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Sppeevm: Development and Validation Technology Package for Solar- Powered Prepaid Electrical Energy Vending Machine for Diffusion

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Abstract

Small businesses, particularly those operating in the informal sector, often face significant challenges in accessing reliable and affordable energy. Mobile vendors, such as street food vendors and market stallholders, are particularly vulnerable to energy insecurity, This study addressed persistent energy insecurity among mobile vendors in informal markets, exemplified by Cebu City's Carbon Night Market, where reliance on conventional, often insufficient, power sources hinders basic needs like lighting, charging, and ventilation. Utilizing the ADDIE model, a Solar-Powered Prepaid Portable Electrical Energy Vending Machine (SPPEEVM) was developed. This innovative system integrates a 200W solar panel, 200Ah LiFePO4 batteries, a 1500W inverter, and a Raspberry Pi/Arduino control system to power up to four vendors simultaneously. Evaluation using the DOST Technology Assessment Protocol (TAP-TEEPS) revealed high technical, economic, environmental, political, and social feasibility. While broadly accepted, especially by younger female vendors, older participants and vendors showed slightly lower conformity ratings. The findings underscore the critical need for alternative energy solutions for mobile vendors, demonstrating the SPPEEVM as a viable, sustainable, and capable option, providing continuous power for 5-6 hours.

Keywords: Solar energy, prepaid vending, mobile vendors, energy insecurity, informal markets, sustainable energy, Carbon Night Market, Cebu City.

INTRODUCTION

Background of the Study

Access to reliable and affordable energy is fundamental for economic development and improved quality of life. Globally, there is a growing recognition of the need to transition to sustainable energy sources to mitigate the impacts of climate change and ensure energy security. This is particularly critical in developing countries, where access to electricity remains challenging for many communities, particularly those in informal settlements or rural areas (Hassan et al., 2024). In the Philippines, the government has committed to increasing the share of renewable energy in the country's energy mix, focusing on promoting solar, wind, and hydro power (Maguire & Maguire, 2023). This policy direction reflects the growing awareness

of the environmental and economic benefits of renewable energy and the need to reduce reliance on imported fossil fuels.

Small businesses, particularly those operating in the informal sector, often face significant challenges in accessing reliable and affordable energy. Mobile vendors, such as street food vendors and market stallholders, are particularly vulnerable to energy insecurity, as they often rely on expensive and polluting diesel generators or have limited access to grid electricity (Peimani & Kamalipour, 2022; Solidum, 2023). This can hinder their productivity, limit operating hours, and increase operating costs, impacting their livelihoods and economic opportunities (Madichie et al., 2021). Therefore, there is a need for innovative and sustainable energy solutions that can address the specific needs and challenges of mobile vendors in informal markets.

Solar energy offers a promising solution for powering mobile businesses due to its clean, renewable nature and decreasing costs. Advancements in solar photovoltaic (PV) technology have increased solar panels' efficiency and affordability, making them a viable option for small-scale applications (Maka & Alabid, 2022; Schmela et al., 2023; Victoria et al., 2021). Furthermore, the modularity and portability of solar energy systems make them well-suited for mobile vendors, who often operate in dynamic and space-constrained environments. However, the initial cost of solar energy systems can still be a barrier for some vendors, and the intermittent nature of solar energy requires efficient energy storage solutions to ensure a reliable power supply.

To address these challenges, this study proposes developing and implementing a Solar-Powered Prepaid Portable Electrical Energy Vending Machine (SPPEEVM) for mobile vendors in the Carbon Night Market in Cebu City. This innovative technology combines solar energy generation with a prepaid energy vending system, allowing vendors to purchase energy credits in advance and access a reliable and affordable source of electricity. The SPPEEVM aims to address the energy needs of mobile vendors, reduce their reliance on fossil fuels, and promote environmental sustainability in the Carbon Night Market in Cebu City.

This study will rigorously investigate the design, development, and implementation of the SPPEEVM, examining its technical feasibility, economic viability, and potential for widespread adoption to address the energy challenges faced by mobile vendors in the Carbon Night Market in Cebu City. This research aims to contribute to the advancement of sustainable energy solutions and promote economic development in informal market settings.

