Design and Solar Sizing of a Green Eco Charge (GEC) Kiosk for Kampung Orang Asli Tewowoh, Mersing

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DOI: https://doi.org/10.51244/IJRSI.2025.120700177

Received: 24 June 2025; Accepted: 09 July 2025; Published: 15 August 2025

ABSTRACT

This paper presents the design, solar sizing, and technical verification of the Green EcoCharge (GEC) Kiosk designed for Kampung Orang Asli Tewowoh, a remote rural village in Mersing, Johor, Malaysia. The GEC Kiosk was envisioned to combat the pressing issues of limited access to electricity by implementing a standalone solar-powered mobile charging kiosk with an integrated IoT-based monitoring system. The approach encompasses thorough load analysis, system design, and power calculation grounded in real-world usage patterns. The community's energy requirement was approximated at 4,696 Wh/day, with a supply setup of 600W solar panel and 2,400Wh battery bank capacity, which is capable of powering mobile phones, laptops, and onboard electronics of the kiosk. The effectiveness of the system is substantiated by its capability to address the daily charging needs of up to 60 mobile phones and 8 laptops, while an integrated IoT system, based on ESP32 and Blynk platform, facilitates real-time performance monitoring and diagnostics. The system also exhibits efficient energy management and sustainability with 246 Wh of excess energy during normal operation. Aside from technical deliverables, the kiosk also aids in enhanced digital connectivity, access to education, and socio-economic empowerment of the Orang Asli people. The GEC Kiosk concept offers a replicable and scalable model in support of Sustainable Development Goal (SDG) 7, granting clean and reliable energy for marginalized rural communities.

Keywords: Green EcoCharge, Renewable Energy, Indigenous Communities, Sustainable Development Goal (SDG) 7

INTRODUCTION

Indigenous communities in Malaysia, particularly those living in remote and rural areas, face significant challenges in gaining access to electricity. In spite of the laudable advances in attaining near-universal national electricity coverage in Malaysia, the reality for Indigenous Peoples, referred to as Orang Asli in Peninsular Malaysia and Orang Asal or natives in East Malaysia (Sabah and Sarawak), is quite disparate. This disparity is attributable to several factors, including the remote geographical location of their settlements, ongoing land rights issues, economic marginalization (Hossain et al., 2015), and reliance on fossil fuel sources of energy. The challenge of reaching these remote areas presents enormous hurdles for initiatives seeking to extend the national electricity grid. Moreover, the lack of secure land tenure discourages investments in basic infrastructure, such as electricity services, due to the risks of possible legal disputes and ownership tussles. Economic disenfranchisement also limits the ability of these communities to pay for electricity even where it is available, while a reliance on diesel generators or the requirement of substantial financial investment in renewable energy sources, such as solar panels, presents additional complications.

In response to these challenges,the Jalinan Digital Negara (JENDELA) program was introduced to expand broadband coverage and upgrade the quality of broadband experiences across Malaysia, thus laying the groundwork for the adoption of 5G technology. For Indigenous communities, this program is particularly significant because, besides aiming to improve their economic well-being, it also aims to enhance cultural identities, increase access to basic services, and ensure sustainable development that is responsive to their aspirations and needs (MCMC_Jendela_2021SummaryReport_Final, n.d.). The core of JENDELA's activities is the construction of telecommunications towers and fiber optic systems in these areas, and there is a particular focus on solar energy stations. These installations are specifically tailored to respond to the energy demands of such communities, and more specifically, to the increased use of mobile phones connected to the internet, which demonstrates a commitment to bridging the digital divide (GENUS & and NOR, 2007) and fostering inclusive development.

