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EXAMINING THE RELATIONSHIP BETWEEN THE PERCEIVED COST-EFFECTIVENESS OF THE PLUG-AND-PLAY MODULAR SOLAR SYSTEM AND THE WILLINGNESS OF MANILA HOUSEHOLDS TO ADOPT SUSTAINABLE RENEWABLE ENERGY

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ABSTRACT

The increasing reliance on conventional electricity sources in urban areas, together with rising energy costs and environmental concerns, highlights the need for sustainable renewable energy (RE) alternatives. Solar energy has emerged as a viable solution aligned with the United Nations' Sustainable Development Goals (SDG 7: Affordable and Clean Energy, and SDG 13: Climate Action). This research, conducted from August to April 2026, examined the relationship between the perceived cost-effectiveness (CE) of the Plug-and-Play Modular Solar System and Manila households' willingness to adopt (WTA) sustainable RE. Using a descriptive-correlational, cross-sectional design, 150 households across Manila's six legislative districts participated in small household-scale simulations of the system's features. Respondents' perceptions regarding CE—through affordability, scalability, maintenance, and usability—and WTA RE systems—through expenditures, coverage, feasibility, and accessibility—were collected through structured questionnaires and analyzed using descriptive statistics and Pearson's correlation coefficient. Findings showed that most respondents perceived the system as highly cost-effective (overall $\bar{x}$ = 3.30) and expressed strong willingness to adopt it (overall $\bar{x}$ = 3.37), with subfactor mean scores ranging from $\bar{x}$ = 3.28 to 3.39 (interpreted as "Strongly Agree") and a statistically significant correlation ($r = 0.912$, $p < .001$). These findings suggest that affordable, scalable, low-maintenance, and user-friendly technologies can encourage urban households to adopt RE innovations. The results may help households make informed decisions regarding RE technologies while providing policymakers, industry stakeholders, and sustainability advocates with insights for promoting sustainable RE solutions.

Keywords: *Renewable Energy, Solar Energy, Perceived Cost-Effectiveness, Sustainable Energy Adoption*

INTRODUCTION

Electricity has become an essential part of modern life, powering household appliances, communication devices, and other daily necessities. It serves as the foundation of modern living, supporting industries, education, healthcare, and transportation. Guevara (2025) wrote in her article that in the City of Manila, one of the most densely populated regions in the Philippines, electricity plays a vital role in sustaining urban life and enabling continuous development. Whether in households, institutions, or industries, the stability of electricity supply remains essential to maintaining daily functions and productivity. This constant reliance on electricity underscores its vital role in sustaining the progress of modern society and enhancing the quality of life.

However, the increasing dependence on electricity also highlights the challenges of relying on conventional energy sources such as fossil fuels. These sources, while effective in meeting high energy demands, come with significant financial and environmental drawbacks. The continued use of non-renewable energy contributes to rising electricity prices, making household expenses more difficult to manage, especially for urban families. Moreover, their environmental impact—such as greenhouse gas emissions and air pollution—disrupts environmental balance and endangers the overall quality of human life (Citicore Renewable Energy Corporation, 2025). As these issues intensify, the need to explore more sustainable and affordable energy alternatives becomes increasingly urgent.

The Philippine Board of Investments (2025) discussed how renewable energy (RE) presents a practical solution to these challenges by reducing both financial and environmental burdens. Technologies such as solar and wind energy provide cleaner alternatives that can significantly reduce greenhouse gas emissions, air pollution, and other harmful effects on the environment. In urban areas like Manila, where electricity demand continues to rise, the adoption of sustainable RE has become essential to balancing household consumption with environmental sustainability. Among these options, solar energy stands out for its ability to address both economic and ecological concerns, enabling communities to manage resources responsibly while ensuring long-term energy stability. Through the integration of cleaner energy systems, urban households can meet increasing energy demands while contributing to a more sustainable future.

RE has become a global priority as nations seek to reduce reliance on fossil fuels and mitigate negative environmental impacts. According to Abeni (2025), countries such as China, the United States, and Japan have made significant progress in implementing solar energy, reflecting a worldwide shift toward sustainable and clean energy solutions. International policies also emphasize the integration of RE into urban planning and infrastructure to promote environmental sustainability (United Nations Educational,

Scientific and Cultural Organization [UNESCO] et al., 2025). These developments underscore that RE adoption is not merely a technical concern but a pressing global environmental priority, offering valuable insights for evaluating practical energy solutions in countries like the Philippines, which relied heavily on fossil fuels for 79% of total electricity in 2024 (Ember, 2025).

In Koons's (2024) article, he discussed the Philippines' initial efforts towards RE transition; however, 77% of the country's energy comes from fossil fuels, with only the remaining 23% as RE—distributed across hydropower, geothermal, wind, and solar. Despite the growing availability of sustainable RE sources that can hasten the transition towards green energy usage nationwide, many households in urban areas, such as Manila, continue to rely on traditional electricity sources. In Palanca-Tan's (2024) study, about 82% of the respondents (urban households in the City of Manila and several provinces in Luzon) expressed their interest in adopting rooftop solar power sources, but only 20% had definite intentions to adopt. Although solar energy is becoming more widespread and recognized as a clean and renewable alternative, its adoption remains limited due to high upfront costs, complex installation processes, and lack of awareness about user-friendly systems (Solaric, 2024). These barriers hinder households from accessing affordable, decentralized energy solutions that could reduce dependence on traditional power grids and promote long-term sustainability. Given the global, national, and household-level importance of sustainable energy, it is evident that practical and affordable solar solutions remain a pressing concern. Addressing existing gaps in RE adoption is essential to promote environmental sustainability and energy efficiency for households in Manila, thereby establishing the need for extensive research on effective and accessible alternatives.

In the Philippine context, solar energy adoption remains limited despite its potential to lower electricity costs and reduce environmental harm. Koons (2024) notes that while solar technologies are gradually being implemented, high installation costs, limited access to financing, and technical challenges have hindered widespread adoption. Moreover, Solaric (2024) further identifies barriers such as insufficient knowledge and infrastructure limitations, preventing many households from fully adopting and benefiting from RE. These challenges are particularly evident at the household level. Palanca-Tan (2024) found that factors such as affordability, ease of use, and perceived reliability significantly influence adoption. Many urban families, especially in Manila, are discouraged from investing in solar technology due to high upfront costs and the technical expertise required. Despite these barriers, its long-term benefits—such as sustainability and energy efficiency—highlight the value of practical solutions tailored to household needs (Solar Energy Industries Association [SEIA], 2024).

Considering the global, national, and household-level importance of sustainable energy, it is evident that developing practical and affordable solar energy options remains urgent. Bridging gaps in RE adoption is essential to promote environmental sustainability and improve energy efficiency for households in Manila, establishing the need for research focused on accessible and effective solar energy alternatives that address both financial and technical barriers to adoption.

The proposed project, the Plug-and-Play Modular Solar System, is designed to provide a cost-effective RE solution for urban households in Manila. This system includes several key features: an affordable entry model for easy financial adoption, a modular design that caters to diverse household needs, a low-maintenance operation to make the system feasible, and a plug-and-play installation that makes it user-friendly for users who have limited technical knowledge. By addressing major barriers to adoption—high upfront costs and complex installation requirements—the system makes the transition to solar energy more feasible for households with varying budgets and technical capabilities. These features of the system's perceived cost-effectiveness (CE) are expected to influence households' willingness to adopt (WTA) RE, highlighting the relationship between the perceived CE and households' WTA of sustainable RE.

This project contributes to the growing body of research on RE adoption by providing insights specific to urban households in the Philippines. It offers practical implications for RE companies, innovators, government agencies, policymakers, and energy providers in designing cost-efficient solar technologies. Ultimately, the Plug-and-Play Modular Solar System demonstrates how user-centered innovations can support both economic sustainability and environmental progress, aiding Manila's transition toward cleaner and more resilient energy systems.

Review of Related Literature

The Review of Related Literature provides an in-depth examination of existing studies, theories, and data relevant to the feasibility, CE, and sustainability of the Plug-and-Play Modular Solar System for households in Manila. This section explores both local and international research addressing sustainable RE adoption, household affordability, and sustainable technological innovations. Specifically, it reviews literature concerning the independent variable, the Plug-and-Play Modular Solar System, focusing on its key subfactors of affordability, scalability, maintenance, and usability, which influence its overall CE. Likewise, it examines the dependent variable, Manila households' WTA of sustainable RE, through the dimensions of expenditures, coverage, feasibility, and adoption. By analyzing the relationship between these variables, this review aims to establish how the system's design and cost-effectiveness may affect residents' willingness to transition to cleaner energy sources. Overall, the Review of Related Literature aims to deepen the understanding of how economic, technical, and behavioral factors shape the relationship between perceived CE and the willingness of Manila households to adopt RE systems.