Review of Related Literature

Renewable Energy Solutions for Mobile Vendors

The increasing global demand for sustainable energy solutions has fueled extensive research into renewable energy sources for mobile vendors, particularly in regions with unreliable electricity access (Njema et al., 2024). A confluence of factors drives this, including growing awareness of climate change, the need to reduce greenhouse gas emissions, and the desire to improve energy access and affordability for marginalized communities. Solar-powered systems have emerged as a promising alternative for powering mobile businesses, such as food carts, market stalls, and mobile shops, offering both environmental and economic benefits (Victoria et al., 2021). Obaideen et al. (2021) emphasize the growing importance of sustainable energy solutions like solar power in achieving energy independence and reducing reliance on fossil fuels, particularly in developing countries where access to reliable electricity can be a significant barrier to economic growth. Their study highlights the potential of solar energy to provide clean and affordable power to off-grid communities, supporting economic development and improving quality of life.

However, integrating solar energy into mobile vending operations presents unique challenges. The initial cost of solar panel installations can be a significant hurdle for small businesses with limited capital (Hassan et al., 2023). This financial barrier can hinder the adoption of solar energy, especially for micro-entrepreneurs operating in informal markets with limited access to credit or financing options. Moreover, the intermittent nature of solar energy, dependent on sunlight availability, necessitates efficient energy storage solutions to ensure a consistent power supply for vendors, especially during peak operating hours or periods of inclement weather (C. Wu et al., 2022). This underscores the need for robust and reliable battery technology to store excess solar energy generated during the day for use during the night or when sunlight is limited.

Research has consistently demonstrated that adopting solar energy can lead to significant cost savings for mobile vendors. A study by Wen et al. (2021) found that solar-powered food carts in China experienced a 40% reduction in energy costs compared to traditional grid electricity or diesel generators. These savings can be attributed to the reduced reliance on expensive and polluting fossil fuels and the lower maintenance requirements of solar energy systems compared to conventional generators. Moreover, using solar energy can enhance the reliability of power supply, particularly in areas with frequent power outages, allowing vendors to operate for longer hours, attract more customers, and increase their income (Ukoba et al., 2024). In addition to economic benefits, solar energy offers significant environmental advantages by reducing greenhouse gas emissions and mitigating the negative impacts of climate change, aligning with global efforts to transition to a more sustainable energy future (Rabaia et al., 2021).

Prepaid energy models have gained traction as a means of promoting responsible energy consumption and providing flexibility for users, particularly in contexts where access to credit or formal banking services is limited (Hussain et al., 2023). Prepaid systems empower users to manage their energy usage and expenditures effectively by enabling them to purchase energy credits in advance. This offers greater control over energy costs and prevents unexpected expenses, benefiting low-income households and small businesses operating with tight budgets. A study in Ghana found that prepaid electricity meters led to a significant reduction in electricity consumption (averaging 14%) and improved bill payment rates among households, indicating a positive impact on energy conservation and revenue collection for utility companies (Keku et al., 2023). Furthermore, prepaid energy models encourage conservation and reduce energy waste, as users are more conscious of their consumption patterns when paying for energy upfront (Huseynli, 2024). This is particularly relevant for mobile vendors who often operate with limited resources and tight profit margins, making efficient energy management crucial for their business sustainability.

Several case studies have documented the successful implementation of renewable energy solutions for mobile vendors in various contexts, providing valuable insights for this research. A project in Bangladesh provided solar-powered lighting and refrigeration to street vendors, resulting in improved food safety, extended working hours, and increased income (Ahmed et al., 2024). The study found that solar-powered systems reduced energy costs and enhanced the quality of life for vendors by providing a more comfortable and safe working environment, free from the noise and fumes of diesel generators. Similarly, a project in Kenya demonstrated the positive impact of solar-powered food carts on the livelihoods of women entrepreneurs, enabling them to increase their income and improve their social status within their communities (Chebii & Ogada, 2022). These case studies underscore the potential of renewable energy to enhance the livelihoods of mobile vendors, promote economic empowerment, and contribute to sustainable development goals.