illustrates the pressing need for innovative energy solutions. The role of JAKOA in protecting Orang Asli communities from the encroachment of civilization and exploitation at a rapid pace underscores the importance of ensuring access to electricity. In villages like Tewowoh, the lack of a reliable source of electricity (Mahmud et al., 2022) constrains economic activities, access to basic services, and effective communication means. Natural disasters and emergencies also often exacerbate underlying energy-related challenges in rural communities, leaving these communities exposed and disconnected due to a lack of communication devices or access to important services. To overcome these conditions, the Green EcoCharge (GEC) Kiosk project was initiated for Kampung Orang Asli Tewowoh, Mersing, with the aim of providing an essential and reliable source of power for mobiles and emergency communication devices. In response to these issues, there is a compelling need to implement mobile solar charger stations (Krishna et al., 2024) in rural areas. These stations would not only provide a sustainable and renewable energy solution but also empower communities by enhancing connectivity, resilience, and economic opportunities. By addressing the energy gap in rural regions, mobile solar charger stations can contribute to bridging the digital divide, promoting inclusive development, and improving the overall quality of life for rural residents.

Currently, each house is equipped with a basic renewable energy system that powers only one light and one fan. This limited supply prevents residents from using power sockets to charge mobile phones or operate other essential electronic devices such as televisions, freezers, and radios. To compensate, many households rely on diesel generators, which are costly, environmentally damaging, and contribute to noise pollution(Tran et al., 2025). These issues hinder communication, access to information, and economic opportunities for the community.

Furthermore, the absence of reliable electricity limits access to digital services and connectivity, exacerbating the digital divide. This divide hampers educational opportunities, economic activities, and communication, further entrenching poverty and isolation. The GEC Kiosk project seeks to improve electricity access through the provision of USB ports for DC supply, which will allow inhabitants to charge mobile phones and utilize other electronic devices.

System Design and Methodology

The GEC Kiosk was created to provide clean and reliable energy solutions to meet the daily charging needs of the Indigenous community living in Kampung Orang Asli Tewowoh, Mersing. The system combines solar energy generation, energy storage through batteries, AC/DC output sockets, and IoT-enabled monitoring to ensure sustainability, ease of maintenance, and user empowerment. The design process followed a modular and scalable approach to accommodate the rural environment and meet community-specific energy needs (M. F. Abdullah et al., 2021).

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue VII July 2025

Proposed System Design.