Diffusion of Innovations Theory (DOI)

The researcher selected a prominent theory that expands the understanding of the adoption of new technologies as well as sustainable practices within households. This theory offers valuable insights into the factors that may influence the decisions of households to adopt and transition towards sustainable RE technology, such as the Plug-and-Play Modular Solar System, particularly in the City of Manila:

The Diffusion of Innovations Theory, developed by Everett Rogers (1962), explains five key factors that influence the rate of adoption of innovations by individuals and how they spread throughout social systems (García-Avilés, 2020):

1. **Relative Advantage —** the degree to which an innovation is perceived as superior to existing ideas and technologies.
2. **Compatibility** — the degree to which an innovation is perceived as consistent and aligned with consumers' needs and knowledge.
3. **Complexity** — the degree to which an innovation is perceived as relatively complex or simple to implement and understand.
4. **Trialability** — the degree to which an innovation is perceived as capable of being tested and evaluated prior to consumer adoption.
5. **Observability** — the degree to which an innovation is perceived as visibly efficient and practical for consumers.

By examining these attributes, the DOI theory can help explain how the perceived CE of the Plug-and-Play Modular Solar System contributes to the willingness of households to adopt sustainable RE. Specifically, the theory can serve as a basis for analyzing the interrelated dimensions between the variables' respective subfactors.

Perceived Cost-Effectiveness of the Plug-and-Play Modular Solar System

The Plug-and-Play Modular Solar System presents a promising yet underexplored approach to affordable and sustainable household energy generation. Majdi et al. (2021) conducted a study on the development of modular solar panels designed to improve durability, repairability, and ease of integration, demonstrating that modular configurations can enhance system longevity and reduce maintenance costs, thereby improving overall cost efficiency. Similarly, innovations in compact solar kits and home battery systems have been found to support affordability through simplified setup and modular functionality, reducing the need for professional installation and lowering upfront costs (EcoFlow, 2025). Despite these technological advancements, few studies have examined the actual CE and adoption potential of plug-and-play solar systems in urban household settings, particularly within the Philippine context, highlighting the need for further research.

Affordability. A key factor influencing the CE of plug-and-play modular solar systems is their affordability, particularly in relation to household income and upfront installation costs. A study by Best & Chareunsy (2022) emphasized that the initial investment required for solar energy systems remains one of the primary barriers to adoption, especially among lower-income households, even as long-term savings on electricity are recognized. In the Philippine context, Bunda et al. (2023) developed a stage model of solar photovoltaic (PV) adoption and found that financial preparedness and perceived affordability play critical roles in shaping adoption decisions. Their findings indicate that many households are aware of the benefits of solar energy but remain hesitant due to high initial expenses and limited access to financing options. According to EcoFlow (2025), the declining price of solar panel kits in the Philippines, now ranging

from ₱30,000 to ₱100,000 depending on capacity, has made small-scale solar systems increasingly attainable for urban households, bridging the gap between affordability and accessibility. Furthermore, a report by MIT News (2025) noted that ongoing technological innovation in solar cell design and manufacturing efficiency continues to reduce costs worldwide. These findings suggest that continuous innovation and financial accessibility are key to enhancing the affordability of plug-and-play modular solar systems, thereby supporting their potential as a cost-effective energy solution for households.

Scalability. Following the discussion on affordability, another crucial factor influencing the CE of plug-and-play modular solar systems is their scalability. Scalability determines how easily a system can be expanded or adjusted to meet changing household energy demands without significant additional costs. Bachanek et al. (2025) emphasized that scalable RE technologies are essential for maintaining grid stability and ensuring that both small and large consumers can adapt to evolving power needs. Similarly, Oliva and Santamaria (2025) emphasized that the long-term adoption of solar technologies in developing countries depends on flexible, durable, and adaptable system designs that can respond to users' changing energy requirements. This scalability aligns with the Plug-and-Play Modular Solar System's purpose, to enable incremental system growth based on financial capacity and energy needs, thereby strengthening its role as a cost-effective and sustainable energy solution.

Maintenance. Ensuring the long-term performance and reliability of plug-and-play modular solar technology requires regular upkeep to address environmental and operational challenges. These systems must be designed so that routine cleaning, inspections, and minor repairs can be performed with minimal technical expertise, making them accessible to ordinary household users (Ogolo et al., 2024). Weather conditions such as high temperatures, humidity, and dust accumulation can significantly reduce energy output and lifespan; therefore, clear maintenance requirements and guidance are essential for households to sustain optimal performance (Richard et al., 2024). Practical resources, such as Solaric's maintenance guidelines, provide accessible support and step-by-step instructions for cleaning, troubleshooting, and monitoring device health, ensuring that even non-technical users can manage their energy solutions effectively (Solaric, 2023). By following routine maintenance practices and utilizing accessible support, households can ensure the long-term reliability and efficiency of the Plug-and-Play Modular Solar System, ultimately supporting its CE.

Usability. After considering affordability, scalability, and maintenance, another crucial factor influencing the overall CE of plug-and-play modular solar technology is usability. Usability addresses how easily households can operate, monitor, and integrate these systems into their daily routines, which directly impacts adoption potential. Research indicates that households are more likely to adopt RE solutions when the technology is easy to understand and use. Debnath et al. (2023) emphasized that simplifying system interfaces and minimizing the need for specialized technical knowledge significantly enhance user confidence and accessibility, particularly in developing countries. Empirical studies on prosumer perceptions show that perceived ease of use and usefulness strongly influence positive attitudes and purchase intentions

for residential PV systems (Zdonek et al., 2023). Intuitive system controls, straightforward installation, and user-friendly features can therefore directly affect households' WTA of solar technology. Additionally, studies examining system design and user experience highlight the importance of continued user support and operational usability, such as accessible customer service, simple maintenance routines, and user-friendly monitoring tools, in making residential solar a practical and sustainable option for diverse households (Guo & Kinfe, 2022). Overall, improving usability through human-centered features and clear interfaces enhances adoption potential, reduces non-technical barriers, and contributes to the CE of plug-and-play modular solar technology for urban households.

The Willingness of Manila Households to Adopt Sustainable RE

Recent studies have emphasized that the willingness of households in developing countries to adopt solar energy is influenced by a multitude of interrelated factors, predominantly ranging from environmental literacy to socio-economic standing. Solaric (2024), one of the leading solar companies in the Philippines, suggested that the low minimum wages and high inflation rates of the country are among the primary hindrances for Filipino families in adopting solar technologies. This highlights that despite corporations and enterprises being capable of investing in solar energy, financial constraints among Filipino households may hinder widespread adoption, thus making the nationwide transition more difficult to achieve. Expanding to a global context, Mahn et al. (2024) analyzed probit regression data from World Bank surveys across 11 countries with up to 36,653 households. It can be inferred from their study that lower-income households tend to adopt solar technology less frequently due to infrastructural constraints and financial limitations. Complementing these insights, Hancevic and Sandoval's (2023) study highlighted that among 1,217 Mexican households, 32% reported that lack of information or technical knowledge about solar energy along with perceived maintenance difficulty are also key reasons for non-adoption. Collectively, these findings underscore the need to examine specific household-level dimensions, such as expenditures, coverage, feasibility, and accessibility, in order to further comprehend the factors influencing their WTA of sustainable RE systems.

Expenditures. Multiple studies emphasized the importance of acknowledging the financial conditions and energy expenditures of households in shaping their WTA of sustainable RE. Palanca-Tan's (2024) study assessed the relationship between the WTA of rooftop solar power (RTSP) to several factors, including pricing of the RTSP and current Meralco electricity bills. Her contingent valuation study revealed that most respondents were knowledgeable about climate change and mainly supported RE adoption to reduce electricity costs, with 80% of the 403 respondents recognizing the reduction in monthly household electricity bills as the most significant benefit. Constantino et al. (2023) further discussed in their recommendations that higher real estate value and reduced carbon dioxide emissions are the potential benefits of adopting solar energy, but households may be discouraged by expensive upfront investment that households often consider. Moreover, the system used in their study, which was a package costing ₱150,000 and was designed to last 20 years—was projected to recover its initial investment within approximately 5.4 years and generate cumulative savings of about ₱402,000.

Complementing these insights, Kobayashi et al. (2024) demonstrated through global case studies that the levelized cost of electricity (LCOE) for solar energy now ranges between 3 and 6 US¢ per kWh and that residential systems can achieve payback periods of 4 to 7 years, indicating how solar energy has now become economically viable compared to other energy alternatives. In essence, these statistics highlight that economic practicality and visible financial returns remain the strongest drivers of households' willingness to transition toward adopting RE, as affordability and savings in electricity expenses directly reflect the perceived value and accessibility of these solar technologies.