Technical Aspects of SPPEEVM

Developing an effective SPPEEVM requires careful consideration of various technical aspects, drawing upon the latest advancements in renewable energy technology and automation. Advancements in solar photovoltaic (PV) technology have led to increased efficiency and reduced costs of solar panels, making them a more viable option for powering mobile businesses (Nagaraja et al., 2025). The efficiency of solar cells, which convert sunlight into electricity, has steadily improved, leading to higher energy output and reduced space requirements for solar panels. Moreover, manufacturing processes have become more efficient, lowering costs and making solar energy more accessible to a broader range of users. However, the lifespan depending on kind, solar panels endure 25–30 years, inverters range from 10–25 years, and batteries between 3–15 years depending on chemistry in a PV solar electrical system. Charge controllers usually last 10 to 20 years, while high-quality wire and mounting structures can last 25 to 30 years. While monitoring systems may require upgrades or replacements within 5 to 15 years, circuit breakers and other protective devices have a lifespan of 15 to 25 years. Proper installation and routine maintenance greatly extend these components' lifespan and maintenance requirements of PV panels remain important considerations for ensuring the long-term sustainability and cost-effectiveness of the SPPEEVM. Research has shown that the performance of solar panels can degrade over time due to factors such as dust accumulation, UV exposure, and temperature fluctuations (Aghaei et al., 2022). Therefore, incorporating durable materials, such as high-quality solar cells and protective coatings, and implementing regular maintenance procedures, including cleaning and inspections, will ensure the longevity and efficiency of the SPPEEVM's solar panels.

Selecting appropriate energy storage systems is essential for ensuring a continuous power supply for the SPPEEVM, especially during periods of low sunlight or peak demand. Lithium-ion batteries have emerged as a popular choice for renewable energy applications due to their high energy density, relatively long lifespan, and decreasing costs (Khan et al., 2023). Their compact size and lightweight nature make them well-suited for mobile applications. In contrast, their ability to store significant energy relative to their size ensures that the SPPEEVM can power vending operations reliably. However, battery disposal's safety and environmental impact must be carefully managed to minimize potential risks. A comprehensive overview of lithium-ion battery technology highlights its advantages, limitations, and safety considerations (Comanescu, 2025). Further investigation is needed to identify the most suitable battery technology for the SPPEEVM, considering capacity, cycle life, safety, and environmental impact. This may involve exploring alternative battery chemistries, such as lithium iron phosphate (LFP) batteries, which offer improved safety and longer lifespans than traditional lithium-ion batteries, albeit at a potentially higher cost. Microcontrollers play a critical role in managing the energy flow, automation, and prepaid vending functionalities of the SPPEEVM. They act as the system's " brain, " monitoring energy generation and consumption, controlling the charging and discharging of batteries, and facilitating secure and efficient prepaid energy vending transactions. While Arduino is a widely used and accessible platform for prototyping and educational purposes, its limitations in terms of processing power, memory capacity, and security features may make it less suitable for a commercial application like the SPPEEVM. Exploring alternative microcontrollers may provide opportunities for enhanced functionality, improved efficiency, or cost-effectiveness in a commercial setting. A comparative study evaluated the performance of different microcontrollers for embedded systems applications, considering factors such as processing speed, power consumption, and cost (Malik et al., 2024; H. Wu et al., 2021). The selection of the microcontroller for the SPPEEVM should be based on a thorough analysis of its capabilities and suitability for managing energy

storage, distribution, prepaid vending functionalities, and compatibility with other system components. Smart metering and e-payment systems are integral to the SPPEEVM, enabling prepaid energy vending and accurate energy consumption monitoring. These systems allow vendors to purchase energy credits in advance and track their energy usage in real time, promoting responsible consumption and efficient energy management. Research on e-payment systems adoption has shown that security, trust, and ease of use are critical factors for user acceptance (Raon et al., 2021). These findings are relevant to the design and implementation of the SPPEEVM's payment system, which must ensure secure transactions, protect user data, and provide a user-friendly interface for mobile vendors with varying levels of technological literacy. A comprehensive overview of digital payment systems, including their security challenges, regulatory frameworks, and emerging technologies such as mobile wallets and blockchain-based payment platforms, provides valuable insights for designing a secure and user-friendly payment system for the SPPEEVM (Putrevu & Mertzanis, 2023). Incorporating these technologies into the SPPEEVM could enhance its security, convenience, and accessibility for mobile vendors.

Synthesis and Gaps in Literature

The literature reviewed highlights the growing interest in renewable energy solutions for mobile vendors and the potential of solar-powered systems to address energy challenges in informal markets, particularly in developing countries with limited access to reliable electricity. Prepaid energy models offer a promising approach to promoting responsible energy consumption, empowering users to manage their energy costs, and improving the financial sustainability of mobile businesses. However, there is a need for further research on the specific application of SPPEEVMs in the context of the Carbon Night Market in Cebu City, considering this informal market's unique socio-economic and environmental characteristics.