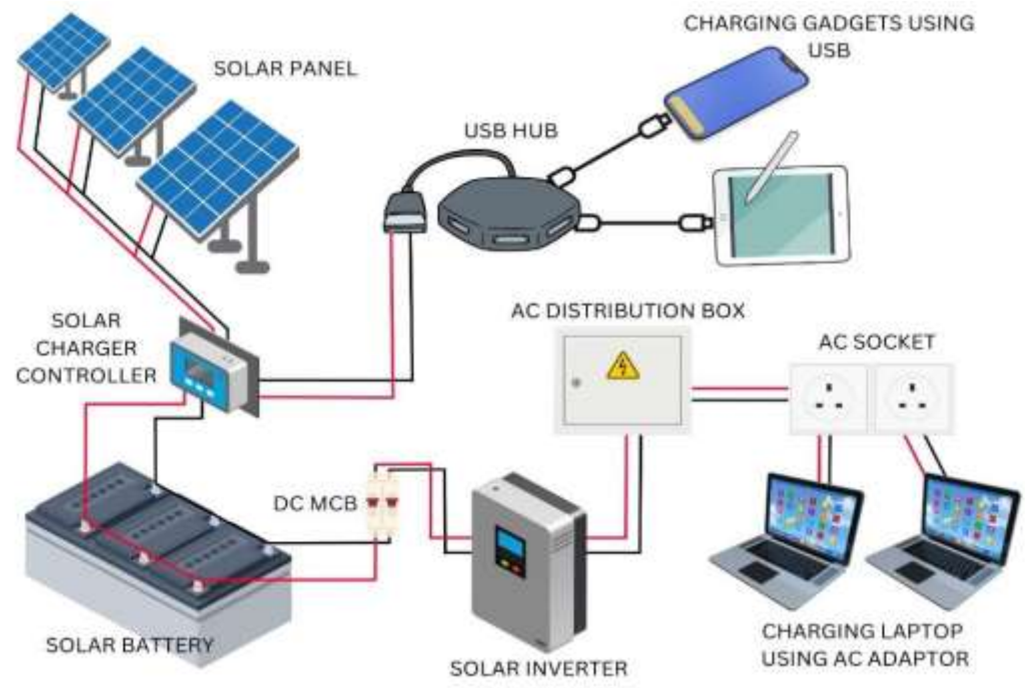

Figure 1: GEC Kiosk Project System Design

The ESP32 WiFi Module is used in an Internet of Things-based solar power monitoring system (Gowri et al., 2024). The ESP32 establishes a WiFi network connection and uploads solar sensing data to Blynk Server, including temperature, light intensity, and solar panel voltage. The project enables monitoring power output of a solar panel, incident light intensity, and operating temperature with the help of an ESP32 WiFi + BLE Microcontroller. The Solar Panel and sensors are connected accurately to the ESP32 controller that monitors the panels and loads. So the users can monitor the voltage, temperature, and Solar Irradiance online from anywhere in the world.

Energy Demand Analysis and Load Calculation

An initial step in the design of the GEC Kiosk was a thorough energy demand analysis. This step was necessary to properly size the photovoltaic system and battery bank for year-round reliable operation. The analysis measured both the primary load of user device charging and the secondary load of the kiosk's own operating equipment.

The main energy load was recognized as the energy for charging the personal electronic gadgets of the community. From observed usage patterns, the system was designed to accommodate three different charging situations: the daily charging of 60 mobile phones through USB ports, another 24 mobile phones through the AC sockets provided, and a maximum of 8 laptops, also through AC sockets. The power consumption of the gadgets was estimated from standard power ratings, with each mobile phone consuming about 18 watts for a session of 1.5 hours, and each laptop taking 75 watts for 2.5 hours.

In addition to this user-driven demand, a continuous secondary load was identified, comprising the kiosk's own internal electronics. This includes the power for the integrated IoT monitoring system, which features an ESP32 microcontroller, various sensors, and communication modules. The cumulative daily energy consumption for these essential operational components was calculated to be approximately 576 watt-hours (Wh).

By aggregating the energy requirements for both primary and secondary loads, the total calculated daily energy demand for the GEC Kiosk was determined to be 4,344 Wh. This figure served as the critical benchmark for designing the system's power generation and storage capacity.

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue VII July 2025

Solar Panel and Battery Sizing

The system is energized by two 300W monocrystalline solar panels, for a total installed capacity of 600W. With an assumed average of 5 peak hours of sunshine per day and an overall system efficiency of 85%, the projected daily energy harvest from solar is 2,550 Wh. To augment energy requirements during low-sunlight or night-time conditions, a battery bank was set up using two 12V, 100Ah deep-cycle batteries. These batteries have a total storage capacity of 2,400Wh, and with an 85% usable depth-of-discharge, they offer approximately 2,040Wh of usable energy. Combined, the solar panel and batteries have a capacity to provide up to 4,590Wh per day, which closely approximates the total load requirement of the kiosk.

Component Integration and Electrical Architecture

The electrical system is built around a hybrid inverter with Maximum Power Point Tracking (MPPT) capability and integrated battery management. The inverter converts solar DC energy to AC for powering standard appliances, while a DC-DC converter regulates voltage output for USB ports. A weatherproof enclosure houses the electronics and user interface, with 5 USB ports and 3 AC sockets accessible for community use.

IoT-Based Monitoring System

For real-time monitoring and ease of maintenance, an extensive IoT system, having a daily energy demand of 576 Wh as calculated in the load analysis, was incorporated into the kiosk through an ESP32 microcontroller. The microcontroller is interfaced using sensors for tracking battery voltage, current flow, ambient temperature, and solar irradiance. The measurements are sent to a cloud server via GSM or Wi-Fi modules and represented through a mobile dashboard interface developed on the Blynk platform. Remote diagnostics and notification of abnormal performance are enabled by this arrangement, improving the solar system's reliability.