Coverage. Coverage represents the extent to which RE systems reach and serve households, reflecting both physical deployment and equitable energy access. Based on the findings of Demoral and Cervera (2025), the coverage of RE, particularly solar photovoltaic (PV) systems, depends heavily on factors such as site suitability, infrastructure proximity, and system scalability. Their techno-economic analysis of a 10-MWp solar PV system for the Lanao del Sur Electric Cooperative revealed that while RE projects have the potential to significantly reduce electricity costs and improve energy affordability, coverage remains uneven due to geographic, infrastructural, and financial constraints. The study found that even with the cooperative's wide service network, only about half of households in its franchise area were electrified, underscoring how limited grid expansion and economic barriers hinder full coverage. Moreover, the identification of optimal solar sites using geographic information systems (GIS) tools highlighted the importance of strategic location planning to maximize coverage efficiency and minimize transmission losses. These insights suggest that in the context of Manila households, achieving broader RE coverage requires integrating spatial planning, infrastructure readiness, and equitable energy distribution strategies to ensure that the benefits of solar adoption reach a wider segment of the population.

Feasibility. The feasibility of adopting sustainable RE among Manila households is determined by both technical and economic considerations that influence their capacity to implement and sustain solar energy systems. Franco and Taeihagh (2024) highlight that while awareness and environmental concern are growing, perceived feasibility, defined by technical accessibility, system reliability, and financial capability, remains a crucial determinant of adoption. Many households in the Philippines recognize the long-term benefits of RE but express uncertainty about system installation, durability, and maintenance, which limits perceived practicality. The study also points out that limited access to reliable information, technical expertise, and affordable financing options restrict households' ability to transition from interest to actual adoption. In addition, infrastructure constraints such as grid connectivity, roof structure, and urban space availability further affect the technical feasibility of solar system deployment in densely populated areas like Manila. These findings indicate that for RE systems, particularly plug-and-play modular solar units, to be considered feasible, they must align with the financial readiness, technical capacity, and infrastructural conditions of urban households. Thus, feasibility acts as a foundational factor that bridges technological innovation with practical implementation, ensuring that the adoption of RE solutions is both achievable and sustainable in the local context.

Accessibility. Lastly, the accessibility of solar technology is an important factor to consider, as user-friendliness and ease of access can substantially increase households' perceived accessibility. Based on the findings of Ang et al. (2022), accessibility is influenced not only by technological availability but also by socio-political and institutional factors that determine who can benefit from RE systems. The study emphasized that RE initiatives in Southeast Asia, including the Philippines, often fail to reach low-income and marginalized communities due to limited infrastructure, inadequate local governance, and the absence of inclusive energy programs. It was also found that bureaucratic barriers, lack of information transparency, and insufficient community engagement reduce households' capacity to participate in RE transitions. Moreover, accessibility improves when energy projects integrate participatory planning, provide local training, and strengthen partnerships between government and private institutions to ensure equitable energy distribution. These findings indicate that accessibility is not merely about affordability or availability but also about ensuring that households have the necessary resources, information, and institutional structures to confidently transition toward RE adoption.

Relationship Between the Perceived Cost-Effectiveness of the Plug-and-Play Modular Solar System and the Willingness of Manila Households to Adopt Sustainable RE

The relationship between the perceived CE of plug-and-play modular solar systems and the willingness of Manila households to adopt sustainable RE is shaped by the combined effects of technological features, financial capacity, and household decision-making behavior. CE, defined through affordability, scalability, maintenance, and usability, determines how feasible and beneficial these systems appear to potential users. In turn, household WTA is reflected through expenditures, coverage, feasibility, and accessibility, which gauge the perceived practicality and long-term value of transitioning to solar technology. Understanding how these dimensions interact provides a clearer view of how the design and functionality of renewable systems influence real-world adoption behaviors.

Firstly, affordability plays a critical role in influencing household expenditures and overall adoption intent. When the system's initial and operational costs are within reach, households perceive RE as a financially viable alternative to conventional power sources. Best & Chareunsy (2022) and Bunda et al. (2023) both underscored that lower upfront expenses and accessible financing options significantly enhance adoption potential, especially in developing contexts where income disparities limit energy investment. As affordability increases, perceived expenditures decrease, motivating households to shift toward solar solutions that promise lower electricity bills and faster payback periods. Similarly, scalability corresponds to coverage, or the extent to which energy needs are met efficiently. Studies by Bachanek et al. (2025) and Oliva and Santamaria (2025) highlighted that modular and expandable solar systems allow households to start small and scale gradually based on their energy consumption and budget, ensuring flexibility without the burden of major reinvestment. This capacity for growth strengthens confidence in the system's long-term CE, which directly supports higher WTA.

Maintenance and usability are equally significant in shaping perceptions of feasibility and accessibility. Systems that require minimal upkeep and provide accessible guidance empower users to manage them independently, reducing dependence on technical specialists and costly repairs (Ogolo et al., 2024; Richard et al., 2024). Furthermore, when solar systems are user-friendly—featuring clear interfaces, intuitive controls, and reliable customer support—they eliminate non-technical barriers to adoption (Debnath et al., 2023; Zdonek et al., 2023; Guo & Kinfe, 2022). Households are more likely to adopt when they feel confident operating and maintaining the system without complex procedures. Collectively, these findings demonstrate that CE—rooted in affordability, scalability, maintenance, and usability—has a direct and positive influence on the willingness of households to adopt RE technologies. As plug-and-play modular solar systems become more practical, affordable, and accessible, they not only improve household-level sustainability but also advance the broader transition toward clean and decentralized energy solutions in urban environments.

Literature Review Synthesis

The reviewed literature provides a comprehensive understanding of how technological, economic, and behavioral dimensions influence the adoption of RE systems. Research on RE adoption highlights that although technological advancements have improved affordability, usability, and system efficiency, the extent to which households, particularly in urban areas like Manila, are willing to adopt such technologies is shaped by their financial capacity, infrastructural feasibility, and access to institutional and informational support. Bunda et al. (2023) and Ang et al. (2022) discussed how despite the growing recognition of solar energy as a sustainable alternative to conventional power, economic limitations, uneven access, and limited policy integration continue to restrict its widespread adoption in the Philippine context.

Regarding CE, existing literature identifies affordability, scalability, maintenance, and usability as the primary factors that determine the practicality and long-term value of the Plug-and-Play Modular Solar System. Vijayan et al. (2023) discussed how innovations in solar panel engineering, particularly modular and integrated designs, have improved cost efficiency by reducing installation requirements and material waste, thereby making solar energy systems more practical for household adoption. Similarly, EcoFlow (2025) found that portable solar kits reduce installation costs and expand household accessibility. The declining market price of small-scale solar systems in the Philippines, which now ranges from ₱30,000 to ₱100,000 depending on capacity, suggests that modular systems are increasingly attainable for urban households. However, Best & Chareunsy (2022) and Bunda et al. (2023) reported that high upfront investments and limited financing opportunities continue to discourage lower-income families, even when they recognize the long-term savings potential of solar energy. Bachanek et al. (2025) and Oliva and Santamaria (2025) emphasized that scalability contributes to CE by enabling households to increase system capacity in proportion to their energy needs and financial growth. Similarly, Ogolo et al. (2024) and Richard et al. (2024) observed that simplified maintenance procedures and environmental resilience enhance reliability and long-term performance. Meanwhile, Guo and Kinfe (2022) and Zdonek et al. (2023) noted

that usability, through intuitive controls, simple operation, and responsive customer support, builds user confidence and increases the likelihood of adoption. Together, these findings highlight that CE depends not only on system price but also on user-centered design, technical durability, and scalability.

Research examining the willingness of households to adopt RE complements these findings by focusing on expenditures, coverage, feasibility, and accessibility as the primary drivers of decision-making. Financial expenditure remains the strongest predictor of adoption intent. Bunda et al. (2023) reported that perceived affordability and financial readiness determine whether households view solar systems as viable investments. Similarly, Palanca-Tan (2024) and Constantino et al. (2023) found that reductions in monthly electricity expenses serve as the most compelling incentive for adoption, with system investments projected to recover within approximately 5.4 years and yield savings of around ₱402,000. International data from Mahn et al. (2024) and Hancevic and Sandoval (2023) revealed that lower-income groups tend to adopt RE technologies less frequently due to economic and infrastructural barriers. Kobayashi et al. (2024) further showed that the global levelized cost of electricity for solar energy has dropped to an estimated cost of between three and six U.S. cents for every kilowatt-hour (kWh) of electricity generated, reinforcing its competitiveness and long-term viability.

Beyond financial considerations, coverage and feasibility define the reach and practical application of RE systems. Demoral and Cervera (2025) found that the distribution of RE resources remains uneven in the Philippines due to limited grid connectivity and spatial constraints. Their techno-economic analysis revealed that only half of the households within their study area had access to electricity, demonstrating how infrastructural limitations impede solar expansion. Franco and Taeihagh (2024) further explained that technical feasibility, defined by installation suitability, system reliability, and household capacity, remains a critical determinant of adoption, particularly in dense urban areas where space and infrastructure pose challenges. These insights suggest that effective adoption requires both technological compatibility and supportive physical environments. Accessibility serves as a cross-cutting factor that bridges technological potential and social inclusion. Ang et al. (2022) observed that accessibility in Southeast Asian RE transitions depends not only on technological availability but also on inclusive governance, community participation, and equitable energy distribution. Barriers such as insufficient public awareness, bureaucratic inefficiency, and inadequate infrastructure continue to limit the reach of RE programs. Accessibility improves when government initiatives are supported by transparent policies, local training, and partnerships with the private sector to make energy systems approachable and adaptable. These conditions align closely with the objectives of the Plug-and-Play Modular Solar System, which aims to enhance user independence and reduce technical complexity for ordinary households.

