Harnessing 'Photo-Voltaic Mainstreaming' for Rural Electrification: Challenges and Opportunities

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ABSTRACT

This study investigated the challenges and opportunities of the Photovoltaic Mainstreaming Solar Home System (PVM-SHS) for rural electrification in Sitio Tibok, Barangay Bacong, Tulunan, Cotabato. Using a mixed-methods design, data were collected from five PVM-SHS recipient households through structured questionnaires and open-ended responses to examine obstacles in program promotion, the impact of monetary obligations, and the role of PVM-SHS in socio-economic development.

Results revealed unanimous strong agreement across all benefit dimensions, with respondents affirming that PVM-SHS significantly improved daily routines, enabled children's education after dark, enhanced safety and security, supported small business activities, and improved overall living conditions. The primary challenges identified were weather dependency (mean rating 2.00) and system capacity limitations (mean 2.20), while cost-related concerns received relatively low ratings (mean 1.60), indicating that monetary obligations do not constitute major barriers to program adoption.

The study concludes that obstacles are primarily technical and infrastructural rather than economic or social. PVM-SHS plays a substantial role in promoting socio-economic development through economic advancement, educational improvement, enhanced security, and social inclusion. Recommendations include upgrading system specifications, establishing local technical support infrastructure, expanding program coverage, implementing comprehensive user education, and conducting longitudinal research on long-term development impacts.

Keywords: Photovoltaic Mainstreaming, Solar Home System, Rural Electrification, Renewable Energy, Sustainable Development, Off-Grid Communities

Chapter 1

INTRODUCTION

Background of the Study

Energy is required to accelerate growth in every sector of the economy to drive development at all levels of society. Solar energy is a rapidly growing sector in the Philippines, driven by high solar potential and government incentives through tax exemptions and subsidized programs to deliver development in the countryside and achieve total electrification by the year 2028. This also affirms, Moore, Charles (2024) renewable energy adoption in fostering rural development across diverse geographical contexts.

In the frameworks of electrification and development, the Philippine government launched the Photovoltaic Mainstreaming Solar Home System (PVM-SHS), designed to energize homes in the off-grid communities, in partnership with the electric cooperatives and sectors in the community. PVM upholds the perception of achieving rural electrification and offers opportunities to boost socioeconomic potential in rural areas. Solar energy in rural areas has proven significant potential in reducing poverty by enhancing economic opportunities and improving livelihoods, Rumbayan, Meita; Kindangen, Jefrey; Sambul, Alwin; Sompie, Sherwin; Cross, Jeffrey (2025)

The program also corresponds to the growing households in the unserved and underserved households in remote, rural and off-grid communities, that also hinders the government in expanding its grid contributed by lack fitting policies and scarcity of resources. In Nigeria, there will be the need for favorable policies and strong political will from the government at all levels to overcome the above barriers and accelerate the development of solar energy applications Ohunakin, Olayinka S.; Adaramola, Muyiwa S.; Oyewola, Olanrewaju. M.; Fagbenle, Richard O. (2014).

Philippines, as a tropical nation that has only two weather conditions has a viable potential in utilizing solar as a convenient source of electricity. The power capacity of a Photovoltaic system is influenced by solar irradiation levels, cell temperature, and the topographical features of the site Samatar, Abdullahi Mohamed; Mekhilef, Saad; Mokhlis, Hazlie; Kermadi, Mostefa; Alshammari, Obaid (2024).

Photovoltaic as another alternate source of electricity that is substantial to reach far-flung areas with lesser costs. That affirms Chakrabarti, Snigdha; Chakrabarti, Subhendu (2002) development of technologies solar power may not, in general, be taken as a substitute, but can serve as a complement to the fossil fuel based conventional power on the power grid.

The Cotabato Electric Cooperative, Inc. (COTELCO) is one of the pioneering power distribution utilities in the country that has been chosen to implement the PVM in its service area. Recently, COTELCO have distributed PVM units to qualified households coming from different barangays. Consumer-recipients were recommended by the local barangay officials based on the established guidelines and qualification of the program that mandates all potential consumers must be at least a kilometer away from the existing power grid.

Each PVM unit comprised of a 1 system unit that serves as the mother board with two USB charging ports, 4 LED (light-emitting diode) bulbs, an emergency flashlight, and a portable radio. Every consumer has been given a free-of-charge delivery and installations provided by COTELCO, also, the maintenance of the PVM-SHS units from repairs and replacements, if needed.

The PVM-SHS service scheme is a load-based technology where each recipient has an individual cards that must be loaded monetarily through COTELCO before availing its service in a specific period of time. Consequently, the service will depend upon the amount loaded to the system. Therefore, the PVM-SHS is not a dole-out project that freely given to each consumer-recipient.