Result and Analysis

This section presents the results of the GEC Kiosk project, beginning with an analysis of the community's demographic profile to establish the project's necessity. It is followed by a quantitative analysis of the system's performance, comparing its energy supply against the community's demand. Finally, it details the IoT-based monitoring system designed to ensure long-term reliability and proactive maintenance.

Community Profile and Justification for the Project

A demographic survey was conducted in Kampung Orang Asli Tewowoh to quantify the need for a public charging solution. The results, detailed in Table I, confirm a significant and unmet demand for electricity, particularly for charging mobile devices.

Table I

Demographic Profile and Mobile Device Ownership in Kampung Orang Asli Tewowoh, Mersing.

Age (Year old)	Male	Female	Total Person	Number of Mobile Phone Owner	Number of Laptop Owner	Number of Mobile Devices Owner	rcentage Mobile Device Owner (%)
0-12	9	8	17	0	0	0	0
13-40	31	26	57	43	2	45	42.5
41-59	10	15	25	20	2	22	20.8

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue VII July 2025

60+	3	4	7	5	0	5	4.7
Total			**106**	**68**	**4**	**72**	**68**

The analysis reveals that out of a total population of 106 residents, 72 individuals own a mobile device, representing a 68% mobile device ownership rate. The highest concentration of ownership is within the 13-59 age group, where 67 of the 82 individuals (approximately 82%) own at least one device. This high penetration of mobile technology underscores the community's reliance on digital communication and validates the need for the GEC Kiosk as a centralized and reliable charging facility.

System Performance: Energy Supply vs. Demand

First, the system's total daily available power was determined. As detailed in Table II, the system provides a total daily available power of 4,590 Wh by combining solar generation and battery storage.

Table II

System Power Capacity.

Power Source	Specification	Calculation	Daily Available Energy (Wh)
Solar Panels	600W total capacity	600W x 5 hours x 0.85	2,550
Battery Bank	2,400Wh total capacity	2,400Wh x 0.85	2,040
Total Daily Available Power			**4,590**

Next, a comprehensive breakdown of the daily energy demand was calculated, accounting for both user device charging and the kiosk's internal equipment consumption. The corresponding daily energy requirement is calculated to be 4,344 Wh, as shown in Table III.

Table III

Consolidated Daily Energy Demand and Consumption

Load Category	Specific Load Type	Quantity	Calculation	Energy Consumption (Wh)
User Devices	Mobile Phones (USB)	60 devices	18W x 1.5 hr	1,620
	Mobile Phones (AC)	24 devices	18W x 1.5 hr	648
	Laptops (AC)	8 devices	75W x 2.5 hr	1,500
	Subtotal (User Devices)			**3,768**
Kiosk Equipment	IoT Monitoring System	-	See Table 4 for breakdown.	576
Total Daily Power Requirement				**4,344**

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A comparison between the total available energy (4,590 Wh) and the total required energy (4,344 Wh) reveals a daily energy surplus of 246 Wh. This surplus confirms that the system is robustly designed and adequately sized to reliably meet the community's daily charging needs, with sufficient reserve capacity to handle minor variations in sunlight or usage.

System Reliability and Proactive Maintenance

To ensure the long-term functionality and sustainability of the GEC Kiosk, a comprehensive IoT-based monitoring and maintenance strategy was implemented. This strategy is critical for proactively addressing potential issues and maximizing the system's operational uptime (Tatas et al., 2022). The details of this strategy are outlined in Table IV.

Table IV

IoT Monitoring and Maintenance Strategy.

