting these strategies, the SEER of a cooling system can be greatly improved, resulting in lower energy use, reduced operational costs, and better overall performance.

Table 6 shows the projected energy consumption and intensity for the FK buildings at University Malaysia Sarawak (UNIMAS) over four key years: 2024, 2030, 2040, and 2050. The data includes total site energy and electrical energy consumption in gigawatt-hours (GWh), along with detailed breakdowns for lighting, cooling, simulation auxiliary systems, and equipment, as well as the Site Energy Use Intensity (EUI) measured in kWh/m². These projections highlight the expected reductions in energy demand due to ongoing energy efficiency measures, technological advancements, and strategic initiatives to meet sustainability goals.

Table 6. Projected energy consumption and site energy use intensity (EUI) for FK buildings at UNIMAS (2024–2050).

	2024	2030	2040	2050	Unit
Total site energy/electrical energy GWh	8.07	7.37	6.78	5.92	GWh
Lighting GWh	1.94	1.29	1.29	1.29	GWh
Cooling MWh	323	314	78.9	49.4	MWh
Sim auxiliary GWh	5.79	5.75	5.39	4.57	GWh
Equipment MWh	16.2	16.1	16.2	16.1	MWh
Site EUI	146	133	123	107	kWh/m^2
Site tCO_2e	1637	1496	1377	711	tCO_2e

To determine the financial feasibility of decarbonizing the FK building, a detailed cost estimate was performed for various energy efficiency retrofit measures aligned with MS 1525 and best practices in tropical building design. These measures focus on improving the building envelope, lighting systems, and mechanical ventilation and air-conditioning (MVAC) performance. Table 7 below shows the estimated cost ranges for each proposed intervention. These estimates serve as the basis for assessing payback periods, potential funding options, and integration into a phased Net Zero Carbon plan for UNIMAS.

Table 7. Estimated costs for energy efficiency retrofits at UNIMAS FK based on local Malaysian material and service rates.

Retrofit Measure	Scope / Description	Estimated Total Cost (RM) Million
1. Roof Insulation (Lower U-Value)	Add 50mm local polyurethane/mineral wool insulation to roof	1
2. Wall Insulation (Internal or Cladded)	Install EPS/mineral wool wall boards, cladded or internal	1.4
3. Facade Shading + External Insulation	Use local aluminium louvres, fins + insulated cladding	0.8
4. Double Glazing (Low SHGC)	Double-glazed units with low-e coating (local suppliers)	0.65
5. LED Lighting + Daylight/Occupancy Sensors	Retrofit with local high-efficiency LED fittings + control sensors	0.9
6. MVAC Upgrade (VAV & BMS)	Retrofit AHUs with VAV, add BMS (local automation integrator)	2
7. Improved SEER: VSD & O&M Optimization	VSD upgrade, local control panel tuning, better O&M contracts	0.7
Total		**7.45**

Table 8 summarizes the projected energy cost savings resulting from the gradual reduction in total site energy use from 2024 to 2050, based on a baseline consumption of 8.07 GWh in 2024. As energy efficiency measures are implemented over four time intervals, the site's energy demand decreases significantly, generating annual cost savings calculated at a tariff rate of RM 0.35 per kWh. These accumulated savings, totalling approximately RM 15 million by 2050, can be reinvested to support the implementation of retrofit measures and further decarbonization efforts.

Table 8. Estimated annual and cumulative energy cost savings from site energy reductions (2025–2050).

Time Period	Total Energy Use GWh	Reduction from Baseline (GWh)	Annual Saving (RM)	Years	Total Saving (RM)
2025–2030	7.37	0.70 GWh = 700,000 kWh	245,000	6	1,470,000
2031–2035	6.78	1.29 GWh = 1,290,000 kWh	451,500	5	2,257,500
2036–2040	5.92	2.15 GWh = 2,150,000 kWh	752,500	5	3,762,500
2041–2050	5.92	2.15 GWh (same as previous)	752,500	10	7,525,000
Total				**26**	**15,015,000**

The projected energy cost savings of approximately RM 15 million over the next 26 years offer a strategic funding opportunity for UNIMAS to systematically plan and execute energy efficiency retrofits across its facilities. By aligning annual savings with phased retrofit investments - such as lighting upgrades, HVAC improvements, and building envelope enhancements - the university can gradually reduce operational emissions without requiring significant upfront capital. In addition to using internal savings, Energy Performance Contracting (EPC) can also be explored as a viable mechanism, enabling UNIMAS to partner with energy service companies (ESCOs) that finance, implement, and guarantee performance-based energy savings [60]. However, effective deployment of these approaches will require further deliberation by campus planners, energy managers, and engineering professionals to prioritize interventions, ensure technical feasibility, and maximize returns in line with long-term sustainability goals.

4.2. Renewable energy integration

The potential for solar PV installation on the building's rooftop was assessed. With a total available roof area of 14,000 square meters, the installation could generate approximately 3965 MWh annually.

To achieve net-zero carbon emissions by 2050, the FK building’s solar PV system will be installed gradually over several phases, covering the entire available area of 18,360 m². The strategy will balance immediate energy needs, financial resources, and technological advancements in solar PV efficiency. Table 9 summarizes the phased approach to reaching net-zero carbon emissions by 2050 through incremental installation of the solar PV system.

Approximately 16% of the solar PV capacity required for the FK building will be sourced from a floating solar farm, while the remaining 84% will come from a combination of rooftop solar PV installations and car park solar PV shades, as shown in Table 10. The building would require approximately 29 MW of on-site solar capacity to meet its energy needs. This diverse approach effectively leverages available space to fulfil the building's energy requirements, enhance sustainability, and achieve a net-zero carbon emission status.