A number of consistent themes emerge across the reviewed literature. Technological innovation alone does not guarantee adoption; it must be complemented by economic accessibility, reliable infrastructure, and institutional support. Financial practicality, usability, and community engagement are widely recognized as catalysts for household adoption, while high costs, technical uncertainty, and information gaps remain

persistent obstacles. Variations in emphasis are evident across studies—some prioritize cost modeling and energy efficiency, while others focus on behavioral and policy-oriented frameworks—but all align on the conclusion that sustainable energy adoption depends on integrating technological feasibility with socio-economic realities. Despite the growing body of literature, certain gaps remain evident. Few studies have specifically analyzed modular solar systems in the Philippine context. Moreover, research tends to address technological and behavioral dimensions separately rather than through an integrated framework, leaving unanswered questions about how CE directly influences WTA. These limitations point to the need for a more holistic and localized examination that accounts for both the system's design and the socio-economic conditions of potential users.

In summary, the existing literature provides strong evidence that the success of the Plug-and-Play Modular Solar System relies on its affordability, scalability, ease of maintenance, and usability, as well as on household-level factors such as expenditures, feasibility, coverage, and accessibility. However, empirical studies focusing on Manila's unique economic and infrastructural context remain limited. This research seeks to address that gap by examining how the perceived CE of the Plug-and-Play Modular Solar System influences the willingness of Manila households to adopt sustainable RE. Through this approach, the study aims to advance the understanding of how technological design, financial practicality, and social inclusivity interact to promote sustainable household energy transitions in urban environments.

Theoretical Framework

The previously discussed attributes of the DOI theory—relative advantage, compatibility, complexity, trialability, and observability—can be linked to the eight subfactors identified by the researcher. To thoroughly investigate and analyze the relationship between the CE of the Plug-and-Play Modular Solar System and the willingness of Manila households to adopt sustainable RE, this study operationalizes the independent and dependent variables through the following eight key respective subfactors:

Independent Variable (IV) — Perceived CE of the Project:

1. Affordability – overall costs and expenses.
2. Scalability – modularity and consistency.
3. Maintenance – performance and reliability.
4. Usability – ease of use/user-friendliness.

Dependent Variable (DV) — Manila Households' WTA of Sustainable RE:

1. Expenditures – household electricity expenses and cost savings.
2. Coverage – the extent to which energy requirements are met.
3. Feasibility – long-term practicality and viability of the system for households.
4. Accessibility – ease of adoption and operation considering households' technical knowledge.

Firstly, relative advantage can be observed by analyzing how the affordability of the system can positively influence the expenditures of Manila households by lowering overall expenses. Secondly, compatibility can be examined through the maintenance requirements of the system, wherein they reflect the feasibility of adoption by exhibiting practicality. Thirdly, complexity can be assessed through the system's usability, which demonstrates how accessible the system is for household use. Lastly, trialability can be perceived through whether or not users view the scalability of the system to be suitable for households' energy necessities; additionally, observability can be assessed as households can scrutinize its coverage.

The Diffusion of Innovations (DOI) Theory by Rogers serves as the main theoretical basis of this study. This theory fits well because it explains how individuals and communities adopt new technologies based on their perceived benefits, how compatible they are with existing needs, how easy they are to use, and the visible results they offer. In this research, the theory provides a clear way to examine how households in Manila assess the perceived CE of the Plug-and-Play Modular Solar System compared to conventional electricity sources. Each aspect of the DOI theory relates to the subfactors under the study's independent and dependent variables, showing how views on affordability, scalability, maintenance, and usability affect households' WTA of sustainable RE systems.

This theoretical connection supports the investigation by offering a clear explanation for patterns of adoption. Previous studies have pointed out financial strain, technical difficulties, and a lack of awareness as major hurdles to adopting RE. The DOI framework helps interpret how these challenges impact consumers' decision-making. It enables the study to identify which specific attributes—whether economic benefit, practical compatibility, or ease of use—most significantly affect households' acceptance of the innovation. Furthermore, the theory has been widely used in research on RE technologies, proving that it is relevant in examining adoption behaviors in similar situations.

By basing the study on the DOI theory, the researcher can analyze how the Plug-and-Play Modular Solar System demonstrates relative advantage, compatibility, complexity, trialability, and observability, and how these characteristics promote or hinder households' WTA of sustainable RE systems. This connection provides a reliable theoretical foundation for understanding the link between the system's perceived CE and the willingness of Manila households to transition toward sustainable RE sources.

Conceptual Framework

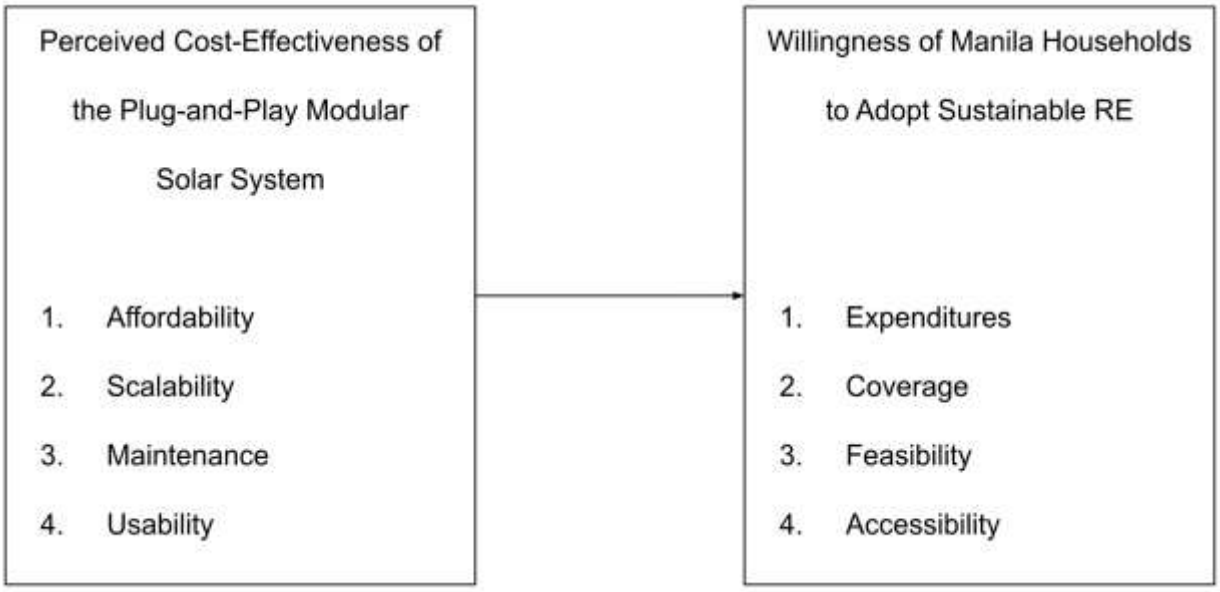


Figure 1
Conceptual Framework Diagram

The conceptual framework illustrates the relationship between the perceived cost-effectiveness of the Plug-and-Play Modular Solar System (independent variable) and the willingness of Manila households to adopt sustainable renewable energy (dependent variable). The independent variable includes factors such as affordability, scalability, maintenance, and usability, which are expected to influence households' perceptions of the system's cost-effectiveness. The dependent variable reflects households' willingness to adopt the system, measured through their perceived expenditures, energy coverage, feasibility, and accessibility. This framework guides the study in analyzing how improvements in the system's characteristics may influence adoption decisions.

Scope of the Study

This study primarily focuses on examining the relationship between the perceived CE of the Plug-and-Play Modular Solar System and households' WTA sustainable RE. Specifically, it examines the system's affordability, scalability, maintenance, and usability (subfactors for the independent variable – CE) in relation to households' expenditures, coverage, feasibility, and accessibility (subfactors of the dependent variable – the WTA). This research aims to determine how the four aspects of the system's CE collectively influence households' WTA or transition toward RE systems as opposed to continuing their reliance on conventional electricity sources.

Significance of the Study

The results yielded from this study will help evaluate the CE of the Plug-and-Play Modular Solar System, with the aim of providing useful insights to the following stakeholders:

Households in Manila. They will be the primary beneficiaries, as the Plug-and-Play Modular Solar System is designed specifically for their daily energy needs and convenience. By exploring the system's affordability, scalability, maintenance, and usability, the research provides households with reliable information on how solar technology can reduce expenses and dependence on traditional power sources. The findings can help families make informed choices about RE adoption and encourage environmentally responsible consumption habits. Moreover, access to a sustainable and cost-effective energy alternative may contribute to long-term savings, improved energy security, and a reduced carbon footprint within urban communities.

