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# Influence of Perceived Benefits on Rooftop Solar Adoption: An Embedded Mixed-Method Study

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Paterson Lim Encabo, DBA, ORCID No. 0009-0007-7326-8189
Professorial Lecturer, Polytechnic University of the Philippines, Sta. Mesa, Manila, Philippines

**Abstract**

This study explores what drives the adoption of rooftop solar panels in Metro Manila's urban buildings – a context where both technical and behavioral factors often make the decision complex. While renewable energy has been widely discussed, little research has examined how these two perspectives interact in dense city environments. To address this gap, the study draws mainly on the Extended Theory of Planned Behavior, supported by ideas from Diffusion of Innovations and UTAUT2, to understand how people's perceptions and attitudes shape adoption. Design thinking framework was used for the qualitative study. The work connects directly to SDG 7 (Affordable and Clean Energy), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action), highlighting its relevance to sustainable development. The research followed an embedded mixed-methods approach. Surveys with facilities managers provided broad insights into adoption patterns, while interviews added richer detail on personal and organizational experiences. Results show that perceived benefits strongly influence adoption decisions, while attitudes toward renewable energy, though positive, do not significantly mediate this effect. Technical feasibility was not a moderator but emerged as an important predictor. The interviews revealed practical challenges such as high upfront costs, regulatory barriers, and structural concerns alongside opportunities from new technologies and supportive policies. Overall, the study underscores the value of combining behavioral, technical, and design perspectives. It suggests that tailored solutions, stronger policies, and strategic partnerships can help accelerate the spread of rooftop solar in urban areas.

Keywords: rooftop solar panel adoption, Extended Theory of Planned Behavior (ETPB), Design Thinking Framework, renewable energy integration, technical feasibility, urban sustainability



## INTRODUCTION

Metro Manila, the National Capital Region of the Philippines, is a densely populated metropolis that grows even busier with daily commuter inflows. Its landscape of high-rises, condominiums, and compact low-rise neighborhoods creates intense pressure on energy demand while limiting space for renewable energy integration. In this context, rooftop solar emerges as both an attractive and complex solution.

Electricity use in Metro Manila is rising steadily. Large commercial centers, government offices, shopping malls, and transport systems consume enormous power daily, while households add to the load with air conditioning, appliances, and gadgets, especially during hot, humid months. Much of this demand is met by fossil fuels like coal and natural gas, worsening greenhouse gas emissions and environmental degradation. To make matters more pressing, the Philippines faces some of the highest electricity prices in Southeast Asia, motivating both residents and businesses to seek alternatives (Cruz et al., 2023).

The city enjoys strong solar potential, but rooftop conditions vary widely. Barriers such as shading, poor orientation, structural limits, and complicated ownership arrangements reduce feasibility (Cruz et al., 2023). Despite high potential, adoption is minimal: AI-based mapping shows solar coverage at only 0.47% of usable rooftops, far below even 1% of potential (Eco-Business, 2025).

Policy support has existed since the Renewable Energy Act of 2008, which introduced net metering, feed-in tariffs, tax breaks, and duty-free importation incentives (Solaric, 2025). Yet on the ground, implementation remains uneven. Complex permits, fragmented governance across local government units, and limited public awareness continue to slow progress (New Energy Nexus, 2025).

Public interest is evident, though. A 2024 contingent valuation study found that 82% of households expressed willingness to adopt solar, but only about 20% were likely to proceed once barriers and weak government support were considered (Palanca-Tan, 2024). Current literature largely focuses on rural electrification and large-scale solar farms, leaving urban adoption underexplored. Quantitative studies identify determinants such as financial value and awareness, but they rarely capture how these play out in everyday decision-making. Qualitative perspectives on how Metro Manila residents actually experience, negotiate, and decide on rooftop solar adoption remain scarce.

This gap underscores the need for an embedded mixed-methods approach—one that combines quantitative insights on adoption drivers with qualitative narratives from stakeholders. Beyond academic relevance, the study directly contributes to global goals. It aligns with SDG 7 (Affordable and Clean Energy), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action). Indirectly, it supports SDG 8 (Decent Work and Economic Growth) through green jobs and SDG 12 (Responsible Consumption and Production) by encouraging responsible energy practices. Together, these connections highlight rooftop solar's role not just in addressing electricity needs, but in advancing sustainable, resilient, and climate-smart urban living.

For the quantitative theoretical framework component, the research applies the Extended Theory of Planned Behavior (E-TPB), which expands Ajzen's (1991) TPB by adding predictors such as perceived benefits, moral norms, and environmental concern to explain context-specific decisions, including renewable energy adoption (Yuriev et al., 2020). It also draws on a hybrid of the Diffusion of Innovations (DOI) and Unified Theory of Acceptance and Use of Technology 2 (UTAUT2). DOI (Rogers, 2003) highlights the innovation attributes that influence adoption, while UTAUT2 (Venkatesh et al., 2012) predicts behavioral intention and use through the consideration of contextual factors. For the quantitative conceptual framework, the independent variable (IV) is the Perceived Benefits of Rooftop Solar Panels, the dependent variable (DV) is the Adoption of Rooftop Solar Panels, the mediating variable (MV) is the Attitude Toward Renewable Energy, and the Technical Feasibility of Adoption is the moderating variable (ModV), shown in Figure 1.