Component	Function	Monitored Parameter	Potential Issues Indicated	Maintenance Plan
ESP32 Microcontroller	Central processing unit; collects and transmits data.	-	-	Remote diagnostics via dashboard.
Temperature Sensor	Monitors kiosk temperature to prevent overheating.	Temperature	Overheating	Trigger alert for increased ventilation.
Voltage Sensor	Measures voltage of solar panels and batteries.	Voltage Levels	Over/ undercharging, faulty connections	Trigger alert for voltage drops or spikes.
Current Sensor	Tracks current flow to detect overcurrent.	Current Flow	Short circuits, overload conditions	Trigger alert for abnormal current.
Light Intensity Sensor	Measures sunlight for optimizing performance.	Sunlight Intensity	Low solar efficiency	Trigger alert for panel cleaning/ repositioning.

The strategy detailed in Table IV utilizes a network of sensors connected to an ESP32 microcontroller to monitor key parameters in real-time. This system is capable of remote diagnostics and is set to generate automated alerts for any potential problems, allowing for proactive maintenance to reduce downtime and increase the overall reliability of the charging station for the community.

Broader Implications and Discussion

The successful implementation of the GEC Kiosk offers several broader implications that align with the project's foundational goals of fostering sustainable and community-centric development.

Cost-Benefit and Long-Term Sustainability

The project was executed with an initial investment of $8,820, which encompassed the physical infrastructure,

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installation, and crucial elements of community integration. The primary economic benefit for the community is the significant reduction in reliance on expensive and environmentally harmful diesel generators. This direct cost saving translates to tangible savings for residents, freeing up resources that can be directed towards other essential needs such as education, healthcare, and local business development.

Beyond the immediate financial benefits, the project's design is centered on a robust, long-term sustainability plan. This plan is conceptualized as a continuous, self-reinforcing cycle, as illustrated in Fig. 1, which ensures the kiosk operates at peak efficiency while fostering a sense of community ownership.

The cycle begins with the establishment of a routine maintenance schedule. This is followed by community training programs designed to empower residents with the necessary skills to perform basic upkeep, such as cleaning solar panels and monitoring battery levels. This localized expertise reduces the community's dependence on external technicians.

The subsequent stages are driven by the integrated IoT system, which provides system output monitoring, monitoring of key data such as energy output and battery state. Thereafter, based on this data, ongoing optimization of energy consumption based on feedback from the real world can be achieved. This integrated approach produces a GEC Kiosk that is more than an installation but a dynamic sustainable community asset, designed to optimize its life span and return.