This study aimed to address the identified gap by developing and validating a technology package for an SPPEEVM specifically tailored to meet the needs of mobile vendors in the Carbon Night Market in Cebu City. This will involved considering their specific energy requirements and unique business practices and ensuring compatibility with their existing technological capabilities. The research will then rigorously evaluate the technical feasibility, economic viability, and user acceptance of the SPPEEVM. This evaluation will involve thorough testing of the technology, comprehensive data analysis, and gathering feedback from the vendors to assess their satisfaction and identify any areas for improvement. Finally, the study will analyze the potential for widespread diffusion of the SPPEEVM and its broader impact on energy sustainability and economic development in the Carbon Night Market in Cebu City and beyond. This analysis will explore the factors that may influence the adoption and scalability of the SPPEEVM and its potential to contribute to a more sustainable energy future and improved livelihoods for mobile vendors in informal markets.

Statement of the Problem

This study aimed to develop and implement a Solar-Powered Prepaid Portable Electrical Energy Vending Machine (SPPEEVM) anchored on the concept of the ADDIE model and evaluate its viability using the DOST Technology Assessment Protocol (TAP-TEEPS). Specifically, it sought to answer the following questions:

1. What is the current energy profile of mobile vendors in the Carbon Night Market in Cebu City, including their:

- average daily energy consumption (in kilowatt-hours),

- the type of electrical energy source, and
- average monthly energy costs.

2. What are the optimal technical specifications and design elements for the SPPEEVM?
3. How is the SPPEEVM technically evaluated in conformity with the Technology Assessment Protocol (TAP) of the DOST using TEEPS in terms of:

- technical feasibility
- economic and financial viability
- environmental soundness
- political acceptability, and
- social acceptability?

Significance of the Study

The findings of this study are perceived to provide information and recommendations to anyone who would make this study as their reference specifically; this would help with the following: Mobile vendor enterprises, such as food trucks, market stalls, and mobile shops, operate in dynamic environments where a reliable and portable power supply is essential, event organizers, including companies and individuals hosting outdoor festivals, concerts, and markets, require temporary power solutions to support various vendors and activities, electrical energy consumers is increasingly interested in supporting sustainable practices through their purchasing decisions or by choosing vendors that demonstrate a commitment to sustainability. The SPPEEVM aligns perfectly with the values of sustainability-conscious consumers by offering a renewable energy source that reduces reliance on fossil fuels, local governments and non-governmental organizations (NGOs) are crucial in promoting sustainable energy solutions within their communities. These organizations often seek innovative ways to support regional economic development while addressing environmental concerns. The SPPEEVM can serve as a model for initiatives to enhance energy access for small businesses and promote renewable energy usage. By collaborating with local governments or NGOs, the implementation of the SPPEEVM can lead to broader community engagement, educational programs on sustainable practices, and the establishment of supportive policies that encourage the adoption of clean energy technologies. This partnership can significantly enhance the SPPEEVM's impact, driving economic and environmental benefits for the community, and future researcher, the study's results may be a reference for researchers conducting further research in this field.

Scope and Limitations

For a comprehensive understanding of the study, the following parameters were considered. The research focused on the development and evaluation of the Solar-Powered Prepaid Portable Electrical Energy Vending Machine (SPPEEVM), specifically designed for mobile vendors at the Carbon Night Market in Cebu City, Philippines. This location was chosen due to the absence of an existing electrical energy vending machine in the area and the study was conducted during the second semester of the 2024-2025 academic year. While the study assessed the potential impact of the SPPEEVM, several limitations were acknowledged. It was confined to the Carbon Night Market, limiting the generalizability of the findings to other settings. Resource constraints restricted the sample size of mobile vendors, potentially affecting the robustness of the results. Since the device was a prototype, its long-term performance remained uncertain. Additionally, external factors such as climate and economic conditions may have influenced the outcomes.

METHODOLOGY

Research Design

This study employed a developmental research design guided by the ADDIE (Analysis, Design, Development, Implementation, Evaluation) model to systematically develop, implement, and evaluate the Solar-Powered Prepaid Portable Electrical Energy Vending Machine. This model provided a structured framework for creating effective solutions and, in this case, guided the development of a technology to address the energy needs of mobile vendors in the Carbon Night Market in Cebu City. The research was conducted in Carbon Night Market in Cebu City, a bustling marketplace characterized by a high density of vendors with limited access to reliable and affordable electricity.