Table 9. Incremental solar PV installation plan (2024-2050).

Phase	Year	Cumulative PV Area (m²)	Coverage/Remarks
Phase 1	**2024-2030**	5,000	Initial installation covering lighting, partial HVAC loads, and pilot assessment.
Phase 2	**2031-2035**	9,000	Increased capacity to cover significant portions of HVAC and office operations.
Phase 3	**2036-2040**	13,860	Significant coverage of energy needs with improved panel efficiency and partial energy storage.
Phase 4	**2041-2045**	16,860	Further increase to approach complete energy independence.
Phase 5	**2046-2050**	18,360	Full deployment of solar PV, achieving net zero carbon emission status with potential surplus.

Table 10. Summary of solar PV capacity contribution from different sources.

PV location	Area m^2	% of total area	Solar PV yield MWh	tCO_2e offset
Carpark area	3000	16%	965	195.9
Floating solar farm	3024	17%	973	198
Roof solar PV	12336	67%	3965	804.1
Total	18360	100%	5,903	1198

Figure 8 presents the digital model of the FK building, highlighting the integration of roof-mounted solar PV panels, solar PV car shades, and the contribution of approximately 16% from a nearby floating solar farm. The model illustrates the comprehensive solar PV strategy, designed to maximize energy generation from multiple sources, significantly supporting the building's sustainability and net zero carbon goals.

The potential for solar PV deployment was evaluated across three locations: rooftop surfaces, a floating solar farm, and a car park canopy system. Using high-efficiency 665 Wp panels (2.38m by 1.3m) and considering effective area utilization, the total estimated installed capacity across all sites is approximately 3.55 MWp. Table 11 offers a detailed breakdown of the installed capacity, estimated number of panels, and cost range.

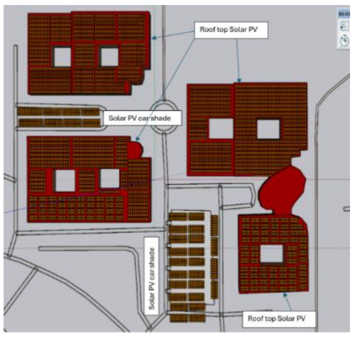


Fig. 8. Digital model of FK buildings- site plan view featuring roof solar PV and solar PV car shade.

Table 11. Estimated installed capacity, panel count, and cost for solar PV deployment by location.

Location	Area (m^2)	Panels (~units)	Capacity (kWp)	Estimated Cost (RM) Million
Rooftop	12,336	3,987	2,653	8.5
Floating Solar	3,024	977	650	2.1
Car Park	3,000	970	645	2.1
Total	18,360	5,934	3,948	12.7

The total estimated cost for comprehensive solar PV deployment from 2025 to 2050 is RM 12.7 million, covering rooftop, floating, and car park systems with a combined capacity of 3.95 MWp. This rollout is divided into five phases (e.g., 2025–2030, 2031–2035, etc.) to align with institutional decarbonization targets and budget constraints. The average annual investment needed for solar PV deployment from 2025 to 2050 is estimated to be between RM 456,000 and RM 564,000 per year, supporting a gradual shift to on-site renewable energy and making a substantial contribution to long-term carbon reduction.

4.3. Net zero building

Table 12 provides a detailed overview of the CO_2 emission reductions achieved through the combined implementation of energy efficiency (EE) measures and renewable energy strategies, specifically the phased installation of solar PV systems. The data reflect a progressive decrease in emissions over time, illustrating the effectiveness of this integrated approach in driving the FK building toward its goal of net zero CO_2e emissions.

Table 12. CO_2 emission reduction achieved through combined energy efficiency measures and renewable energy strategies.

	2024	2030	2040	2050	Unit
Site tCO_2e	1637	1496	1377	711	tCO_2e
Emission offset by solar PV	0	326	915	711	tCO_2e
Total PV area m^2	0	5000	13860	18360	m^2
Total PV yield GWh	0	1.6	4.6	6.04	GWh
Excess emission offset tCO_2e	0	0	0	13.7	tCO_2e
Annual PV contribution vs total energy use GWh	0	1.6	4.6	5.92	GWh
Access PV yield MWh	0	0	0	114	MWh

A significant contributor to this reduction is the substantial improvement in the building's Site Energy Use Intensity (EUI), which dropped from 146 kWh/m² to 107 kWh/m² as a result of targeted EE strategies. These strategies include the reduction of the U-value of the building envelope and the installation of Low-E double glazing, both of which enhance the thermal performance of the building by minimizing heat transfer. Additionally, incorporating daylighting techniques and high-efficiency lighting systems not only reduces energy demand for artificial lighting but also enhances occupant comfort.

The building's mechanical ventilation system was also upgraded, ensuring that air conditioning and ventilation are more efficient, further contributing to the overall reduction in energy consumption. These measures collectively not only lower the building's carbon footprint but also position it well for achieving green building certifications, such as the Green Building Index (GBI) in Malaysia [61].

Achieving GBI certification requires meeting criteria across multiple areas, including water and energy efficiency. The retrofit programs implemented on the FK buildings, which focus on improving both aspects, show that it is possible to meet the strict standards needed for certification. By addressing both energy use and water consumption, the FK building not only advances toward net zero emissions but also supports broader sustainability goals, ensuring long-term environmental and operational benefits.