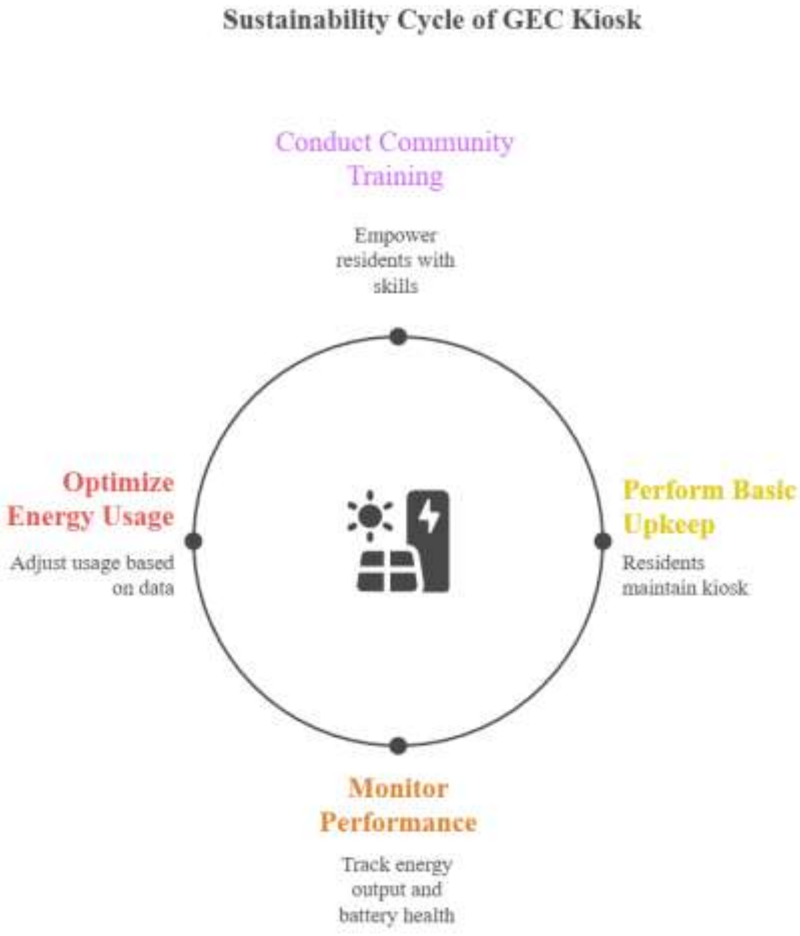

Fig. 1 The four-stage sustainability cycle for the GEC Kiosk, which integrates community training and basic upkeep with technical performance monitoring and optimization.

Socio-Cultural Context and Scalability

A core principle of this project was active community engagement from the initial planning stages. This approach ensures the project is not merely a technical installation but a valued community asset, which is critical for the long-term adoption of the technology(Anthony, 2024). The engagement strategy for this project

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was therefore designed as a continuous, five-stage cycle, as illustrated in Figure 2. This model fosters local ownership and ensures the long-term adoption of technology.

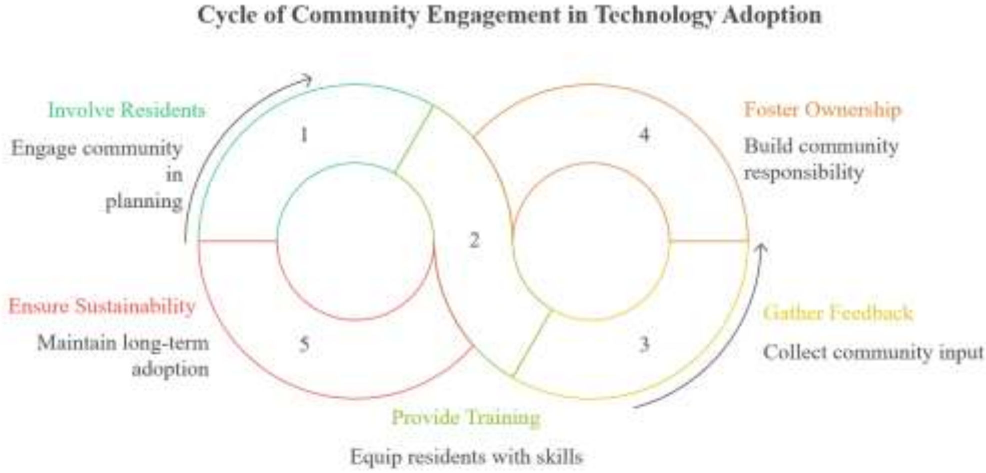

Fig. 2: The cyclical model of community engagement, outlining the five key stages from initial involvement to long-term sustainability.

The cycle starts by engaging the residents at the level of planning so that the project goals are aligned with the community goals. This is followed by facilitating training, which assists the residents with the initial usage skills and maintenance Stefanon et al., 2023). An active feedback loop is established by actively seeking feedback from the residents such that appropriate adjustments can be made. These stages are designed to create a sense of responsibility, such that the residents internalize the perception of having an ownership stake. Maintaining this, the last stage of the cycle, closes the loop through long-term use of the project, which enforces the central role of the community for the long-term success of the project.

This cyclical approach, which emphasizes capacity-building and shared responsibility, creates a successful and highly replicable model of community-integrated development. It can be scaled to other remote Indigenous communities facing similar energy challenges, providing a viable strategy for bridging the global energy gap through decentralized solutions.

The success of this initiative also underscores the importance of a socio-culturally considerate approach. The project aligns with the protective role of the Department of Orang Asli Development (JAKOA), aiming to empower the community while respecting its needs and aspirations. Future work could build on this by exploring the cultural and behavioral aspects of technology adoption more deeply to ensure the kiosk remains a valued and integrated community asset.