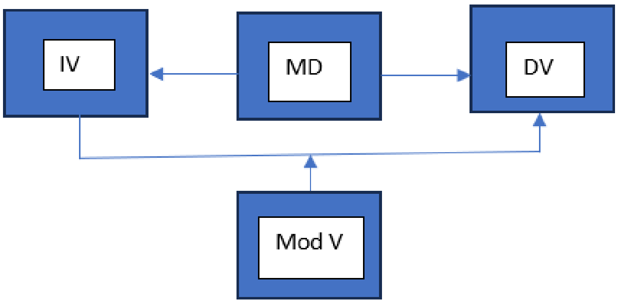


Figure 1
*The Conceptual Framework (Quantitative)*

Research Inquiries for Quantitative Method. The quantitative component aims to explore the determinants of rooftop solar panel adoption in urban buildings. Below are the research questions:

1. Do perceived benefits significantly influence the adoption of rooftop solar panels in urban buildings?

2. Does attitude toward renewable energy mediate the relationship between perceived benefits and adoption decisions?

3. Does technical feasibility moderate the influence of perceived benefits on the adoption of rooftop solar panels?

For the qualitative component, the study used the Systems Thinking Theory (Senge 1990, Meadows, 2008). This theory is an approach to understanding complex phenomena by viewing them as interconnected systems rather than isolated parts. Instead of focusing on linear cause-and-effect, Systems Thinking highlights how components influence one another over time, often producing unintended consequences. In practice, Systems Thinking fosters long-term, adaptive strategies by making visible the interdependencies and leverage points where meaningful change can occur (Senge, 1990; Meadows, 2008). This theory is appropriate since the study looks at how Design Thinking addresses complex, interconnected problems. It positions Design Thinking, as illustrated in Figure 2, as a method to explore feedback loops, interdependencies, and holistic solutions. It is composed of five stages: Empathize, Define, Ideate, Prototype, and Test. These will be explained further in the Results and Discussion for the qualitative aspect.

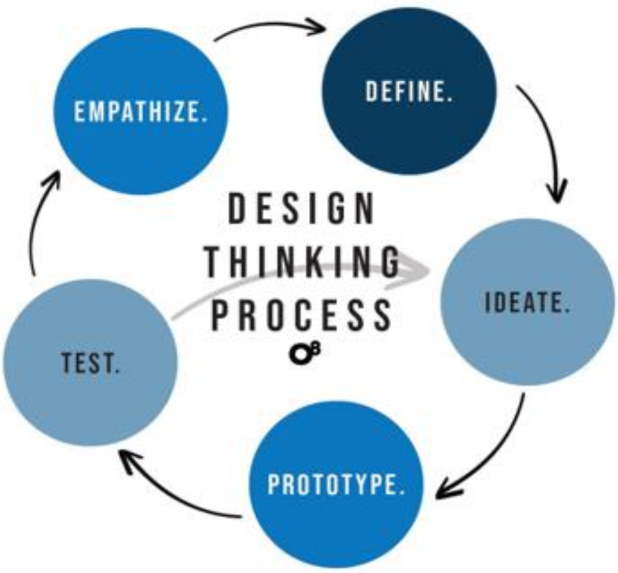


Figure 2
*The Conceptual Framework (Qualitative)*

## LITERATURE REVIEW

The literature consistently emphasizes that perceived benefits are the strongest driver of rooftop solar adoption, especially in urban areas where energy demand is high. In Metro Manila, Palanca-Tan (2024) found that although 82% of households expressed interest in rooftop solar, only about 20% were willing to move forward once they factored in costs, installation challenges, and concerns about provider reliability. This finding highlights how perceptions of economic and environmental benefits shape real decision-making. Globally, Schulte et al. (2022) reinforced this through a meta-analysis of over 100 studies, showing that cost savings, reliability, and environmental advantages matter more than demographic factors. In Malaysia, Lau et al. (2020), applying the UTAUT2 framework, also found that price value, knowledge, and facilitating conditions strongly influence intention. Social influence further reinforces adoption: Bollinger and Gillingham (2012) demonstrated a "solar contagion" effect, where neighbors adopting solar panels reduce perceived risks for others. Attitude plays a key mediating role in this process. Ajzen's (1991) Theory of Planned Behavior underscores that attitudes connect beliefs—such as the expectation of cost savings or environmental benefits—with behavioral intention. Yuriev et al. (2020) confirmed that perceived benefits shape attitudes, which then guide behavior. Scheller et al. (2023) added nuance, showing that environmental benefits tend to strengthen attitudes, while financial benefits may act more directly on intention.