Furthermore, PVM-SHS directly advances this goal by providing reliable, clean, and sustainable electricity to off-grid households, demonstrating that renewable energy solutions can effectively serve remote, marginalized communities, PVM contributes to (SDG 7: Affordable and Clean Energy). The adoption of solar photovoltaic technology contributes to climate change mitigation by displacing fossil fuel-based energy sources and promoting renewable energy transition (SDG 13: Climate Action). Additionally, PVM supports SDG 4: by enabling children to study after dark, PVM-SHS removes a critical barrier to educational achievement and creates foundations for long-term human capital development. The impact of PVM extends to SDG 1: No Poverty and SDG 8: Decent Work and Economic Growth. By enables extended business operating hours and supports income-generating activities, creating pathways for economic advancement and poverty reduction in low-income rural households, and by serving geographically isolated and economically marginalized communities, the program addresses spatial and socio-economic inequalities in energy access and development opportunities.

Moreover, PVM aligns with SDG 3: the replacement of kerosene lamps with clean electric lighting eliminates indoor air pollution, while improved nighttime safety and security contribute to physical and psychological well-being., SDG 10: by serving geographically isolated and economically marginalized communities, the program addresses spatial and socio-economic inequalities in energy access and development opportunities., and SDG 11: PVM-SHS supports inclusive and sustainable rural community development, enhancing resilience and improving quality of life in underserved settlements.

Statement of the Problem

This study aims to explore the challenges and opportunities associated with harnessing the Photovoltaic Mainstreaming Solar Home System for rural electrification, specifically with a focus on the following:

1. What are the obstacles in promoting PVM-SHS in rural communities.
2. How the monetary obligations affect the promotion and continuity of the program?

What role can PVM-SHS play in promoting socio-economic growth and improving the living standards to attain sustainable development in the underserved areas?

Significance of the Study

The result of this study is an essential tool for the following:

Government. To generate allocations and enact laws that could warrant rural electrification and development in the countryside in parallel with supporting the United Nation's Sustainable Development Goal.

Distribution utility. To assess the challenges and the impact of PVM-SHS in this specific community in order to enhance solar programs for rural areas. Also, the data will serve as proof of the effectivity of the program to drive rural electrification and development in the countryside.

Community: To fully acknowledge the opportunities and promote the adoption of the renewable, non-destructive energy source for sustainable development.

Scope and Limitations

This study is confined to the remote Sitio Tibok in Barangay Bacong in Tulunan town, an off-grid community nested in the mountainous portion of the tri-boundaries of Cotabato, South Cotabato, and Sultan Kudarat provinces. Tibok is one of the pioneering communities that adopted the Photovoltaic Mainstreaming Solar Home System to illuminate homes and to venture into socio-economic potentials.

Thus, the result of the study is based on their statements fundamentally rooted in their experiences, socio-economic capabilities, culture, and geographical location. Therefore, the outcome of the study doesn't necessarily portray the outcome of the PVM program throughout the country.

Definition of Terms

Photovoltaic Mainstreaming Solar Home System—a program initiated by the national government to energize the off-grid households.

COTELCO (Cotabato Electric Cooperative, Inc.) - a power distribution utility that serves the second and third districts of Cotabato province.

Off-Grid—an area with no electric grid.

Chapter 2
REVIEW OF RELATED LITERATURE

The deployment of solar photovoltaic (PV) systems has emerged as a critical strategy for addressing energy poverty and advancing sustainable development in rural areas of developing countries. Over recent decades, PV technology has demonstrated significant potential as a means of decentralized rural electrification, with impressive advances made in technical, organizational, economic, and financial domains (Food and Agriculture Organization [FAO], n.d.). The implementation of solar energy in rural communities has become a critical strategy for advancing multiple Sustainable Development Goals (SDGs), providing reliable, decentralized energy access that enables economic empowerment, job creation, improved healthcare, and enhanced educational opportunities (Solar energy implementation in rural communities, 2025).

Rural electrification remains a significant development challenge globally, with over 45 million people in Southeast Asia alone still lacking access to reliable electricity (Potential of renewable energy technologies, 2025). The energy sector faces supply-demand imbalances and regulatory hurdles that complicate the transition to renewable energy sources (Rural electrification as a catalyst, 2025). However, solar PV systems offer transformative solutions to address these challenges, particularly in regions with abundant sunlight where extending standard grid infrastructure is either impracticable or excessively expensive (Adaptation of solar energy in the Global South, 2024).

Technical and Economic Feasibility

The technical and economic viability of PV systems for rural electrification has been extensively examined across different geographical contexts. Research comparing levelized costs of electricity reveals that solar photovoltaic systems are significantly more cost-effective than traditional diesel solutions, with costs ranging from USD 0.40/kWh to USD 0.61/kWh compared to diesel's USD 0.92/kWh to USD 1.30/kWh (Rural electrification through village grids, 2013). Hybrid renewable energy systems integrating solar, wind, and biomass can reduce costs by up to 30% compared to standalone systems while enhancing supply reliability (Potential of renewable energy technologies, 2025).