Renewable Energy Companies and Industries. Renewable energy companies and industries can utilize the findings of the evaluation to enhance the design, affordability, and accessibility of user-friendly solar technologies. The study provides valuable insights into the practical needs, preferences, and challenges faced by households in adopting the Plug-and-Play Modular Solar System. By understanding these user experiences and technical limitations, companies can refine their products to improve efficiency, scalability, and ease of installation. Furthermore, the results may guide future product development and marketing strategies aimed at promoting sustainable and cost-effective solar solutions that align with household energy demands and support the broader shift toward RE adoption in urban areas.

Innovators, Entrepreneurs, and Investors. Innovators, entrepreneurs, and investors can identify emerging opportunities in the RE market by assessing the system's economic viability, scalability, and potential for widespread adoption. The evaluation of the Plug-and-Play Modular Solar System provides concrete data on CE, market demand, and long-term sustainability, helping them make informed investment decisions. Through insights on affordability, feasibility, and user adoption, they can explore business models that support accessible solar technologies for households while contributing to the expansion of the clean energy sector. This can encourage entrepreneurship that balances profitability with environmental responsibility and social impact.

Government Agencies and Policymakers. Government agencies and policymakers can use the findings to efficiently shape RE policies and incentives that promote the wider adoption of solar technologies. Insights drawn from the evaluation, such as the system's affordability, maintenance needs, and user accessibility, can directly inform the creation of regulations and support programs that make solar technology safer, more affordable, and more practical for household residents. By aligning these programs with actual household experiences and challenges, policymakers can design targeted initiatives that encourage adoption, expand RE access, and accelerate Manila's transition toward a sustainable energy future.

Environmental Sector and Sustainability Advocates. Environmental organizations and sustainability advocates can utilize the findings to promote cleaner, more responsible energy consumption within urban communities. The evaluation of the Plug-and-Play Modular Solar System highlights how accessible solar innovations can reduce carbon emissions and household dependence on non-RE sources. By emphasizing affordability and user accessibility, the study supports ongoing efforts to encourage eco-friendly practices and RE awareness. These insights can strengthen local and national sustainability campaigns, contributing to the broader transition toward a greener and more energy-resilient future for Manila.

Definition of Terms

Renewable Energy (RE): One of the most potentially effective methods for achieving the Sustainable Development Goals by reducing greenhouse gas emissions (Sayed et al., 2023).

Plug-and-Play: Enables operating systems to instantly recognize and identify compatible devices upon connection (Keyprod, 2024).

Modular: A design approach that employs interchangeable components and modules as “building blocks” that can be configured to consolidate functionality and enable efficiency (Martin, 2022).

Solar Panel System: A system composed of multiple essential components that collaboratively transform solar energy into electricity suitable for practical applications (Malogica Solar, 2024).

Households: Consist of all individuals who live in a housing unit or similar accommodation as their primary place of residence, with household size determined by the total number of persons residing there (Statistics Austria, 2024).

Cost-Effectiveness (CE): Refers to the extent to which a project achieves its objectives while minimizing expenses, ensuring the efficient use of financial resources for long-term sustainability (Obiuto et al., 2024).

Affordability: Refers to the capacity of a product or service to be obtained and sustained while aligning with the available resources and maintaining the ability to meet other essential needs over time (Magno-Ballesteros et al., 2024).

Scalability: Refers to the development of consistent and efficient systems capable of adjusting to growing demand while ensuring the delivery of high-quality results (Higgins, 2025).

Maintenance: Refers to the combination of all technical and preservation actions that will result in the improvement or restoration of an item (Zonta et al., 2020).

Usability: Refers to how effectively, efficiently, and satisfactorily a particular group of users can utilize a product to accomplish defined objectives within a given context of use (Derisma, 2020).

Willingness to Adopt (WTA): A precursor to actual adoption; it reflects a person's readiness or disposition to accept and use new technology (Sharit et al., 2020).

Expenditures: Refer to the actual funds disbursed or spent, which often differ from the approved budget for a given year because certain expenses may draw from allocations made in earlier fiscal periods (Silva, 2024).

Coverage: Refers to the extent or range within which a particular system or function can operate and be made available to users (Cambridge Dictionary, 2025a).

Feasibility: Refers to the possibility that something can be practically or reasonably accomplished (Cambridge Dictionary, 2025b).

Accessibility: Refers to the right of all individuals, regardless of ability, to engage fully without encountering physical or digital obstacles that are not experienced by those with typical abilities (Slatin, 2024).

Research Questions

As the global drive for clean energy intensifies, it is crucial to identify specific ways to assist households that struggle with adopting these renewable technologies due to financial and technical constraints. With the introduction of the Plug-and-Play Modular Solar System, this research aimed to answer the following research questions:

1. What is the perceived level of cost-effectiveness of the Plug-and-Play Modular Solar System among Manila households in terms of:
    a. affordability,
    b. scalability,
    c. maintenance, and
    d. usability?
2. What is the level of willingness of Manila households to adopt sustainable RE in terms of:
    a. expenditures,
    b. coverage,
    c. feasibility, and
    d. accessibility?
3. Is there a significant relationship between the perceived cost-effectiveness of the Plug-and-Play Modular Solar System and the willingness of Manila households to adopt sustainable RE?

Hypotheses

H_0: There is no significant relationship between the perceived CE of the Plug-and-Play Modular Solar System and the willingness of Manila households to adopt sustainable renewable energy.

H_1: There is a significant relationship between the perceived CE of the Plug-and-Play Modular Solar System and the willingness of Manila households to adopt sustainable renewable energy.

METHODOLOGY

This section outlines the methodology employed to investigate the perceived CE of the Plug-and-Play Modular Solar System and its correlation with the willingness of Manila households to adopt sustainable RE systems. A descriptive explanation of the research design, participants and setting, instruments, and data collection methods will be presented to provide readers with an in-depth understanding of how the study was conducted.

Research Design

The researcher used a descriptive correlational design to examine the relationship between the perceived CE of the Plug-and-Play Modular Solar System and the willingness of Manila households to adopt it.

Descriptive research primarily focuses on describing the current characteristics of phenomena (Singh, 2024). In this study, the descriptive component aims to present the current perceptions of households regarding the perceived CE of the Plug-and-Play Modular Solar System and their WTA. This will help create a comprehensive overview of how the project is viewed by its potential users in Manila. Meanwhile, correlational research is a type of non-experimental research in which researchers measure two or more variables to assess the relationship between them without any manipulation (Sreekumar, 2025). Thus, the correlational aspect of this study will examine whether or not a significant relationship exists between the CE of the project and the willingness of Manila households to adopt this RE technology. This is needed to provide valuable insights on how CE is or is not statistically linked to the likelihood of adoption of sustainable RE, which can then help future researchers, policymakers, and energy companies in promoting the use of sustainable RE technologies.

Thus, the research design is cross-sectional as data will be collected from a sample of Manila households at a single point in time (Thomas, 2020). This is a typical approach in descriptive correlational research because it allows the researcher to observe variables and their subfactors in the present without influencing or manipulating them at different points in time.

Participants and Sampling Technique

The respondents selected for this study are household residents from each district in Manila who evaluated the project implemented and documented by the researcher. These respondents were chosen because the project focuses on providing households with affordable, scalable, maintainable, and user-friendly solar technology designed to cover their energy needs—primarily targeting power appliances and technology that are used daily by these residents. The researcher employed a stratified sampling technique in order to select the participants of the study. As the City of Manila was stratified into its six legislative districts, an approximate quota of 25 households per district were invited to participate in the demonstration of the Plug-and-Play Modular Solar System.

This approach is consistent with recent studies conducted in Manila that also stratified respondents by district to ensure equitable distribution and geographic representation. For instance, Auma et al. (2023) studied the urban nutrition of households during the COVID-19 pandemic by stratifying Manila into its six districts. Similarly, Palanca-Tan et al. (2024) stratified Metro Manila into four districts (Capitol, Eastern Manila, Northern Manila, and Southern Manila) in order to conduct a multi-stage stratified survey to evaluate households' preferences for RE technologies. These studies support the appropriateness of a stratified sampling technique for research conducted in heterogeneous urban settings like Manila, where socio-economic conditions vary.

The sample size (n) for this study was determined using the Raosoft Sample Size Calculator software (Raosoft, n.d.). Given the total population of approximately 483,508 households in Manila as of 2020 (Philippine Statistics Authority, 2020), and based on a 95% confidence level and a 0.08 margin of error, the computed minimum sample size was approximately 150 respondents. This aligns with the chosen quota of 25 households per district. Given the finite population of Manila households, this allows the researcher to determine an appropriate sample size to ensure accuracy when representing the entire population (Ellen, 2022). Overall, this stratified sampling technique was selected to minimize sampling error and enhance the generalizability of findings to the urban household population in Manila.