At the same time, technical feasibility moderates' adoption potential. Research from the U.S. National Renewable Energy Laboratory (Gagnon et al., 2016; Sigrin & Mooney, 2018) reveals that roof orientation, shading, and structural limits significantly constrain installations. In dense urban environments, many suitable rooftops are located on multi-family or rental buildings, where legal and administrative hurdles add another layer of difficulty. In Metro Manila, Palanca-Tan et al. (2023) found that governance factors such as condominium rules and shared decision-making often block installations even when perceived benefits are high.

Overall, adoption trends show promise but also persistent barriers. Studies note rising awareness and advances in solar technology (Kazem et al., 2017), but challenges such as shading, older building designs, and regulatory hurdles remain (Mancini et al., 2018; Gooding & Edwards, 2016; Hernandez-Moro & Martinez-Duart, 2013). Promising innovations—such as lightweight panels (Karteris et al., 2016) and flexible financing models like PPAs—could expand uptake. To accelerate adoption, integrated strategies are necessary. Policy incentives like feed-in tariffs and tax credits (Byrne et al., 2017; Barbose et al., 2017), paired with awareness and education campaigns (Zhai & Williams, 2012), can help bridge the gap between widespread interest and actual installations.

## QUANTITATIVE METHODS

This embedded mixed-methods study collected both quantitative and qualitative data, analyzed the data, and sequentially interpreted the findings from both methods. Embedded mixed methods is a type of research design in which one methodological approach is embedded within the other to provide a supportive, supplementary, or exploratory role. (Creswell & Plano, 2018). In this study, the quantitative component serves as the primary framework, and qualitative data are gathered to add context, depth, and insight into the findings (explanatory).

In preparing this manuscript, the author utilized ChatGPT to support the refinement of language, enhance sentence flow, and aid in reorganizing sections for clarity. No part of the data collection, statistical analysis, or interpretation of results was performed by ChatGPT. All outputs generated by the AI were carefully reviewed, fact-checked, and edited by the authors to ensure accuracy, maintain academic integrity, and comply with the ethical standards of research.

In the quantitative phase, a survey was administered to individuals involved in the installation of rooftop solar panels. The survey instrument measured the perceived benefits of rooftop solar panels, the adoption of rooftop solar panels, the attitude toward renewable energy, and the technical feasibility of adoption.

The study was conducted at several establishments in Metro Manila, utilizing both virtual and face-to-face modes. Sixty qualified participants, primarily members of the Facilities Management Organization of the Philippines, responded to the quantitative survey, of whom 52 were valid. The sample size of 52 is appropriate as it meets established guidelines for detecting medium to large effects with a 95% confidence level and 80% statistical power, particularly when using two predictors (Cohen, 1988). This number also aligns with Green's (1991) recommendation of at least 50 cases for testing overall model fit, making it both statistically sound and practical for the study's data collection constraints. This sampling is purposive considering the selection criteria.

The researcher considered participants with basic knowledge of rooftop solar panel adoption. Variables were operationalized in the quantitative questionnaire as the average score on a 5-item Likert scale measuring benefits, attitude, adoption, and technical feasibility. Most participants have technical knowledge or occupy managerial positions. The results of the statistical treatment apply only to the sample participants and cannot be generalized to the entire population.

Although formal ethics committee approval was not required for this study, all research procedures adhered to ethical standards in social research. Participants provided informed consent and were assured of their right to withdraw at any time. The anonymity and confidentiality of responses were maintained throughout the data collection and analysis process, with all data stored securely and used solely for academic purposes.

The researcher designed the questionnaire, but the statements were primarily derived from the review of the related literature and studies. A pretest was administered to a few respondents to determine if there were ambiguous words. A pilot test was also conducted on a small sample to determine the effectiveness of the statements and to assess the applicability of the 5-point Likert scale. Some respondents interpreted questions differently than intended, so testing allowed the researcher to revise or reword items to ensure clarity and consistency. The statements were also analyzed for internal consistency, as measured by Cronbach's Alpha. The Cronbach's alpha value was calculated to be 0.77, which is acceptable and exceeds the standard of 0.70. Questionnaire was distributed via email, Facebook Messenger, and Viber while explanation of study objectives was done through virtual and face-to-face modes.

Simple linear regression was performed to find the significant effect of the (a) perceived benefits of rooftop solar panels, and (b) Actual adoption or installation of rooftop solar panels. Multiple regression analysis was employed to examine the mediating effect of the perceived benefits of rooftop solar panels on attitudes toward renewable energy. Hierarchical regression was used to determine if the technical feasibility moderated the relationship between the perceived benefits and adoption of rooftop solar panels.

## QUANTITATIVE RESULTS

**Quantitative Analysis**. Influence of perceived benefits on the adoption of rooftop solar panels in urban buildings.

Table 1 shows the influence of perceived benefits on the adoption of rooftop solar panels in urban buildings.