Furthermore, the table emphasizes the creation of surplus PV output, which is intentionally planned to support future increases in energy demand. This proactive approach ensures that as the building's energy needs change, it will stay on course to reach and sustain net zero CO_2e emissions well beyond 2050. A notable decrease in CO_2e emissions is also anticipated from the greening of the grid by 2050, as the utility company gradually reduces the emission factor linked to electricity production. Sarawak Energy Berhad (SEB) has successfully lowered its grid emission intensity, dropping from 0.698 tCO_2eq/MWh in 2011 to 0.199 tCO_2eq/MWh in 2022. This achievement supports SEB's commitment to the Paris Agreement's climate goals and its goal to reach net-zero carbon emissions by 2050. The company's continuous investments in renewable energy, especially hydropower and floating solar projects, along with plans to retire coal-fired power plants like the Sejingkat station by 2026, indicate a path toward further decarbonization of its electricity generation mix [62].

The significant decrease in site emissions from 1,377 to 711 tonnes of CO_2e is mainly due to the greening of the grid, as the emission factor for electricity generation is expected to decline steadily with the increased adoption of renewable energy sources into the national energy mix. This proactive approach highlights the importance of integrating flexible and scalable renewable energy solutions into the building's overall energy strategy, ensuring its sustainability for years to come.

Figure 9 shows how CO_2e emissions decrease over time as energy efficiency measures, phased solar PV installations, and grid greening are put into action, ultimately reaching net zero CO_2e emissions for the FK buildings by 2050. The graph emphasizes the combined effect of these strategies on reducing carbon emissions.

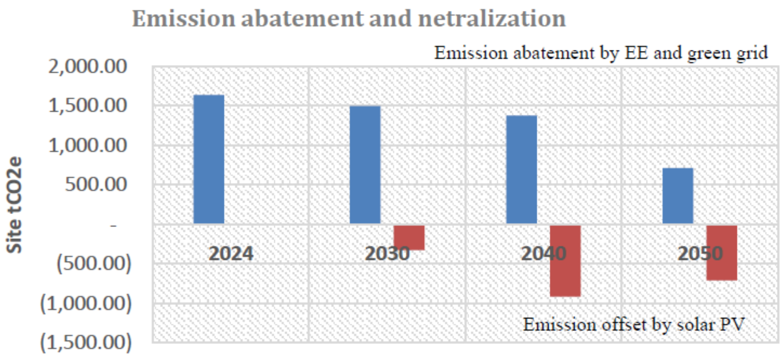


Fig. 9. Achieving net zero CO_2 emissions by 2050 with energy efficiency measures and further carbon offset with solar PV.

Table 13 presents the calculated solar PV capacity, panel count, and estimated cost and savings based on a standardized 665 Wp panel with physical dimensions of 2.38 m × 1.3 m (3.094 m² per panel). Using the total available area across the rooftop, floating platform, and car park installations, the system is expected to reach a combined installed capacity of approximately 3.95 MWp. This setup would generate over 5.13 GWh of electricity annually, saving about RM 1.80 million in utility costs at RM 0.35/kWh.

Table 13. Updated solar PV capacity, panel count, estimated cost, and annual billing offset based on 665 Wp panel deployment at full area utilization.

Phase	Period	PV Area (m²)	Capacity (kWp)	Annual Output (kWh)	Annual Billing Offset (RM)	Total for Period (RM)
Phase 1	2025–2030 (6 yrs)	5,000	1,075	1,397,500	489,125	2,934,750
Phase 2	2031–2035 (5 yrs)	9,000	1,935	2,515,500	880,425	4,402,125
Phase 3	2036–2040 (5 yrs)	13,860	2,980	3,874,000	1,355,900	6,779,500
Phase 4	2041–2045 (5 yrs)	16,860	3,622	4,708,600	1,648,010	8,240,050
Phase 5	2046–2050 (5 yrs)	18,360	3,948	5,131,100	1,795,885	8,979,425
Total						**31,335,850**

Table 14 provides a comprehensive summary of estimated cost savings from both energy efficiency (EE) measures and solar PV deployment over the planning period from 2025 to 2050. Energy efficiency improvements - including lighting upgrades, HVAC enhancements, and building envelope improvements - are projected to save a total of RM 15.02 million in utility costs. At the same time, phased installation of solar PV systems on rooftops, parking areas, and floating platforms will gradually boost the site's renewable energy capacity, resulting in an estimated RM 32.07 million in cost offsets by 2050. Together, these approaches could produce total savings of around RM 47.09 million, supporting a long-term decarbonization strategy while lowering operational expenses.

The projected cost savings of approximately RM 47.09 million from energy efficiency (EE) measures and solar PV billing offsets over the 2025–2050 period provide a strong financial basis to support UNIMAS's transition toward a net-zero emissions campus. These savings, accumulated through reduced energy consumption and self-generated renewable electricity, can be reinvested into further EE and renewable energy (RE) upgrades across university facilities. To accelerate implementation without requiring significant upfront capital, UNIMAS may also adopt an Energy Performance Contracting (EPC) model, where energy service companies (ESCOs) finance, implement, and maintain energy-saving measures, with costs repaid through guaranteed utility bill reductions [63-65]. This approach aligns with long-term sustainability objectives while mitigating budgetary constraints during the transition to net zero.

Table 14. Combined cost savings from energy efficiency measures and solar PV billing offset (2025–2050).