Policy Implications

The GEC Kiosk serves as a practical blueprint for achieving both national and international policy objectives. It directly supports Malaysia's Jalinan Digital Negara (JENDELA) plan by providing the energy infrastructure necessary for digital inclusion. Furthermore, the project embodies the principles of the UN's Sustainable Development Goal 7 (SDG 7), demonstrating a viable pathway to providing affordable, reliable, and clean energy for underserved populations (Madurai Elavarasan et al., 2023).

The project's alignment with Malaysia's JENDELA plan highlights its contribution to national development goals (Suruhanjaya Komunikasi Dan Multimedia Malaysia Malaysian Communications and Multimedia Commission 2 Nd Quarterly Report, 2021). By providing reliable and affordable energy access, the GEC Kiosk enables digital inclusion, empowering residents to participate in the digital economy and access online education, healthcare, and government services. This contributes to bridging the digital divide and promoting equitable access to opportunities for all Malaysians.

The project's embodiment of the UN's SDG 7 demonstrates its contribution to global sustainable development goals. By providing affordable, reliable, and clean energy, the GEC Kiosk addresses a fundamental need for underserved populations, improving their quality of life and promoting economic development. The project's focus on community engagement and long-term sustainability aligns with the broader principles of sustainable development, ensuring that the benefits of energy access are sustained over time (Machado et al., 2022).

Finally, GEC Kiosk serves as a model for other countries seeking to achieve SDG 7 and promote sustainable development in remote and underserved communities. By demonstrating the viability of community-integrated renewable energy solutions, the project can inspire and inform policy decisions, leading to the widespread adoption of sustainable energy practices and the achievement of global sustainable development goals.

CONCLUSION

This study has successfully demonstrated the viability of the design, solar sizing, and deployment of a Green EcoCharge (GEC) Kiosk as a customized renewable energy setup for Kampung Orang Asli Tewowoh, an isolated Orang Asli settlement in Mersing, Malaysia. In addressing the problems of limited electricity access, digital connectivity, and community resilience, the project provides a replicable and sustainable model of off-grid electrification using solar photovoltaic systems with IoT-based monitoring.

Systematic design, from overall energy demand calculations to system planning, revealed that a 600W solar PV system supplemented by a twin 12V 100Ah battery bank could provide maximum charging loads of 60 mobile phones' and 8 laptops' day usage, with a small buffer for the installation of IoT monitoring devices. 5 USB socket provision, with 3 AC sockets, was a decent setup for device provision and shared usage. Real-time monitoring via ESP32-based microcontrollers and sensors—included through the Blynk platform—made fault detection, system monitoring, and offsite diagnosis possible, thus maximizing long-term reliability and planning for maintenance.

In addition to technical validation, the GEC Kiosk provides considerable socio-economic and environmental benefits. It provides Indigenous residents with access to communications, education, digital services, and economic participation, while reducing the use of costly, polluting diesel generators. Furthermore, demographic data indicates that approximately 68% of community members own mobile devices underscores the direct relevance of and pressing need for this charging solution. Furthermore, the kiosk's alignment with the Sustainable Development Goal 7 (Affordable and Clean Energy) enhances its broader developmental implications for energy equity among marginalized communities.

ACKNOWLEDGEMENT

The authors appreciate funding supplied via the IEEE Humanitarian Technologies Board (HTB) (Grant Number: 24-T4G1-132). The authors also wish to acknowledge the invaluable guidance and support provided by the IEEE Malaysia Section, particularly the 2024 Humanitarian Activities and Climate Change (HACC) committee. Support from Politeknik Mersing, Department of Orang Asli Development (JAKOA) and project team members from Universiti Tun Hussein Onn (UTHM), Universiti Teknologi Malaysia (UTM) and Universiti Teknologi MARA (UiTM) were also vital to the project's success and is greatly appreciated. Finally, the authors thank the community of Kampung Orang Asli Tewowoh, Mersing for their warm collaboration and active participation.

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