Table 1

*Simple Linear Regression Predicting DV From IV*

| Predictor | B | SE B | t | p |
|---|---|---|---|---|
| Constant | 1.03 | 0.43 | 2.38 | 0.021 |
| Ind Var | 0.74 | 0.11 | 6.90 | <0.001 |

*Note.* $R^2 = .49$, Adjusted $R^2 = .48$, $F(1, n - 2) = 47.59$, $p < .001$. *B = unstandardized regression coefficient; SE B = standard error of B.*

A simple linear regression was conducted to examine the influence of perceived benefits on the adoption of rooftop solar panels. The results revealed that the model was statistically significant, F = 47.59, $p < 0.001$, and explained approximately 49% of the variance in DV ($R^2 = .49$, Adjusted $R^2 = .48$). The regression coefficient for IV was statistically significant ($B = 0.74$, $SE\ B = 0.11$, $t = 6.90$, $p < .001$), indicating that for each one-unit increase in IV, DV increased by approximately 0.74 units. These findings support the hypothesis that IV is a strong predictor of DV, highlighting its vital role in influencing the outcome variable.

Table 2 shows the mediating effect of attitude towards renewable energy on the impact of perceived benefits on the adoption decisions.

Table 2

*Multiple Linear Regression Testing the Mediating Effect of MV on the Relationship Between IV and DV*

| Predictor | B | SE B | t | p |
|---|---|---|---|---|
| Constant | 0.44 | 0.65 | 0.67 | 0.504 |
| Ind Var | 0.73 | 0.11 | 6.53 | <0.001 |
| Med Var | 0.16 | 0.13 | 1.22 | 0.229 |

*Note.* Multiple $R = .71$, $R^2 = .50$, Adjusted $R^2 = .48$, $F(2, n - 3) = 23.37$, $p < .001$. *B = unstandardized regression coefficient; SE B = standard error of B; t = t statistic; p = probability.*

The multiple regression analysis examined the combined effects of the independent variable (IV) and the mediating variable (MD) on the dependent variable (DV). The model showed a moderately strong positive relationship (R = 0.706) and explained about 49.86% of the variance in the dependent variable ($R^2 = 0.4986$, Adjusted $R^2 = 0.4772$). The overall regression model was statistically significant, F = 23.3654, $p < 0.001$, indicating that the predictors collectively contribute meaningfully to explaining the outcome. Analysis of the coefficients revealed that the IV had a significant positive effect ($B = 0.7293$, $p < 0.001$), suggesting that for every one-unit increase in IV, the dependent variable increases by approximately 0.7293 units, holding MD constant. In contrast, the effect of MD was positive but not statistically significant ($B = 0.1633$, $p = 0.229$), implying that MD does not independently explain meaningful variance in the dependent variable when controlling for IV.

In practical terms, the addition of MD slightly increased the model's $R^2$. However, it did not improve the model enough to justify its inclusion as a meaningful independent predictor in explaining the outcome. The predictive strength still primarily driven by IV.

Table 3 shows the moderating effect of technical feasibility on the impact of perceived benefits on the adoption decisions. Model 1 shows that the independent variable (IV) alone explains 48% of the variance in the dependent variable (DV), with a highly significant model fit ($p < 0.001$). Model 2 adds the moderator variable as a main effect, increasing the explained variance to 64%, which is a substantial improvement ($\Delta R^2 = 0.16$). This suggests ModV contributes additional explanatory power beyond IV alone.

Table 3

*Hierarchical Regression Testing the Moderating Effect of ModV on the Relationship Between IV and DV*

| Model | $R^2$ | $R^2$ | F | p____ |
|---|---|---|---|---|
| 1.IV | 0.48 | - | 44.80 | <0.001 |
| 2.IV+ModV | 0.64 | 0.16 | 41.66 | <0.001 |
| IV+ModV+Interaction | 0.64 | 0.001 | 27.25 | -____ |

*Note. Model 1 includes the independent variable (IV). Model 2 adds the moderator variable (ModV). Model 3 adds the interaction term (IV × ModV) to test moderation. $\Delta R^2$ = change in $R^2$ from the previous model.*

Model 3 includes the interaction term (IV × ModV) to test for moderation. The increase in $R^2$ is minimal ($\Delta R^2 = 0.001$) and statistically negligible, meaning that the interaction effect does not meaningfully improve the model. While ModV has a significant main effect when added with IV, the lack of improvement in Model 3 indicates no significant moderating effect of ModV on the relationship between IV and DV. Instead, ModV appears to be an independent predictor, not a moderator, in this particular relationship.