Setting of the Study

The study was conducted in the City of Manila, stratified into its six legislative districts where the respective participants were located. The districts and their locations are as follows: **First District** – Tondo 1 (North Harbor); **Second District** – Tondo 2 (Gagalangin); **Third District** – San Nicolas, Binondo, Quiapo, and Santa Cruz; **Fourth District** – Sampaloc; **Fifth District** – Malate, Ermita, Intramuros, Port Area (South Harbor), Paco, and San Andres; and **Sixth District** – Pandacan, San Miguel, Sta. Ana, and Sta. Mesa (City Council of Manila, 2023).

The urban setting provided a sufficient number of residential households for participant selection making the area both convenient and accessible for conducting the study. The city was divided to ensure sufficient representation of a more complete

demographic of residents—varying in social class, household size, and energy requirements. In order to effectively evaluate the perceived CE of the Plug-and-Play Modular Solar System and the WTA of these households, six areas were selected—one per district—for participants to test and observe the project's demonstration in a simulated household setting.

Research Instrument

The survey was distributed to respondents online through Google Forms and contained the following sections:

Introduction Letter. This section was provided to respondents in order to give them an overview of the study being conducted by the researcher. It provides a brief description of the research, its objectives, and the type of data collected. Additionally, it provides all the necessary information that participants need to know before they participate in the study. It includes the title of the study and its purpose, procedures, risks and benefits, confidentiality and data privacy compliance declarations, and the contact information of the researcher and their adviser. At the latter portion, respondents were asked to agree to a voluntary consent statement to ensure informed consent before they participate.

Part I. Perceived Cost-Effectiveness of the Plug-and-Play Modular Solar System. This section specifically aims to answer the first research question, which analyzes the perceived CE of the Plug-and-Play Modular Solar System through its four subfactors: affordability, scalability, maintenance, and usability. This part assesses the participants' needs in terms of budget (affordability), system expansion (scalability), upkeep requirements (maintenance), and overall functionality or convenience (usability).

Part II. Willingness of Manila Households to Adopt Sustainable Renewable Energy. This section specifically aims to answer the second research question, which evaluates the WTA of Manila households through its four subfactors: expenditures, coverage, feasibility, and accessibility. This part assesses the participants' needs in terms of spending capacity (expenditures), household reach (coverage), practical application (feasibility), and ease of availability (accessibility).

The data gathered from these two parts were then used to determine the correlation between the IV and DV, thereby addressing the third research question—whether or not there exists a significant relationship between the perceived CE and the WTA of Manila households.

Before the pilot testing and survey were conducted, the researcher sought the approval of the research adviser, Mr. Fernando Mira, in order to validate the instrument to be used for this study. Additionally, an expert of the field, grammarian, and statistician were consulted to verify the accuracy and conciseness of the survey instrument used in order to ensure that the data collected would be accurately interpreted by the researcher.

Prior to data collection from the respondents, a pilot test was conducted in order to verify the reliability of the survey items. This was evaluated using Cronbach's alpha (α) to determine the internal consistency of the items within each subscale. Each of the instrument's subcategories—affordability, scalability, maintenance, usability, expenditures, coverage, feasibility, and accessibility—was tested separately to ensure that each of the questions consistently measures their intended constructs.

Cronbach's alpha values ranging from 0.70 and above are deemed acceptable, values higher than 0.80 are considered good, and values from 0.90 to 0.99 indicate excellent internal consistency (Sheposh, 2024). The resulting coefficients from the reliability analysis ranged from 0.737 to 0.882, interpreted as good.

Data Analysis

The collected data from the survey were systematically processed and analyzed in order to answer the research questions and objectives. Descriptive statistics, including mean and standard deviation, were computed for each item to summarize the central tendencies and variability of the responses. This provided an overview of their perceptions regarding the CE of the Plug-and-Play Modular Solar System and their WTA sustainable RE.

For the first research question, which assessed the perceived CE of the system through affordability, scalability, maintenance, and usability, the mean scores are calculated for each subcategory. These descriptive statistics highlighted the overall trends and areas of strength and concern of the project as perceived by the respondents (Qualtrics, 2022).

For the second research question, which examined the willingness of those households to adopt sustainable RE based on expenditures, coverage, feasibility, and accessibility, similar descriptive statistics were computed. The results allowed for a clear understanding and insights towards the respondents' readiness and motivation to adopt the system.

Lastly, for the third research question, which aims to determine whether or not there is a significant relationship between the perceived CE of the project and the respondents' WTA, Pearson's correlation coefficient was employed in order to determine if there is a significant association between the two variables (Turney, 2022). A positive correlation indicated that as perceptions of affordability, scalability, maintenance, and usability increase, the WTA of the system also tends to increase. This analysis determines whether the households' positive evaluations of the system are associated with higher adoption intent.

Data Gathering Procedure

A comprehensive overview of the data collection procedure is thoroughly explained in this section—from the preparation of the research instruments to the actual data gathering process.

Project Preparation. Before the start of the implementation, all components of the Plug-and-Play Modular Solar System—including the solar panels, charge controller, inverter, DC–AC inverter, breakers, wiring, and the testing loads (such as LED bulbs and small household appliances)—were inspected, cleaned, and tested to ensure proper functionality and safety. The system components were assembled according to the manufacturer's specifications and verified using a multimeter to confirm the correct voltage and current outputs. Each unit was also labeled and arranged to ensure easy setup and monitoring during testing.

As previously discussed, the final version of the questionnaire was validated by the research adviser, a subject-matter expert, grammarian, and statistician before official distribution. The researcher also conducted a pretest of the instrument among a small group of student respondents to ensure the clarity and reliability of the survey before its official administration to the target participants.

Project Set-Up. The Plug-and-Play Modular Solar System was installed in designated testing areas designed to simulate typical household conditions, including lights, charging outlets, and small appliances such as electric fans. Permission was secured from the respective barangays in each district prior to the data collection. Each setup consisted of a solar panel connected to a charge controller that regulates the power flowing into the battery. The stored energy then passed through a DC–AC inverter, which converts the electricity into usable power for household appliances. Circuit breakers were also installed to provide protection and allow control of the system. The components were arranged in an organized and accessible layout to allow easy observation and monitoring during testing. The testing area operated under normal daylight conditions to ensure consistent solar input. Safety precautions were observed throughout the setup to protect both participants and system components during demonstrations.

Project Implementation. Participants visited the testing area, where the researcher guided and demonstrated the system's features and operations. During this time, participants had the opportunity to observe and interact with the system, testing its functionality with small household loads. After the demonstration and hands-on experience, participants were asked to complete a survey questionnaire to assess their perceptions of the system's cost-effectiveness and their willingness to adopt it as a sustainable household energy solution. The survey was administered immediately following the demonstration to capture participants' responses, and all observations and survey responses were recorded systematically, ensuring consistency and reliability across all participants.

RESULTS

This section presents the analysis, and interpretation of the findings obtained from the data gathered through the survey questionnaires administered to the respondents. The collected data were carefully organized, analyzed, and interpreted in order to address the research questions and objectives regarding the perceived cost-effectiveness of the system and households' willingness to adopt it. Statistical analysis was conducted using the Microsoft Excel Data Analysis ToolPak, and the results are presented through tables accompanied by textual interpretations by the researcher. These statistical results provided meaningful insights into the relationship between the system's perceived cost-effectiveness and the respondents' willingness to adopt sustainable RE.

The study surveyed 150 households across the six legislative districts in Manila, with each district represented by 25 respondents to ensure balanced geographic representation within the city. Most households reported having 2 to 7 members, with a mean household size of approximately five individuals. In terms of electricity consumption, respondents had a wide range of average monthly electricity bills, ranging from as low as ₱300 to as high as ₱50,000, indicating considerable variation in household energy usage and financial capacity. Despite this range, the majority of households noted average monthly expenditures of ₱5,000 and ₱3,000, with 17 and 16 respondents, respectively. These demographic characteristics provide context for interpreting the respondents' perceived CE of the system as well as their WTA sustainable RE systems, with a substantial portion of households falling within moderate electricity spending levels.

Research Question 1: *What is the perceived level of cost-effectiveness of the Plug-and-Play Modular Solar System among Manila households in terms of: a. affordability, b. scalability, c. maintenance, and d. usability?*

Table 1
Perceived Level of Cost-Effectiveness of the Plug-and-Play Modular Solar System

Perceptions	Mean (x̄)	Standard Deviation (s)	Description
Affordability	3.35	0.57	Strongly Agree
Scalability	3.35	0.56	Strongly Agree
Maintenance	3.28	0.58	Strongly Agree
Usability	3.30	0.64	Strongly Agree
OVERALL	**3.30**	**0.53**	**Strongly Agree**

Legend: (1.00–1.74) Strongly Disagree, (1.75–2.49) Disagree, (2.50–3.24) Agree, (3.25–4.00) Strongly Agree

Table 1 presents the descriptive analysis of the perceived level of cost-effectiveness of the Plug-and-Play Modular Solar System in terms of its affordability,

scalability, maintenance, and usability. The overall mean score and standard deviation ($\bar{x}$ = 3.30 – *Strongly Agree*, s = 0.53) indicate that respondents generally perceive the system and its aspects as cost-effective and have relatively consistent responses among them, with slight variations in their perceptions and opinions regarding the system's overall cost-effectiveness.