Research Environment

The study was conducted in Carbon Night Market in Cebu City. This bustling marketplace was a vital hub of commercial activity, hosting a diverse range of vendors selling various goods, including fresh produce, seafood, meat, dry goods, and prepared food. The market was characterized by a high density of vendors operating in close proximity, often with limited access to electricity and relying on a mix of energy sources, including grid electricity, diesel generators, and batteries. This presented challenges and opportunities for implementing sustainable energy solutions like the SPPEEVM.

The Carbon Night Market in Cebu City was a dynamic environment with a unique socio-economic and cultural context. The majority of vendors were micro-entrepreneurs operating small-scale businesses with limited resources. Many relied on traditional practices and technologies, and their awareness and understanding of renewable energy technologies varied. Therefore, it was crucial to consider the social and cultural factors that might have influenced the adoption and acceptance of the device. By conducting the study in the Carbon Night Market in Cebu City, the research aimed to develop and implement a solution tailored to the specific needs and challenges of this informal market setting. The findings provided valuable insights for promoting sustainable energy solutions in similar contexts and contributed to the broader goal of achieving energy access and sustainability in urban areas.

Research Respondents

The research involved a total of 45 participants strategically chosen to represent both the commercial and academic sectors interacting with or influenced by technology. Students constituted the largest portion with 20 individuals (44.4%), representing the emerging generation of technology users and innovators, especially within educational settings. Mobile vendors formed the second-largest group, with 15 respondents (33.3%), offering valuable insights from small-scale entrepreneurs in Cebu City's Carbon Market, particularly on how digital tools influence informal commerce. Lastly, BSEE faculty members comprised 10 participants (22.2%), bringing their professional expertise in Information Technology to add depth regarding technical knowledge and the practical challenges of integrating engineering in both educational and commercial domains. This combination of three distinct groups allowed for a balanced and multifaceted exploration of the research topic, with each offering unique yet interconnected perspectives.

Research Instrument

This study utilized a developmental approach, and during the evaluation phase of the system, a survey was conducted. The survey was answered and completed by key stakeholders and assessed the perceived ease of use, and perceived usefulness of the system. The questionnaire included an informed consent statement, which informed the respondents of the survey's purpose. The researcher prepared a two-part questionnaire to obtain the necessary data. The first part of the questionnaire gathered the demographic profile of the

respondents. This section included information such as the respondent type, age, gender, and highest educational attainment. The second part of the questionnaire evaluated the system. To ensure the validity and dependability of the survey questionnaire, a pilot testing procedure was performed before data collection. This procedure consisted of a trial test of the survey questionnaire with a small sample of twenty participants who were not included in the final study.

Ethics and Data Gathering Procedure

Data for the SPPEEVM (Solar-Powered Portable Energy-Efficient Vending Machine) evaluation in Cebu City's Carbon Market was collected through a meticulous, phased approach, ensuring a comprehensive assessment of its technical, economic, environmental, and social impacts in alignment with the TAP-TEEPS protocol. The initial phase involved establishing a baseline understanding of the current energy landscape through structured questionnaires administered to mobile vendors and observations of the market environment. Subsequently, SPPEEVM prototypes were deployed at selected vendor stalls, with smart meters continuously recording energy consumption and usage patterns. Researchers meticulously tracked initial investment, maintenance, and operational costs. The final phase focused on evaluating the SPPEEVM's impact on vendors, their businesses, and the environment through follow-up surveys, interviews, and data collection on revenue generation, electricity generation, and battery usage. Ethical considerations like informed consent, data privacy, and confidentiality were prioritized throughout the process. All collected data was securely stored and systematically analyzed to generate meaningful findings for sustainable energy solutions in informal markets.

RESULTS AND DISCUSSION

This study aimed to develop and implement a Solar-Powered Prepaid Portable Electrical Energy Vending Machine (SPPEEVM) using the ADDIE model as a framework and to evaluate its viability through the Department of Science and Technology's Technology Assessment Protocol (TAP-TEEPS). Specifically, the study sought to understand the current energy profile of mobile vendors in the Carbon Market, Cebu City, including their average daily energy consumption, reliance on different energy sources, monthly energy costs, experiences with power outages, energy-related challenges, and preferences for an ideal energy solution. It also aimed to determine the optimal technical specifications and design elements of the SPPEEVM, such as solar panel and battery capacities, microcontroller functionalities, and features that enhance user-friendliness and safety. Moreover, the study examined the profile of the participants in terms of type, age, and sex, and evaluated the SPPEEVM's conformity to DOST's TAP-TEEPS in the areas of technical feasibility, economic viability, environmental soundness, political acceptability, and social acceptability.