## QUALITATIVE METHODS

Considering that the moderating variable, which is Technical Feasibility, was determined to be a predictor rather than a moderator, a qualitative study involving narrative interpretation was done to support the quantitative aspect of the study. Below are the research inquiries for the qualitative component on Technical Feasibility:

1. What do building owners and stakeholders see as the main challenges when it comes to installing rooftop solar panels? (Empathize)

2. What are the most important technical problems that need to be solved to make rooftop solar panels work on a building? (Define)

3. What creative ideas or solutions can be suggested to overcome the technical issues in installing rooftop solar panels on a building? (Ideate)

4. How can sample design layouts be improved so they work well, are safe, and fit the building's needs? (Prototype)

5. What can we learn from trying out a design or small-scale model, and how can it be made better before installing it fully? (Test)

The qualitative phase involved a smaller number of participants. The purposeful sampling technique was employed to determine the maximum sample size, which ranged from 5 to 25, according to Creswell and Plano (2018). The interviews focused on the participants' experiences with the technical feasibility of adoption. Data analysis was conducted using the thematic method, which involves coding and identifying themes. Intercoder reliability, or peer review, was achieved by having another technical person independently code a subset of the interviewees' answers. For the reflexivity, the researcher recognizes that their familiarity with the subject matter could also introduce bias, particularly in the way they framed interview questions, interpreted responses, and identified themes. To mitigate this, they kept a reflexive journal throughout the research process to document their thoughts, assumptions, and potential influences at each stage of data collection and analysis.

In order to validate the findings and ensure they reflected the participants' experiences, the researcher conducted member checking after the initial thematic analysis. A summary of identified themes, along with selected quotes and interpretations, were shared to the interviewees through email or in-person.

Using the Design Thinking framework, the research process is mapped into five distinct phases: (a) Empathize, which aims to understand stakeholders' perspectives related to rooftop solar panel integration; (b) Define articulates the problem statement; (c) Ideate generates a wide range of potential solutions for optimizing the integration of rooftop solar panels; (d) Prototype develops tangible models that embody the most promising ideas, and (e) Test validates the prototypes through feedback from stakeholders and iterative refinement.

Design Thinking, often applied in social innovation contexts, emphasizes empathy-driven and iterative solutions to complex problems (Brown & Wyatt, 2010).

**Ethical Considerations**. The study adhered to ethical standards by securing informed consent and ensuring participants understood the purpose, data use, and right to withdraw, promoting autonomy (Diener & Crandall, 1978). Confidentiality was safeguarded through anonymization, coding, and secure storage, vital when handling sensitive data from building owners to foster trust (Babbie, 2015). Guided by the principle of "do no harm," the research avoided physical, psychological, or financial risks, protecting dignity and well-being in line with non-maleficence (Beauchamp & Childress, 2001).

## QUALITATIVE RESULTS

**Qualitative Analysis.** Tables 4, 5, 6, 7 and 8 show the key statements of the participants and the codes generated from interview questions 1, 2, 3, 4, and 5, respectively. Below each table are the themes that the grouped codes revealed.

Table 4
*Challenges in Installing Rooftop Solar Panels (RQ1 – Empathize)*

| Part | Key Statement | Code |
|---|---|---|
| P1 | Our roof is old and may not handle the extra weight. | Structural limitation |
| P2 | Shading from nearby tall buildings makes solar panels less effective. | Shading issue |
| P3 | Permits and paperwork from the city take too long. | Regulatory barrier |
| P4 | High upfront cost is the biggest barrier. | Financial cost |
| P5 | Tenants in our condominium cannot agree on sharing installation costs. | Ownership conflict |
| P6 | The design of our building makes maintenance access difficult. | Maintenance difficulty |
| P7 | Some homeowners are worried about aesthetics affecting property value. | Aesthetic concern |
| P8 | Lack of reliable installers and contractors is a concern. | Skilled labor issue |
| P9 | We worry about fire hazards or safety issues. | Safety concern |
| P10 | Uncertainty about net metering discourages us. | Policy uncertainty |
| P11 | Maintenance is expensive and hard to schedule. | Maintenance cost |
| P12 | Our building association doesn't prioritize renewable energy. | Lack of stakeholder support |
| P13 | The structural layout of the roof isn't designed for solar. | Roof design limitation |
| P14 | Weather damage and typhoons pose risks. | Environmental risk |
| P15 | Owners are skeptical about long-term savings. | Financial uncertainty |

*Generated themes: Barriers to rooftop solar adoption can be grouped into structural limitations, financial constraints, regulatory processes, and stakeholder resistance.*

Table 5
*Technical Problems to Solve (RQ2 – Define)*

| Part | Key Statement | Code |
|---|---|---|
| P1 | We need stronger roof structures to hold the panels. | Structural support |
| P2 | Better solutions for wiring integration with existing systems. | Electrical integration |
| P3 | Shading analysis tools must be more accurate. | Shading analysis |
| P4 | Simpler net-metering connection is needed. | Policy-technical integration |
| P5 | Waterproofing after installation is a common issue. | Waterproofing |
| P6 | More lightweight panel options should be available. | Panel weight |
| P7 | Inverter compatibility with older electrical systems is a problem. | System compatibility |
| P8 | Fireproof cabling and safety systems should be standardized. | Safety compliance |
| P9 | Our roof angle and orientation are not optimal. | Orientation issue |
| P10 | The panels should withstand strong typhoon winds. | Durability |
| P11 | Condos need clear rules for shared installation. | Shared governance |
| P12 | Cost-efficient battery storage is still missing. | Energy storage |
| P13 | There's a lack of skilled technicians for repairs. | Skilled labor shortage |
| P14 | Space is too limited for large-scale panels. | Space constraint |
| P15 | Easier integration with backup generators is needed. | Backup integration |