Period	EE Savings (RM/year)	Solar PV Offset (RM/year)	Annual Total Saving (RM)	Cumulative Total (RM)
2025–2030 (6 yrs)	245,000	489,125	734,125	4,404,750
2031–2035 (5 yrs)	451,500	880,425	1,331,925	6,659,625
2036–2040 (5 yrs)	752,500	1,355,900	2,108,400	10,542,000
2041–2045 (5 yrs)	752,500	1,648,010	2,400,510	12,002,550
2046–2050 (5 yrs)	752,500	1,795,885	2,548,385	12,741,925
Total	15,015,000	31,335,850.00		46,350,850

4.3.1. Power purchase agreements (PPAs)

Power Purchase Agreements (PPAs) are long-term contracts between energy consumers and renewable energy producers, where the consumer agrees to buy electricity at a fixed rate for a specified period. These agreements offer several benefits. Primarily, PPAs provide cost stability, which protects consumers from market volatility and fluctuating grid prices [66]. They also facilitate access to renewable energy, even if on-site generation is limited or impractical, thereby supporting broader renewable energy adoption [67]. By entering into a PPA, businesses and institutions can support and finance large-scale renewable energy projects, which contribute to the overall growth of the renewable energy sector [68].

In Malaysia, the regulatory framework for PPAs is managed by the Energy Commission and the Sustainable Energy Development Authority (SEDA). These bodies provide guidelines to facilitate the development of large-scale renewable energy projects [69]. Several Malaysian companies and institutions have leveraged PPAs to source renewable energy, often using these agreements to meet their sustainability goals and corporate social responsibility commitments [70].

4.3.2. Renewable energy certificates (RECs)

Renewable Energy Certificates (RECs), also called Renewable Energy Credits, represent the environmental benefits of generating one megawatt-hour (MWh) of electricity from renewable sources. Buying RECs allows organizations to claim the environmental benefits of renewable energy without directly producing it. This flexibility helps organizations meet their renewable energy goals and supports the development of renewable energy infrastructure. Additionally, RECs can help organizations comply with regulatory requirements and improve their sustainability credentials [71].

The Malaysian Green Attribute Tracking System (MGATS) is a digital platform that facilitates the issuance, tracking, and trading of Renewable Energy Certificates

(RECs) in Malaysia. The Malaysia Green Attribute Tracking System (mGATS) is managed and operated by Tenaga Nasional Berhad (TNB) through its subsidiary TNBX Sdn. Bhd. MGATS ensures transparency and accountability in tracking renewable energy generation, allowing businesses to offset their carbon footprints by purchasing RECs. These certificates represent 1 MWh of electricity generated from renewable sources. MGATS supports the country's renewable energy goals by enabling voluntary REC markets, which are pivotal for companies aiming to meet sustainability targets or achieve carbon neutrality [72].

4.3.3. Combining PPAs and RECs

To achieve comprehensive carbon abatement and sustainability goals, Malaysian organizations can effectively combine PPAs and RECs. If on-site renewable energy generation is insufficient, PPAs can be utilized to procure additional renewable electricity from the grid. Concurrently, RECs can be purchased to claim the environmental benefits associated with this energy. Integrating both PPAs and RECs into carbon management strategies enables organizations to enhance their renewable energy sourcing, reduce reliance on fossil fuels, and contribute significantly towards achieving net-zero emissions.

To assess the effectiveness of different renewable energy options for buildings in Malaysia, it is essential to compare Power Purchase Agreements (PPAs), Renewable Energy Certificates (RECs), and traditional on-site solar PV systems. Each option provides unique benefits and limitations that can impact their suitability based on specific needs and conditions. Table 15 outlines these factors, offering insights into their respective advantages and challenges within the Malaysian context.

To date, there are Renewable Energy Certificate (REC) projects based in Sarawak that are traded on Bursa Carbon Exchange (BCX) [73]. One notable example is the Murum Hydroelectric Plant (HEP), which is a major renewable energy project in Sarawak. In 2024, Sarawak Energy auctioned 268,800 Hydropower Renewable Energy Certificates (HRECv24) generated by this plant, marking a significant step in the region's contribution to renewable energy. This auction was the first of its kind hosted by Bursa Carbon Exchange, and it saw strong demand from various industry buyers, showcasing the market's interest in renewable energy initiatives from Sarawak [74].

Sarawak Energy has been actively involved in the REC market since 2019, with projects like Batang Ai and Murum HEP being part of their REC portfolio. These RECs, registered under international standards like I-REC, allow corporations to support sustainable energy production while meeting their carbon reduction goals [75].

Given the extensive infrastructure at FK - including large rooftop areas, open-space parking lots, and water bodies suitable for floating solar - solar PV deployment is very feasible. However, instead of depending only on the traditional capital expenditure (CapEx) model, a Power Purchase Agreement (PPA) offers a more practical and strategic option. With a PPA, a third-party developer funds, installs, and maintains the solar PV system. At the same time, UNIMAS buys the electricity generated at a fixed rate, usually lower than the grid tariff. This approach removes the need for upfront investment, lowers financial risk, and speeds up deployment across various campus assets without putting stress on the university's capital budget.

Table 15. Comparison of renewable energy solutions in Malaysia.

Aspect	Power Purchase Agreements (PPAs)	Renewable Energy Certificates (RECs)	Conventional On-Site Solar PV Installation
Definition	Long-term contracts to purchase electricity from renewable sources at a fixed rate.	Tradable certificates representing the environmental benefits of generating renewable energy. Managed by Bursa Malaysia for efficient trading and market transparency.	On-site systems are installed to generate renewable energy directly.
Advantages	- Cost stability and predictability - Access to renewable energy without on-site systems - Supports large-scale projects.	- Flexibility in meeting renewable energy targets - Simple and easy to purchase - Efficient trading managed by Bursa Malaysia	- Direct generation and cost savings - Control and ownership over energy production.
Constraints	- Long-term commitment required - Dependence on external providers.	- Indirect impact on energy costs and emissions - Market prices and availability can vary.	- High initial investment and maintenance costs - Requires significant space.
Suitability in Malaysia	- Supported by a regulatory framework - Increasingly adopted by larger organizations	- Growing market with systems like MRECS - Useful for organizations with limited on-site space - Effective REC trading managed by Bursa Malaysia/mGATS	- High solar potential and government incentives - Suitable for organizations with available space and capital

Furthermore, the PPA model ensures professional operation and maintenance throughout the contract period, guaranteeing system performance and reliability. It is especially suitable for large-scale installations such as floating PV systems on campus lakes or solar canopies over parking areas - projects that might otherwise be too costly under a CapEx approach. By using PPAs, UNIMAS can achieve substantial decarbonization benefits and cost savings, while maintaining the flexibility to expand its renewable energy strategy in line with long-term sustainability goals. This approach supports the university's net-zero ambition and enables earlier emission reductions without waiting for internal funding cycles.