Data were collected through a questionnaire adapted from the DOST Technology Assessment Protocol and administered to a total of 45 participants, consisting of faculty members (22.2%), students (44.4%), and vendors (33.3%). The analysis employed several statistical tools: frequency counts and percentages were used to describe the participant profiles, while mean and standard deviation were applied to evaluate the SPPEEVM's conformity to the TAP-TEEPS framework.

Findings. This study found that: Mobile vendors predominantly rely on batteries (55%) and grid electricity (35%), with most (55%) spending less than ₱500 monthly on power. Their primary energy demands are for universal LED lighting (12 hours/day), followed by cellphone charging (7 hours/day), and clip fans (6 hours/day), This solar-powered vending system requires: a 200 W solar panel with charge controller for power; a 2 battery with 100 AH rating each for storage; an 12V to 220V, 1500 W inverter; a buck converter

12V to 5V for voltage regulation; a Raspberry PI for control (coin input, LCD, relay, current and voltage sensor); a 10A, 220V AC relay module for load switching; an LCD for user feedback; and an ACS712 current sensor for energy monitoring that could supply at least 4 vendors andThe SPPEEVM has technical feasibility, economic viability, environmental soundness, political acceptability, and social acceptability to a great extent.

CONCLUSION

Based on the findings of the study, it can be concluded that the mobile vendors in Carbon Market need alternative electrical supply, the developed SPPEEVM was capable to supply at maximum of 1500W of electrical power and can accommodate 4 vendors simultaneously with an average electrical power consumption of 70W – 100 W each vendor in about 5-6 hours continuously using the system, the overall high evaluation of the SPPEEVM across technical, economic, environmental, political, and social dimensions confirms its strong potential as a sustainable and acceptable energy solution for mobile vendors.

RECOMMENDATIONS

Based on the findings, mobile retail enterprises such as food trucks, market stalls, and mobile shops are encouraged to adopt and invest in SPPEEVM units as part of their business operations. The SPPEEVM provides a reliable, cost-effective, and sustainable power solution that addresses common challenges like inconsistent electricity and high operational costs. Given the predominance of young female entrepreneurs among the respondents, it is also recommended that training and support be tailored to empower these women, recognizing them as key stakeholders. The SPPEEVM allows businesses to operate longer hours and deliver better service, supporting their potential for expansion and greater profitability, Event organizers hosting outdoor markets, concerts, and festivals should consider integrating the SPPEEVM into their event infrastructure to provide a clean, efficient, and portable energy solution for vendors. Utilizing this technology not only ensures a stable power source but also significantly reduces the carbon footprint of events. By employing a prepaid system, organizers can also better manage energy distribution and control costs. Promoting the use of solar-powered energy during events enhances their appeal to eco-conscious attendees and contributes to a more sustainable public image, Consumers and organizations that prioritize environmentally responsible practices are encouraged to support vendors using SPPEEVMs. Their purchasing decisions can promote a culture of sustainability by rewarding businesses that invest in renewable energy. These consumers may also advocate within their communities and networks for wider adoption of clean energy practices, helping raise awareness and generate demand for sustainable market solutions. Supporting such initiatives not only fosters environmental protection but also encourages small-scale vendors to take meaningful steps toward sustainability, local governments and non-governmental organizations play a critical role in supporting the implementation of renewable energy solutions like the SPPEEVM. It is recommended that they develop incentive programs such as subsidies, training, and microfinancing opportunities to encourage adoption among small vendors. Given the study's finding that older participants were more hesitant about the technology, awareness campaigns and capacity-building programs should be designed to bridge this gap and foster inclusive participation. Moreover, the SPPEEVM can serve as a model for broader policy efforts promoting energy access, environmental sustainability, and women-led entrepreneurship, future researchers are encouraged to build on this study by examining the long-term impact of SPPEEVM adoption on vendor productivity, cost savings, and environmental outcomes. Additionally, researchers may replicate this study in other informal urban markets

to validate and expand the applicability of the findings. Given the important role of young women identified in this study, gender-focused inquiries can offer deeper insights into the intersection of energy access, empowerment, and sustainable development.

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