All of the subfactors fall within the *Strongly Agree* range, indicating a consistently positive evaluation across all four of the system's dimensions. Among the four, affordability and scalability both obtained the highest mean score of 3.35 (s = 0.57 & 0.56, respectively), suggesting that respondents strongly believe that the system provides good value for its price while also being highly adaptable to their diverse household energy needs. Meanwhile, usability followed with a mean of 3.30 (s = 0.64) and maintenance obtained a mean of 3.28 (s = 0.58), indicating that respondents find the overall system generally easy to operate and convenient to adopt within their households.

Research Question 2: *What is the level of willingness of Manila households to adopt sustainable RE in terms of: a. expenditures, b. coverage, c. feasibility, and d. accessibility?*

Table 2
Level of Willingness of Manila Households to Adopt Sustainable Renewable Energy

Perceptions	Mean ($\bar{x}$)	Standard Deviation (s)	Description
Expenditures	3.39	0.57	Strongly Agree
Coverage	3.36	0.59	Strongly Agree
Feasibility	3.37	0.63	Strongly Agree
Accessibility	3.37	0.60	Strongly Agree
OVERALL	**3.37**	**0.56**	**Strongly Agree**

Legend: (1.00–1.74) Strongly Disagree, (1.75–2.49) Disagree, (2.50–3.24) Agree, (3.25–4.00) Strongly Agree

Table 2 presents the descriptive analysis of the willingness of Manila households to adopt sustainable RE in terms of expenditures, coverage, feasibility, and accessibility. The overall mean score and standard deviation ($\bar{x}$ = 3.37 – *Strongly Agree*, s = 0.56) indicate that respondents demonstrate a high level of WTA sustainable RE solutions in their households, having a general level of agreement with slight differences in the degree of their readiness or eagerness.

All of the respondents showed a general response of *Strongly Agree* toward adopting the system after being introduced to its features and capabilities. Among the four subfactors, expenditures obtained the highest mean score of 3.39 (s = 0.57), suggesting that respondents strongly agree that they are willing to allocate financial

resources to adopt sustainable RE technology. Meanwhile, feasibility and accessibility followed with a mean of 3.37 (s = 0.63 & 0.60, respectively), describing how respondents consider the adoption of the system to be practical and attainable, especially highlighting its ease of use and convenience. With coverage following at 3.36 (s = 0.59), households also believe that the system can sufficiently meet their energy needs and that the modular design is suitable for diverse types of households.

Research Question 3: *Is there a significant relationship between the perceived cost-effectiveness of the Plug-and-Play Modular Solar System and the willingness of Manila households to adopt sustainable RE?*

Table 3

The Relationship Between the Perceived Cost-Effectiveness of the Plug-and-Play Modular Solar System and the Willingness of Manila Households to Adopt Sustainable Renewable Energy

Correlation Between	r-value	Description	p-value	Remark
Perceived cost-effectiveness of the Plug-and-Play Modular Solar System and the willingness of Manila households to adopt sustainable RE	0.912	Very High	p < .001	Significant

Legend: (.00–.30) Negligible correlation, (.31–.50) Low positive correlation, (.51–.70) Moderate positive correlation, (.71–.90) High positive correlation, (.91–1.00) Very high positive correlation

The above results show the relationship between the perceived cost-effectiveness of the Plug-and-Play Modular Solar System and the willingness of Manila households to adopt sustainable RE. With an r-value of 0.912, there is a very strong positive relationship. Moreover, the *p*-value of less than .001, which is lower than the significance level of 0.05, indicates that the relationship is statistically significant.

This relationship can be understood through the interplay of the system's technological features and households' decision-making behaviors and tendencies, as highlighted in the literature. Perceived CE, defined through affordability, scalability, maintenance, and usability, shapes the benefits of households in terms of expenditures, coverage, feasibility, and accessibility, thereby increasing their WTA sustainable RE.

DISCUSSION

This section presents the summary of findings derived from the analysis of the data gathered in the study. It highlights the key results regarding the perceived cost-effectiveness of the Plug-and-Play Modular Solar System and the willingness of Manila households to adopt sustainable RE. The section also provides the conclusions drawn from these findings, as well as the implications of the study, its limitations, and recommendations for future research.

These results align with the existing literature on RE adoption, which emphasizes how the perceived cost-effectiveness of an innovation, through its subfactors, significantly influences consumer acceptance. From a user's perspective regarding their overall experience of the system, the findings suggest that they value not only the initial affordability of the system that enables them to adopt RE with less financial difficulty, but also its long-term practicality, emphasizing the importance of low-maintenance setups for RE technology. This supports existing literature that emphasizes the importance of financial preparedness and reduced upfront investment, while visible economic returns, especially supported by a system's long-term reliability and convenience, can significantly influence adoption. Overall, the system's pricing and overall design can reduce notable barriers that may hinder respondents from lower socioeconomic backgrounds with strong priorities for low-maintenance technologies in adopting sustainable RE (Best & Chareunsy, 2022; Bunda et al., 2023; Ogolo et al., 2024; Richard et al., 2024).

The strong agreement in scalability also implies that households appreciate the modular design, which allows flexibility in adopting and expanding the system to cater to their households' dynamic needs. Positive ratings in usability also reflect confidence that the system would not require as much complex or frequent servicing, which multiple respondents considered an important factor when prioritizing convenience and reliability. Studies similarly highlighted that scalable and adaptable RE systems enhance user confidence by enabling incremental growth without major reinvestment, while simplified interfaces and ease of operations can greatly increase purchase intentions by making their scalable design manageable without much technical knowledge. Overall, the system enables respondents to easily adapt it to their households' changing needs, reducing the static limitations of RE technology. (Bachanek et al., 2025; Oliva & Santamaria, 2025; Debnath et al., 2023; Zdonek et al., 2023).

Existing literature regarding the interrelated factors of adoption further supports the findings on how aspects such as improved expenditures, wide coverage, overall feasibility, and supportive accessibility have a great impact on WTA RE. Connecting respondents' perspectives with their experiences during the presentation, their responses exhibit their awareness of the budgetary advantages of the system as well as its overall feasibility in adopting RE technology. Studies show that the lowered upfront costs and shorter return on investment (ROI) have a significant impact on households' WTA, especially when an innovation is perceived as feasible by consumers. Additionally, when upfront costs are manageable and long-term benefits are clear, integration in a household becomes more viable and hassle-free. Overall, the system's perceived benefits on reduced costs and expedited transition can significantly enhance adoption potential (Palanca-Tan, 2024; Constantino et al., 2023; Franco & Taeihagh, 2024).

Their positive responses regarding the system's coverage also indicate that households value the system's inclusive capacity to meet their households' needs, emphasizing the high adaptability of the system's modules. Lastly, their agreement on its accessibility highlights the overall user-friendliness of the system, making RE technology more approachable and easier to navigate for all types of users. Studies also suggest that a comprehensive understanding of RE systems can greatly benefit users who are seeking to transition towards solar technology by giving them the confidence to operate the system and to increase its capacity through its scalable design. By fostering user confidence, its incremental expansions become accessible—not only for households with prior knowledge of RE, but also for those who are interested in transitioning towards solar technology. With simplified operations greatly influencing many households, its diverse capabilities further influence households' WTA RE, particularly those prioritizing flexibility and serviceability (Demoral & Cervera, 2025; Guo & Kinfe, 2022; Ang et al., 2022).

The data gathered closely aligns with the frameworks provided by the literature. Affordability, for instance, directly affects household expenditures and adoption intent. When initial investment and operational costs are within budget constraints, households perceive the system as a financially viable alternative (Best & Chareunsy, 2022; Bunda et al., 2023; Palanca-Tan, 2024; Constantino et al., 2023). Scalability corresponds to coverage, allowing households to incrementally expand their system through modules to accommodate both their current energy requirements and future electricity needs (Bachanek et al., 2025; Oliva & Santamaria, 2025; Demoral & Cervera, 2025). Maintenance directly influences system feasibility, where minimal upkeep and maintenance reduce technical barriers and increase practicality (Ogolo et al., 2024; Richard et al., 2024; Franco & Taeihagh, 2024). Lastly, usability greatly influences how households perceive its accessibility, with user-friendly interfaces and intuitive operation for all kinds of users (Debnath et al., 2023; Zdonek et al., 2023; Guo & Kinfe, 2022; Ang et al., 2022).

Therefore, the statistically significant and very strong correlation between the CE and WTA underscores how the perceived features of an innovation directly influence households' willingness and interest to adopt it, as well as how economic viability, flexible design, ease of maintenance, and operational usability are critical determinants of consumers' adoption behaviors. These findings demonstrate that when an RE system is perceived as cost-effective, it decisively shapes urban households' WTA sustainable energy solutions.