4.3.4. Constraints on installing solar PV for self-consumption in Malaysia

The Net Energy Metering (NEM) scheme in Malaysia is designed for grid-tied Solar PV systems, allowing consumers to reduce their electricity bills by exporting excess energy to the grid. However, it does not support complete grid independence [76]. NEM is cost-effective and supported by government incentives. Still, it comes with constraints such as capacity limits, including a restriction that the maximum allowable capacity for Solar PV systems is limited to 75% of the consumer's maximum demand, and export caps. In contrast, the Self-Consumption Guide (SELCO) offers more flexibility, including the potential for grid independence, especially in off-grid setups. However, in the state of Sarawak, a SELCO guideline has yet to be introduced, meaning only the NEM scheme is currently applicable [77]. It is expected that SELCO guidelines will be issued in the near future, which would allow for grid independence in Sarawak. Renewable Energy Certificates (RECs) are effective strategies to address the limitations of on-site solar PV systems and advance towards net-zero carbon buildings [78].

At UNIMAS, adopting Power Purchase Agreements (PPAs) provides an effective way to deploy large-scale solar PV systems across campus assets without requiring upfront capital. However, under Malaysia's current Net Energy Metering (NEM) framework, solar PV installations are limited to a maximum of 75% of the building's peak demand, which restricts the full potential of on-site renewable energy generation. Consequently, part of the building's energy consumption - and its carbon emissions - remains dependent on the grid. To fill this gap, UNIMAS can add Renewable Energy Certificates (RECs) as a complementary strategy. By purchasing RECs through platforms like the Malaysian Green Attribute Tracking System (mGATS), the university can offset the remaining carbon emissions that cannot be reduced through on-site PV or PPAs alone. This hybrid approach not only navigates regulatory limits but also supports broader renewable energy growth in Malaysia while helping UNIMAS better achieve its institutional net-zero carbon goals.

5. Conclusions

This feasibility study shows that achieving net-zero carbon emissions for the Faculty of Engineering at Universiti Malaysia Sarawak is both technically and operationally possible. The integration of targeted energy efficiency (EE) measures - such as optimized lighting, HVAC upgrades, and passive design improvements - along with a phased deployment of solar photovoltaic (PV) systems, offers a solid way to offset the faculty's energy-related carbon emissions fully.

The analysis confirms that solar PV can gradually scale to meet the faculty's demand, with a potential of 100% rooftop deployment estimated to generate over 2,300 kWp, supported by a favourable solar yield in Kota Samarahan's equatorial climate. When combined with demand-side reductions from EE measures, this approach can cut utility dependence by up to 60–70% within the first two phases of implementation.

Financially, the study highlights the viability of using performance-based mechanisms such as Energy Performance Contracts (EPC) or Power Purchase Agreements (PPA) to fund capital investments without requiring enormous significant upfront costs from the university. These models ensure long-term savings and risk-sharing with private energy service companies.

Furthermore, the proposed net-zero roadmap aligns with national and institutional sustainability goals, including the Malaysia Renewable Energy Roadmap (MyRER), MS1525, and the university's own Net Zero Carbon 2050 target. The Faculty of Engineering, as a leading academic and innovation centre, is strategically positioned to act as a demonstration site and living lab for decarbonization technologies and policy tests. The study's comprehensive results not only lay the foundation for actionable steps at the faculty level but also serve as a model for other buildings and faculties across the campus. This positions

Universiti Malaysia Sarawak as a leader in Malaysia's higher education sector in advancing institutional climate leadership and campus-wide decarbonization.

Nevertheless, this study focuses only on operational carbon emissions (Scope 2) from electricity use. It does not include direct emissions (Scope 1), like those from fuel burning or equipment leaks, or indirect emissions (Scope 3), such as embodied carbon and activities related to users. Future research should look at a complete life cycle assessment to understand the total carbon footprint of campus operations.

Since this study focused solely on the Faculty of Engineering complex, future research should expand to include other academic and support buildings across the UNIMAS campus. With more resources and time, a campus-wide simulation could develop a more comprehensive roadmap toward reaching institutional Net Zero targets. Additionally, there is potential to investigate alternative renewable energy sources beyond solar PV, such as biomass, small-scale hydro, or waste-to-energy systems, to diversify the campus energy mix and improve long-term sustainability.