*Generated themes: Key technical barriers can be grouped into roof capacity, system compatibility, safety standards, and space constraints.*

Table 6
*Creative Solutions to Technical Issues (RQ3 – Ideate)*

| Part | Key Statement | Code |
|---|---|---|
| P1 | Use lightweight, flexible solar sheets. | Flexible technology |
| P2 | Create shared solar farms for condo owners. | Shared solar solution |
| P3 | Introduce modular panels that are easy to install. | Modular design |
| P4 | Offer government-backed loan programs for installation. | Financial innovation |
| P5 | Use drone-based shading assessments. | Tech-based assessment |
| P6 | Combine solar with rooftop gardens to reduce heat. | Dual-purpose design |
| P7 | Introduce community solar cooperatives. | Collective ownership |
| P8 | Develop foldable solar panels for small spaces. | Compact innovation |
| P9 | Offer pre-approved designs to speed up permits. | Regulatory facilitation |
| P10 | Use transparent solar windows as alternatives. | Building-integrated PV |
| P11 | Install wind barriers to protect panels during typhoons. | Structural protection |
| P12 | Develop local training programs for installers. | Capacity building |
| P13 | Add solar-ready designs in new construction. | Futureproofing |
| P14 | Combine solar with battery-sharing systems. | Energy innovation |
| P15 | Encourage partnerships with property developers. | Strategic collaboration |

*Generated themes: Innovative solutions range from technological advancements (flexible, modular panels) to policy and social strategies (shared solar, cooperatives, training).*

Table 7

*Improving Design Layouts (RQ4 – Prototype)*

| Part | Key Statement | Code |
|---|---|---|
| P1 | Designs should consider roof load capacity from the start. | Structural |
| P2 | Add clear safety zones for maintenance staff. | Safety layout |
| P3 | Layouts must ensure easy water drainage. | Drainage |
| P4 | Provide visualizations so owners can see the impact. | Visualization |
| P5 | Avoid panel placement near HVAC systems. | System separation |
| P6 | Ensure wiring is hidden and safe from the weather. | Wiring protection |
| P7 | Create modular designs for easy expansion. | Scalability |
| P8 | Include typhoon-resistant anchoring systems. | Weather resilience |
| P9 | Designs should minimize shading effects. | Shading optimization |
| P10 | Add fire-safety systems in layouts. | Fire safety |
| P11 | Consider aesthetics—panels should blend with architecture. | Aesthetic integration |
| P12 | Allow for future upgrades like batteries. | Future adaptability |
| P13 | Ensure spacing for cleaning access. | Maintenance access |
| P14 | Layouts should maximize efficiency per square meter. | Efficiency maximization |
| P15 | Include cost-saving configurations. | Cost-efficiency |

*Generated themes: Good solar layouts balance structural safety, aesthetic integration, maintenance ease, and energy efficiency.*

Table 8

*Lessons from Testing/Pilot Models (RQ5 – Test)*

| Part | Key Statement | Code |
|---|---|---|
| P1 | Testing shows how panels perform in actual weather. | Performance validation |
| P2 | We can identify unexpected shading issues. | Shading detection |
| P3 | Small-scale trials reveal maintenance needs. | Maintenance insight |
| P4 | We learn about compatibility with electrical systems. | System compatibility |
| P5 | Pilot runs help calculate real savings. | Financial validation |
| P6 | It builds homeowner confidence before large investment. | Stakeholder confidence |
| P7 | We can test safety systems like breakers. | Safety validation |
| P8 | Trials show if the roof can handle vibrations. | Structural durability |
| P9 | Pilot helps improve installation speed. | Process improvement |
| P10 | We can measure durability in heavy rains. | Weather durability |
| P11 | It gives data for adjusting the panel tilt. | Design optimization |
| P12 | Pilot avoids costly mistakes in full rollout. | Risk reduction |
| P13 | We can test the visual impact on the building. | Aesthetic testing |
| P14 | It helps refine maintenance schedules. | Maintenance planning |
| P15 | Testing shows which designs are most efficient. | Efficiency validation |

*Generated: Pilot testing provides insights into real-world performance, safety, cost-effectiveness, and stakeholder confidence.*

## DISCUSSIONS

**For Quantitative Component.** On the influence of perceived benefits on the adoption of rooftop solar panels in urban buildings, Lau et al. (2020) stated that using UTAUT2 in Malaysia, they found that price value, knowledge, and facilitating conditions strongly influenced adoption intention. This reinforces the idea that perceived benefits (particularly financial ones) drive solar adoption.

Regarding the mediating effect of attitude towards renewable energy on the impact of perceived benefits on the adoption decisions, based on the Review of Related Literature, Yuriev et al. (2020) mentioned that their scoping review confirmed that beliefs about benefits influence attitudes, which in turn influence pro-environmental behavior. However, they also noted that in some contexts, attitudes add little explanatory power when strong benefit perceptions exist. This matches the finding that attitude was not a significant mediator.