Summary of Findings

The perceived cost-effectiveness of the Plug-and-Play Modular Solar System was rated highly by respondents across all subfactors, with mean scores ranging from $\bar{x} = 3.28$ to 3.35 (overall $\bar{x} = 3.30$), and demonstrated a statistically significant correlation ($r = 0.912$, $p < .001$) with willingness to adopt (overall $\bar{x} = 3.37$). Affordability and scalability were identified as the strongest aspects, indicating that respondents believe the system provides good value for its price while being adaptable to their energy needs. Usability

and maintenance were also rated positively, showing that respondents find the system easy to operate and maintain.

Respondents' WTA sustainable RE was similarly high across its subfactors. Expenditures received the highest attention, showing that respondents are willing to allocate financial resources to adopt the system. Coverage indicates that respondents are confident the system can adequately meet their energy needs. Feasibility demonstrates that respondents consider the system practical and manageable for daily use, while accessibility indicates that respondents find the system convenient and easy to operate. Collectively, these findings suggest that the system is economically viable, scalable, low-maintenance, and user-friendly, with respondents recognizing its financial, adaptive, operational, and accessible benefits in supporting their transition to RE.

Finally, the relationship between the perceived cost-effectiveness of the system and respondents' willingness to adopt renewable energy was very strong and statistically significant. Respondents' perceptions of the system's CE were closely associated with their WTA. Specifically, affordability influenced their willingness to allocate financial resources; scalability gave respondents confidence that the system could meet household energy needs; maintenance affected the perceived practicality of daily use; and usability contributed to the convenience of operating the system. These findings demonstrate that when the system is affordable, scalable, easy to maintain, and user-friendly, respondents are more likely to adopt it, confirming a strong positive relationship between the system's CE and their WTA renewable energy.

Conclusions

1. Perceived Cost-Effectiveness of the Plug-and-Play Modular Solar System

The respondents perceive the Plug-and-Play Modular Solar System as an economically viable, technologically adaptable, sustainably reliable, and user-friendly RE solution, with consistently high mean scores across all subfactors. This suggests that households not only acknowledge the financial and maintenance advantages of the system but also its scalable design and technical suitability. Supported by existing studies and theories, these results further reinforce that affordable initial costs, flexible system adaptability, low maintenance requirements, and ease of use are all critical attributes that encourage the adoption of an innovation. Consequently, the strong perceptions and agreements establish a strong foundation for increasing households' WTA sustainable RE solutions.

2. Willingness of Manila Households to Adopt Sustainable Renewable Energy

The respondents demonstrate a high willingness to adopt sustainable RE after being presented and oriented with the system and its features, perceiving it as a great benefit in terms of expenditures, coverage, feasibility, and accessibility. With consistently high mean scores across all the subfactors, households' perceptions regarding the benefits of solar technology are not limited to its economic and operational advantages

but also its overall flexibility and approachability. Backed by research and frameworks, these results underscore the factors that greatly influence a consumer's WTA, particularly in the field of RE technology. Thus, the information and data gathered through this section of the questionnaire provides a nuanced understanding of the background of sustainable energy system's adoption.

3. Relationship Between the System's Perceived CE and Manila Households' WTA

The strong and significant correlation between consumer evaluation and their willingness to adopt confirms that the perceived features and benefits of an innovation directly affect households' adoption behavior. This suggests that households tend to base their adoption decisions on their overall evaluation of the system's aspects. Therefore, when renewable energy systems are seen as cost-effective, reliable, and adaptable, they greatly enhance urban households' willingness to shift toward sustainable energy solutions.

Implications of the Study

The findings presented in the Results revealed that Manila households perceive the Plug-and-Play Modular Solar System as an overall cost-effective RE solution, while also demonstrating a high willingness to adopt sustainable RE technologies. The consistently high mean scores and statistically significant correlation between the two variables carry several practical implications for multiple stakeholders.

For households in Manila, the findings imply that adopting a modular solar system may provide a cost-effective means of reducing their total electricity expenses while promoting environmentally responsible energy consumption. Increased awareness and access to reliable information regarding RE technologies may help households make more informed decisions when considering the adoption of sustainable energy systems. Consequently, renewable energy companies and industries may utilize these results in order to further develop other RE technologies, while innovators, entrepreneurs, and investors can identify trends and behaviors in RE adoption that align with urban consumers' preferences and needs. Improvements in product design, components' accessibility, and simplified installation processes may further enhance the market acceptance of these RE systems. Additionally, government agencies and policymakers may use these insights to design sustainable policies, provide tax incentives, or financial assistance programs that can encourage the wider adoption and transition towards RE-sustained communities and cities. These efforts may be supported by programs and initiatives that the environmental sector and sustainability advocates can create to promote sustainable energy campaigns for the reduction of non-renewable energy sources in urban communities.

Limitations of the Study

This study is limited to the urban households in Manila, excluding rural and provincial areas as energy demand, affordability, and access to solar technologies may differ substantially. Focusing solely on the Plug-and-Play Modular Solar System, the study does not include other RE sources such as wind, hydropower, geothermal, or biomass. In addition, the scope is confined to the perceived measures of CE, including overall costs (affordability), modular expandability (scalability), upkeep requirements (maintenance), and ease of use (usability).

The evaluation of affordability relied on overall production and maintenance costs and markups in relation to electricity rates, which may vary once the prototype is fully operational and implemented. The assessment of scalability is confined to the expansion of the system's modular capacity to accommodate household energy demands over time based on the presented specifications and costs. Maintenance is solely concerned with the anticipated frequency, cost, and technical specifications of system upkeep to be managed by users; and usability was examined based on anticipated ease of installation and operation rather than observed user performance. As for the willingness of households to adopt sustainable RE, it was measured through the outcomes of the system on corresponding household factors: electricity savings (expenditures), proportion of energy demand met (coverage), long-term practicality (feasibility), and ease of adoption and operation (accessibility). The study only assesses whether or not there is a significant relationship between the perceived CE of the system and the willingness of households to adopt it, based on the variables' eight respective subfactors.

Additionally, a methodological limitation in this study is the potential susceptibility of the data collected to Common Method Variance (CMV) as the evaluation of both independent and dependent variables was made immediately after the live demonstration. This could partially account for the exceptionally strong correlation ($r = 0.912$, $p < .001$) that was observed between the two variables.

Other limitations of the study primarily arise from data collection and system production. For the perceived CE and level of willingness of Manila households to adopt sustainable RE, data collection was limited by its reliance on a single Plug-and-Play Modular Solar System, as the researcher could only manufacture one unit due to financial constraints. This restriction limited large-scale testing and comparative analysis across multiple households at a time. Additionally, time constraints also hindered the number of households who tested the unit (150 respondents as the sample size for Manila households), and as a result, data was collected from a limited number of household respondents who tested the system individually and sequentially, which may influence the consistency and generalizability of findings.

Recommendations

Based on the findings and conclusions of the study, several recommendations are proposed to further support the adoption of the Plug-and-Play Modular Solar System and other similar RE technologies. Future researchers may conduct larger-scale testing in other urban residential areas around Metro Manila or neighboring regions to evaluate the

system's reliability, energy coverage, and long-term cost savings, thereby expanding the scope of investigation to different populations. Longitudinal studies could also examine the long-term economic benefits and adoption patterns of RE systems to provide more comprehensive data on their overall cost-effectiveness. To mitigate CMV and potential halo effects observed in post-demonstration surveys, future researchers should implement temporal separation by assessing adoption intent at a separate time interval after the demonstration. Additionally, researchers are encouraged to further improve the Plug-and-Play Modular Solar System by exploring more efficient solar panels, longer-lasting battery technologies, and smarter monitoring systems to enhance performance. Future studies can also investigate ways to make the system more affordable and accessible for low-income households, ultimately ensuring that renewable energy becomes a practical, sustainable, and widely adopted solution for many urban communities.

Compliance with Ethical Standards

This study was conducted in full compliance with the Data Privacy Act of 2012 (Republic Act No. 10173) to ensure that all personal information collected from participants is lawfully processed, protected, and used solely for academic purposes. Falsification, manipulation, and deception were strictly avoided, and all survey responses were recorded accurately and analyzed objectively to maintain the integrity and reliability of the findings. Informed consent was obtained from all participants before they tested the Plug-and-Play Modular Solar System, and before completing the survey questionnaire. Each respondent was clearly informed about the study's purpose, procedures, potential risks, their right to withdraw at any time without penalty, and the measures in place to protect their safety and well-being throughout the testing and survey process. Participation was entirely voluntary, and no coercion or deception was applied at any stage of the research.

The researcher declared that no conflicts of interest influenced the study, which was conducted solely for academic purposes without external sponsorship or commercial intent. Anonymity and confidentiality were rigorously maintained: no personal identifiers appeared in the survey or reports, and all data were anonymized and securely stored in files accessible only to the researcher. Participants were also debriefed after completing the survey to explain how their information contributed to evaluating the Plug-and-Play Modular Solar System, reinforcing transparency and ethical responsibility throughout the study.

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