References

1. United Nations Environment Programme. (2021). 2021 Global status report for buildings and construction. Retrieved October 5, 2024, from https://www.unep.org/resources/report/2021-global-status-report-buildings-and-construction
2. Dean, B.; Dulac J.; Petrichenko, K.; and Graham, P. (2016). Towards zero-emission efficient and resilient buildings. Global status report. *Global Alliance for Buildings and Construction* (*GABC*).
3. Filho, W.L. et al. (2019). The role of higher education institutions in sustainability initiatives at the local level. *Journal of Cleaner Production*, 233, 1004-1015.
4. Ahmed, F. (2017). Stanford energy system innovations (SESI). Retrieved October 5, 2024, from https://cbe.berkeley.edu/wp-content/uploads/2019/01/Fahmida-Ahmed-ZNE-Oct-25-2017.pdf
5. The University of British Columbia. (2020). The University of British Columbia climate action plan 2020. An update to UBC's climate action plan. Retrieved December 15, 2023, from https://planning.ubc.ca/sites/default/files/201911/PLAN_UBC_ClimateActionPlan.pdf
6. Mohsenzadeh, M.; Marzbali, M.H.; Tilaki, M.J.M.; and Abdullah, A. (2021). Building form and energy efficiency in tropical climates: A case study of Penang, Malaysia. *Urbe Revista Brasileira de Gestão Urbana*, 13, e20200280.
7. Rattanongphisat, W.; and Rordprapat, W. (2014). Strategy for energy efficient buildings in tropical climate. *Energy Procedia*, 52, 10-17.
8. Kwong, Q.J.; Adam, N.M.; and Sahari, B. (2014). Thermal comfort assessment and potential for energy efficiency enhancement in modern tropical buildings. A review. *Energy and Buildings*, 68, 547-557.
9. Belhamadia, A.; Mansor, M.; and Younis, M.A. (2013). Assessment of wind and solar energy potentials in Malaysia. *Proceeding of* 2013 *IEEE Conference on Clean Energy and Technology* (*CEAT*), Langkawi, Malaysia, 152-157.
10. Jakhrani, A.; Othman, A.; Rigit, A.; and Samo, S. (2011). Model for estimation of global solar radiation in Sarawak, Malaysia. *World Applied Sciences Journal*, 14, 83-90.

11. Jakhrani, A.; and Rigit, A. (2012). Assessment of solar and wind energy resources at five typical locations in Sarawak. *Journal of Energy and Environment*, 4(1), 1-6.
12. ISURE. (2022). UNIMAS low carbon campus roadmap 2030. Retrieved January 28, 2024, from https://anyflip.com/dwbrw/nneh/basic
13. de Franco, C.; Nicolle, J.; and Tran, L.-A. (2022). The challenge to meet net-zero. *The Journal of Impact and ESG Investing*, 3(1), 71-79.
14. McGivern, A. et al. (2022). Defining Net Zero for organizations: How do climate criteria align across standards and voluntary initiatives. *Univ. Oxford*, *Oxford*, UK.
15. SBTi. (2025). SBTi launches draft Corporate Net-Zero Standard V2 for consultation. Retrieved February 15, 2024, from https://sciencebasedtargets.org/news/sbti-launches-draft-corporate-net-zero-standard-v2-for-consultation
16. SBTi. (2025). SBTi corporate near-term criteria (version 5.3). Retrieved February 15, 2024, from https://files.sciencebasedtargets.org/production/files/SBTi-criteria.pdf
17. SBTi. (2023). SBTi corporate net-zero standard (version 1.3). Retrieved February 15, 2024, from https://files.sciencebasedtargets.org/production/files/Net-Zero-Standard.pdf
18. Department of Standard Malaysia. (2007). Code of practice on energy efficiency and use of renewable energy for non residential building. Retrieved February 15, 2024, from https://www.pam.org.my/images/resources/notes_circular/Code_of_Practice_on_EE_MS1525-200.pdf
19. Tang, C.; and Chin, N. (2013). Building energy efficiency technical guideline for passive design. *Public Works Department Malaysia*, *Kuala Lumpur*.
20. Tang, C.; and Chin, N. (2013). Building energy efficiency technical guideline for active design. Public Works Department Malaysia, Kuala Lumpur.
21. Brown, D.; Sorrell, S.; and Kivimaa, P. (2019). Worth the risk? An evaluation of alternative finance mechanisms for residential retrofit. *Energy Policy*, 128, 418-430.
22. Pomponi, F.; and Moncaster, A. (2016). Embodied carbon mitigation and reduction in the built environment–What does the evidence say? *Journal of Environmental Management*, 181, 687-700.
23. Prasad, D. et al. (2023). *Operational carbon in the built environment: measurements, benchmarks and pathways to net zero*. In Prasad, D. et al. (Eds.), *Delivering on the Climate Emergency*. Springer Nature, 29-78
24. Borghi, A.D.; Spiegelhalter, T.; Moreschi, L .; and Gallo, M. (2021). Carbon-neutral-campus building: Design versus retrofitting of two university zero energy buildings in Europe and in the United States. *Sustainability*, 13(16), 9023.
25. Goldstein, B.; Gounaridis, D.; and Newell, J.P. (2020). The carbon footprint of household energy use in the United States. *Proceedings of the National Academy of Sciences*, 117(32), 19122-19130.
26. Filho, W.L. et al. (2019). The role of higher education institutions in sustainability initiatives at the local level. *Journal of Cleaner Production,* 233, 1004-1015.