As regards the moderating effect of technical feasibility on the impact of perceived benefits on the adoption decisions, Gagnon et al. (2016) and Sigrin & Mooney (2018) studies highlighted that roof orientation, shading, and structural limitations are critical determinants of rooftop solar adoption. They show that feasibility factors directly predict adoption potential, independent of perceptions of benefits. This supports the finding that technical feasibility acts as a direct predictor, rather than a moderator.

**For Qualitative Component.** Guided by the Design Thinking framework (Empathize, Define, Ideate, Prototype, Test), participants were interviewed to capture diverse perspectives. Their responses were thematically analyzed, producing six overarching themes:

***Theme 1: Structural and Physical Limitations.*** Several interviewees pointed to structural weaknesses as a primary obstacle. One building manager admitted, "Our roof is old and may not handle the extra weight" (P1), while another emphasized the impact of shading: "Shading from nearby tall buildings makes solar panels less effective" (P2). Limited roof space was also cited: "Space is too limited for large-scale panels" (P14). These findings echo Gagnon et al. (2016) and Mancini et al. (2018), who identified roof strength, orientation, and available area as critical technical determinants of rooftop solar feasibility. Recent assessments reaffirm these feasibility constraints, estimating detailed rooftop solar potential in the U.S. using high-resolution data (Gagnon, Margolis, & Phillips, 2019). Studies also note that in dense cities, panel orientation and rooftop geometry critically affect yield, requiring optimization for maximum performance (Shukla, Khosla, & Singh, 2016).

***Theme 2: Financial Barriers and Economic Uncertainty.*** The high upfront investment required for installation was repeatedly mentioned. As one participant explained: *"High upfront cost is the biggest barrier"* (P4). Others expressed doubts about economic returns: *"Owners are skeptical about long-term savings"* (P15). Maintenance costs were also raised: *"Maintenance is expensive and hard to schedule"* (P11). This reflects Palanca-Tan's (2024) contingent valuation study, which revealed that while 82% of households expressed interest in rooftop solar, only 20% were likely to proceed when costs and government support were considered. International evidence likewise suggests that economic feasibility remains the strongest predictor of adoption (Schulte et al., 2022). Some participants proposed innovative financial solutions. One suggested: *"Offer government-backed loan programs for installation"* (P4), while another envisioned community solar cooperatives (P7). These align with global strategies where financing innovations, such as power purchase agreements and collective ownership models, have enabled wider adoption (Byrne et al., 2017).

***Theme 3: Regulatory and Governance Constraints.*** Participants described cumbersome bureaucratic processes. One lamented: *"Permits and paperwork from the city take too long"* (P3). Another highlighted policy gaps: *"Uncertainty about net metering discourages us"* (P10). Governance conflicts also surfaced in multi-unit dwellings. A condominium administrator explained: *"Tenants in our condominium cannot agree on sharing installation costs"* (P5). These observations align with findings from New Energy Nexus (2024), which identified fragmented local governance and inconsistent enforcement of renewable energy incentives as barriers in the Philippines. International studies also confirm that bureaucratic inefficiency and unclear policy frameworks delay rooftop solar implementation (Gooding & Edwards, 2016; Hernandez-Moro & Martinez-Duart, 2013).

***Theme 4: Safety and Maintenance Concerns.*** Several worried about fire hazards: *"We worry about fire hazards or safety issues"* (P9). Others mentioned waterproofing: *"Waterproofing after installation is a common issue"* (P5, RQ2). A number of respondents also emphasized the shortage of skilled labor: *"There's a lack of skilled technicians for repairs"* (P13). These concerns are consistent with Shukla et al. (2016), who emphasized the need for fireproof cabling and safe integration of rooftop solar systems, and Mills & Wiser (2019), who noted reliability issues when solar is integrated into existing networks.

Participants suggested solutions such as "*standardized fireproof wiring and typhoon-resistant anchoring systems*" (P8). These align with international best practices in urban solar integration, where resilience and safety measures are built into system design (Probst & Roecker, 2018).

Theme 5: Technological Innovations and Design Improvements. Several participants advocated for lightweight flexible solar sheets (P1), foldable panels for small spaces (P8), and transparent solar windows (P10). One suggested: *"Create modular designs for easy expansion"* (P7), while another emphasized aesthetics: *"Consider aesthetics—panels should blend with architecture"* (P11). These align with research on building-integrated photovoltaics, which emphasizes the value of aesthetically integrated, multifunctional solar designs in urban contexts (Probst & Roecker, 2018; Trullenque & Azari, 2020).

***Theme 6: Stakeholder Trust and Social Acceptance.*** Some participants mentioned skepticism: *"Owners are skeptical about long-term savings"* (P15). Others raised concerns over aesthetics: *"Some homeowners are* *worried about aesthetics affecting property value"* (P7). In contrast, several underscored and highlighted the value of pilot projects: *"It builds homeowner confidence before large investment"* (P6).