27. Voytenko, Y.; McCormick, K.; Evans, J.; and Schliwa, G. (2016). Urban living labs for sustainability and low carbon cities in Europe: Towards a research agenda. *Journal of cleaner production*, 123, 45-54.
28. Udas, E.; Wölk, M.; and Wilmking, M. (2018). The "carbon-neutral university"–A study from Germany. *International Journal of Sustainability in Higher Education*, 19(1), 130-145.
29. Kourgiozou, V.; Commin, A.; Dowson, M.; Rovas, D.; and Mumovic, D. (2021). Scalable pathways to net zero carbon in the UK higher education sector: A systematic review of smart energy systems in university campuses. *Renewable and Sustainable Energy Reviews*, 147, 111234.
30. Aghamolaei, R.; and Fallahpour, M. (2023). Strategies towards reducing carbon emission in university campuses: A comprehensive review of both global and local scales. *Journal of Building Engineering*, 76, 107183.
31. O'Flynn, C. et al. (2021). The road to net zero: A case study of innovative technologies and policy changes used at a medium-sized university to achieve czero by 2030. *Sustainability*, 13(17), 9954.
32. Ürge-Vorsatz, D. et al. (2020). Advances toward a net-zero global building sector. *Annual Review of Environment and Resources*, 45, 227-269.
33. University of Leeds. (2021). Pathway to Net Zero Emission by 2030.
34. University of Worcester. (2024). Carbon reduction target. Retrieved January 21, 2025, from https://www.worc.ac.uk/about/sustainability/what-we-do/carbon-emission-targets.aspx
35. University of Oxford. (2024). Targets. Retrieved January 21, 2025, from https://www.ox.ac.uk/about/building-our-future/environmental/targets
36. UTM. (2022). UTM sustainability blueprint 2030. Retrieved January 21, 2025, from https://chancellery.utm.my/wp-content/uploads/sites/10/2023/07/Sustainability-Blueprint-2030.pdf
37. University Malaya. (2024). Tracking GHG & carbon emissions. Retrieved January 21, 2025, from https://sustainability.um.edu.my/tracking-ghg-amp-carbon-emissions
38. University Malaya. (2022). UM eco-campus blueprint (UMECB). Retrieved January 21, 2025, from https://sustainability.um.edu.my/um-eco-campus-blueprint
39. TNB. (2024). Green electricity tariff. Retrieved January 25, 2025, from https://www.tnb.com.my/get
40. Axelsson, K. et al. (2024). Oxford principles for net zero aligned carbon offsetting (revised 2024). *Smith School of Enterprise and the Environment, University of Oxford*.
41. Saleh, N.M. et al. (2023). Energy audit of al-Qalam University, katsina state Nigeria: A simulation approach. *World Academics Journal of Engineering Science*, 10(2), 17-25.
42. Faremi, J.O. et al. (2023). Energy performance benchmarking in University of Lagos Hostel Buildings. *LAUTECH Journal of Civil and Environmental Studies*, 10(2), 1-12.

43. Muhammad, J.Y.; Adamu, A.A.; Alhaji, A.M.; and Ali, Y.Y. (2018). Energy audit and efficiency of a complex building: A comprehensive review. *Engineering Science*, 3(4), 36-41.
44. Yahya S.S.; Ariffin, A.; and Ismail, M.A. (2015). *Building energy index and students' perceived performance in public university buildings*. In Yahya S.S.; Ariffin, A.; and Ismail, M.A. (Eds.), *Renewable Energy in the Service of Mankind Vol I*. Springer, 541-550
45. Pereira, L.D.; Raimondo, D.; Corgnati, S.P.; and da Silva, M.G. (2014). Energy consumption in schools–A review paper. *Renewable and Sustainable Energy Reviews*, 40, 911-922.
46. Khoshbakht, M.; Gou, Z.; and Dupre, K. (2018). Energy use characteristics and benchmarking for higher education buildings. *Energy and Buildings*, 164, 61-76.
47. Samad, A.A.; Idin, M.A.M.; Othman, M.F.; and Napiah, N.A.M. (2018). *Assessment of energy efficiency level on UiTMPP's Baiduri college building*. In Samad, A.A.; Idin, M.A.M.; Othman, M.F.; and Napiah, N.A.M. (Eds.), *Proceedings of the Second International Conference on the Future of ASEAN* (*ICoFA*) 2017 – *Volume* 2. Springer , 203-213.
48. Mu, Q.; Taherian, H.; and Penko, Z.S. (2020). Optimization of a renewables-integrated distributed generation system for a university campus using Hooke-Jeeves algorithm. *International Journal of Advanced Thermofluid Research*, 6(1), 15-34.
49. Kubota, T.; Jeong, S.; Toe, D.H.C.; and Ossen, D.R. (2011). Energy consumption and air-conditioning usage in residential buildings of Malaysia. J*ournal of international Development and Cooperation*, 17(3), 61-69.
50. Aqilah, N.; Zaki, S.A.; Hagishima, A.; Rijal, H.B.; and Yakub, F. (2021). Analysis on electricity use and indoor thermal environment for typical air-conditioning residential buildings in Malaysia. *Urban Clim*, 37, 100830.
51. Hong, W.Y.; and Rahmat, B.N.N.N. (2022). Energy consumption, CO2 emissions and electricity costs of lighting for commercial buildings in Southeast Asia. *Scientific Reports*, 12(1), 13805.
52. Ismail, M.I.; and Yaziz, M.Y. (2023). Kajian terhadap building energy index (BEI) di Kolej Komuniti Temerloh. *Asian Journal of Civilizational Studies* (*AJOCS*), 5(3), 7-27.
53. Hakimi, I.D.M.; Ahmad, N.A.; Abidin, Z.Z.; and Jamil, S.J.T. (2024). The building energy index (BEI) evaluation for libraries in Malaysian public universities: A case study of UiTM Perak. *International Journal of Business and Technology Management*, 6(S2), 329-343.
54. Tahir, M.Z.; Jamaludin, R.; Nawi, M.N.M.; Baluch, N.H.; and Mohtar, S. (2017). Building energy index (BEI): A study of government office building in Malaysian public university. *Journal of Engineering Science and Technology,* 12(2), 192-201.
55. Singh, J.; Velu, V.; Shafeek, M.A.; and Nirmal, U. (2021). A review on building energy index (BEI) in different green government buildings (GGBS) in Malaysia. *Malaysian Journal of Science and Advanced Technology*, 1(2), 46-56.

56. Melo, F.C.; da Graça, G.C.; and Panão, M.J.O. (2023). A review of annual, monthly, and hourly electricity use in buildings. *Energy and Buildings*, 293, 113201.
57. Tan, X.Y.; Mahyuddin, N.; and Zaid, S.M. (2023). Efficacy of energy conservation measures and building energy intensity of a multi-building complex in Malaysia. *Proceedings of the* 11*th International Conference on Indoor Air Quality, Ventilation & Energy Conservation in Buildings* (*IAQVEC*2023), Tokyo, Japan, 396, 03004
58. Kimura, S.; and Meng, L.S. (2021). Technical guidelines for energy efficiency and conservation in commercial buildings. *ERIA Research Project Report* 2021, *No*. 14.
59. Seghier, T.E.; and Wah, L.Y. (2022). A BIM-based method for building energy intensity (BEI) evaluation. *Proceedings of* 2021 4*th International Conference on Civil Engineering and Architecture*, Seoul, South Korea, 365-372.
60. AEPCA (2019). A best practice guide to energy performance contracts.
61. GBI. (2011). GBI assessment criteria for non-residential existing building (NREB). Retrieved January 30, 2024, from https://www.greenbuildingindex.org/Files/Resources/GBI%20Tools/GBI%20NREB%20Non-Residential%20Existing%20Building%20Tool%20V1.1%20Final.pdf
62. Sarawak Energy. (2023). Annual and sustainability. Retrieved January 30, 2024, from https://www.sarawakenergy.com/investors/annual-and-sustainability-reports
63. Hwang, G.H.; Saar, C.C.; and Chen, G.K. (2019). Energy performance contract (EPC) in Malaysia and other countries. Retrieved January 30, 2024, from https://ipm.my/energy-performance-contract-epc-in-malaysia-and-other-countries/
64. Imran, M.S.; Rahman, N.M.A.; and Mohamed, R. (2020). Energy performance contracting initiative in Malaysian public hospitals. *International Journal of Integrated Engineering*, 12(9), 234-245.
65. Munir, Z.H.M. et al. (2023). A rational plan of energy performance contracting in an educational building: A case study. *Sustainability*, 15(2), 1430.
66. Aleluia, J.; Tharakan, P.; Chikkatur, A.; Shrimali, G.; and Chen, X. (2022). Accelerating a clean energy transition in Southeast Asia: Role of governments and public policy. *Renewable and Sustainable Energy Reviews*, 159, 112226.
67. Chua, S.C.; and Oh, T.H. (2010). Review on Malaysia's national energy developments: Key policies, agencies, programmes and international involvements. *Renewable and Sustainable Energy Reviews*, 14(9), 2916-2925.
68. Abdullah, W.S.W.; Osman, M.; Kadir, M.Z.A.A.; and Verayiah R. (2019). The potential and status of renewable energy development in Malaysia. *Energies*, 12(12), 2437.
69. IRENA. (2018). Power purchase agreements for variable renewable energy. Retrieved February 10, 2024, from https://www.irena.org/-/media/Files/IRENA/Agency/Presentations/Financing-projects/2018/Aug/Renewable-Energy-PPAs.pdf
70. Leong, W.; Heng, L.; and Leong, Y. (2024). Malaysia's renewable energy policy and its impact on ASEAN countries. *Advances in Science*, *Technology and Engineering Systems Journal*, 9(2), 67-73.

71. Hazim, A. (2024). Malaysia kicks off renewable energy certificates commercial trading. Retrieved February 11, 2024, from https://theedge malaysia.com/node/710964
72. Harinderan, K. (2024). Renewable energy certificate through mGats help corporate companies fulfil ESG commitments. Retrieved February 11, 2024, from https://www.businesstoday.com.my/2024/05/08/renewable-energy-certificate-through-mgats-help-corporate-companies-fulfil-esg-commitments/
73. Keong, K.C.; and Jun, T.Z. (2024). Bursa carbon exchange commences continuous trading for renewable energy certificates. Retrieved February 11, 2024, from https://www.skrine.com/insights/alerts/september-2024/bursa-carbon-exchange-commences-continuous-trading
74. Sarawak Energy. (2023). Bursa carbon exchange signs MOC with Sarawak Energy. Retrieved February 12, 2024, from https://www.sarawakenergy.com/media-info/media-releases/2023/bursa-carbon-exchange-signs-moc-with-sarawak-energy-hydropower-sustainability-alliance-and-i-rec-at-cop28-signalling-its-future-offering-of-renewable-energy-certificates
75. Dayak Daily. (2024). Sarawak Energy partner with Bursa carbon exchange for inaugural hydropower renewable energy certificate auction. Retrieved February 12, 2024, from https://dayakdaily.com/sarawak-energy-partners-with-bursa-carbon-exchange-for-inaugural-hydropower-renewable-energy-certificate-auction/
76. Sarawak Energy. (2025). Net energy metering scheme. Retrieved February 12, 2024, from https://www.sarawakenergy.com/customers/net-energy-metering-scheme
77. Suruhanjaya Tenaga Malaysia. (2023). Guidelines on the connection of solar photovoltaic installation for self-consumption. Retrieved February 12, 2024, from https://www.st.gov.my/contents/publications/guidelines_electricity/2017/Guidelines%20on%20the%20Connection%20of%20Solar%20Photovoltaic%20Installation%20for%20Self-Consumption-280417.pdf
78. SEB. (2024). Engineering Circular No. 11/2024. Retrieved February 12, 2024, from https://www.sarawakenergy.com/assets/pdf/EC-No.-11-2024-Guidelines-and-Requirements-for-LSS-Connection-to-Sarawak-Grid-System.pdf