These findings resonate with Bollinger & Gillingham's (2012) concept of "solar contagion," where visible adoption by peers reduces skepticism and builds trust. They also align with Zhai & Williams (2012), who demonstrated that community engagement and awareness have a direct impact on the acceptance of rooftop solar.

**Integrated Discussions.** Bringing together the quantitative and qualitative findings paints a clear picture: rooftop solar adoption is not just a matter of numbers or engineering; it is a blend of practical realities, financial decisions, and human considerations. The survey results made it clear that the strongest factors driving adoption are the perceived benefits and the actual feasibility of installing the panels. However, the interviews revealed that these factors are far from straightforward when people face real-world challenges.

Take perceived benefits, for example. On paper, the promise of lower electricity bills and environmental gains is enough to convince many. But in conversations, participants shared doubts, worries about whether the savings would truly materialize, concerns about high maintenance costs, and hesitation over committing to such a significant investment. What looks like a clear financial win on the surface often becomes clouded by uncertainty once people weigh the risks.

The same holds true for technical feasibility. Statistically, it came out as a strong predictor, and the interviews reinforced why. Stakeholders spoke of old roofs unable to carry the weight, limited space in crowded neighborhoods, and the constant threat of typhoons. Even with good intentions, many felt their buildings were not designed with solar in mind. Regulatory red tape and disagreements among condominium owners only added to the challenge.

Attitudes toward renewable energy, while not statistically significant in the model, showed up strongly in people lived experiences. Participants described how issues of trust, aesthetics, and social acceptance could make or break a project. For example, some worried that solar panels would make their property less attractive, while others noted that seeing neighbors successfully adopt solar built their confidence. These subtle but powerful human factors show that attitudes may not directly push adoption, but they create the social environment that makes it easier—or harder—for adoption to spread.

In short, rooftop solar adoption in Metro Manila is a collective journey. It calls for more than just panels on rooftops—it demands collaboration across engineers, policymakers, communities, and homeowners. By combining technical innovation with financial accessibility, good governance, and social trust, the pathway to widespread renewable energy adoption becomes not only possible but sustainable for the long term.

**Conclusions**. Perceived benefits, particularly financial savings and environmental gains, are the strongest drivers of rooftop solar adoption, yet feasibility factors—such as roof strength, shading, and space—independently shape outcomes and cannot be ignored. Adoption is hindered by structural, financial, and social barriers, while technical limitations remain critical bottlenecks that require engineering innovation and standardization. Stakeholders, however, are receptive to innovative models that combine technology with financial and governance reforms. Effective designs must integrate safety, functionality, aesthetics, and adaptability. Trial installations are crucial for mitigating risks, establishing trust, and fostering confidence, underscoring the importance of a comprehensive, integrated adoption strategy.

**Recommendations**. Encouraging rooftop solar adoption in Metro Manila requires strategies that highlight financial value, build confidence through real-life demonstrations, and remove technical and bureaucratic hurdles. Awareness campaigns should emphasize cost savings and return on investment (ROI), showing relatable examples where households or buildings cut electricity bills by as much as 40%. By linking these financial gains with environmental protection, campaigns can appeal to both pragmatic and sustainability-minded audiences. Real-life demonstrations—such as pilot projects in schools, offices, or condominiums—can further bridge the gap between favorable attitudes and actual decisions. At the same time, feasibility must be tackled upfront. Building assessments and technical audits should become standard practice to ensure roofs are structurally sound and electrical systems are safe. Government support is equally vital: one-stop service centers at city halls could streamline permitting, inspections, financing, and installer accreditation in a single location, reducing delays and confusion. In parallel, investment in research and development of lightweight, modular, and weather-resistant solar technologies, along with updated building codes requiring solar-ready features in new constructions, will future-proof urban energy infrastructure and lower retrofit costs.

Beyond these immediate measures, fostering adoption in dense communities requires innovation in design and implementation. Pilot testing modular or shared systems is especially important in condominiums, where individual rooftop ownership is limited. Demonstrating shared energy solutions under government-backed financing can build trust and reduce resistance. Likewise, requiring solar feasibility in architectural designs ensures future projects integrate safety, aesthetics, and adaptability from the start, making adoption smoother and more cost-effective. Small-scale pilots should precede larger rollouts, particularly in multi-unit buildings, to validate savings, durability, and resilience under local conditions. Looking ahead, future research should extend beyond Metro Manila to provincial and rural areas, where challenges may include financial barriers or policy gaps rather than space constraints. Long-term studies on savings, maintenance, and user experiences will provide valuable evidence for policymakers and investors. Exploring innovations such as solar windows and affordable battery storage could further reshape perceptions of renewable energy, making it more accessible and trusted. Collectively, these recommendations highlight that adoption will thrive only through an integrated strategy—one that combines financial incentives, technical innovation, supportive governance, and stakeholder trust.

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