Despite these economic advantages, several technical challenges persist. The main barriers to widespread adoption of solar PV systems include low efficiency, high investment costs, and the need for continuous research and development efforts to improve technology and make products cost-effective for end users (Opportunities and challenges in setting up solar photo voltaic based micro grids, 2012). In rural areas of India, studies have identified portability, maintenance, functionality, affordability, and user satisfaction as issues of paramount importance affecting the adoption of solar home systems (Drivers and barriers to rural electrification in India, 2022).

Environmental and Landscape Considerations

The expansion of photovoltaic technology in rural contexts raises important concerns related to the unique characteristics of natural environments and the intrinsic landscape qualities of these areas. A systematic literature review examining 89 scientific publications identified three critical application areas marked by tension between innovation and conservation: the integration of photovoltaics in protected buildings and landscapes, the electrification of remote agricultural areas, and agrivoltaics as a compromise between production needs and landscape compatibility (Photovoltaic Technology and Rural Landscapes, 2025). In internationally protected contexts such as UNESCO World Heritage Sites, the adoption of PV technologies encounters not only technical but also regulatory barriers, necessitating careful evaluation of perceptual and symbolic impacts on the landscape (Photovoltaic Technology and Rural Landscapes, 2025).

Agrivoltaics has emerged as an experimental strategy aimed at preserving agricultural productivity while promoting sustainable development, leveraging technological innovation to address multiple objectives including energy transition, food security, and socio-economic development (Photovoltaic Technology and

Rural Landscapes, 2025). This approach demonstrates how land policies can guide the evolution of PV projects into multifunctional systems that deliver economic benefits, reduce land costs, and achieve poverty alleviation through electricity generation (Chinese adapting land policy, 2024).

Socio-Technical Barriers and Community Engagement

The successful deployment of solar mini-grids and PV systems in rural areas is significantly influenced by socio-technical factors embedded in the socio-cultural contexts of rural communities. Research conducted in Ghana's rural island communities revealed critical social barriers including lack of community engagement, limited technical knowledge, insufficient awareness of technology benefits, and socio-cultural resistance to new technologies (The socio-technical barriers and strategies, 2021). Similarly, studies in isolated Amazonian systems identified 19 barriers across six dimensions, including high initial costs, shortage of supporting infrastructure, and absence of clear legal frameworks for distributed generation in remote areas (Solar electrification in isolated Amazonian systems, 2024).

Engaging with local communities, understanding their specific needs, and incorporating their input into project design are critical for ensuring the success of rural electrification efforts (Renewable Energy in Rural Areas, 2024). Research emphasizes that social factors occupy an important place in energy transitions, and despite technological breakthroughs and financial support, deployment still faces significant barriers rooted in community contexts (The socio-technical barriers and strategies, 2021). Training programs and local partnerships with renewable energy companies are essential to building the necessary technical expertise and overcoming limited technical capacity in rural areas (Renewable Energy in Rural Areas, 2024).

Policy Frameworks and Institutional Support

Policy frameworks play a crucial role in enabling or constraining the adoption of photovoltaic systems for rural electrification. Using multiple regression and analytical hierarchy process approaches, researchers have identified policy-related barriers as among the most significant obstacles to solar project implementation in developing economies (Barriers to Solar PV Adoption, 2024). A multi-stakeholder analysis of rural electrification in India systematically prioritized drivers and barriers for both centralized grid and renewable energy-based mini-grids, emphasizing the importance of understanding these factors for successful policy formulation (Drivers and barriers to rural electrification in India, 2022).

Government support and subsidies have proven instrumental in promoting PV adoption, though their implementation must be carefully designed to avoid market distortions. Subsidized projects have been criticized for distorting existing private PV market infrastructure, with recent projects attempting to balance subsidy components with market-based approaches (FAO, n.d.). In China, photovoltaic poverty alleviation policies implemented since 2014 demonstrated mixed results, with some studies showing significant income increases of 7-8% in pilot counties (Solar photovoltaic interventions, 2020), while others revealed weak policy implementation effects requiring more robust technology, adequate maintenance, and financing strategies (Policy evaluation and optimization, 2024).

Reliability, Maintenance, and Long-Term Sustainability

Ensuring the long-term sustainability of renewable energy systems in rural areas presents significant challenges related to ongoing maintenance, component availability, and technical expertise. A comprehensive analysis of solar PV systems in Uganda's Lango region identified harsh environmental conditions, limited availability of certified components, and insufficient maintenance infrastructure as factors collectively leading to system inefficiencies and reduced operational lifespans (Reliability and maintainability analysis, 2024). Batteries, essential for energy storage, are particularly prone to degradation under extreme temperatures, and inferior batteries often have limited charge-discharge cycles, compromising their ability to store and deliver energy reliably (Reliability and maintainability analysis, 2024).

To address these challenges, research recommends implementing preventive and predictive maintenance practices, capacity-building programs for local technicians, and government-supported policies aimed at reducing the cost of quality components (Reliability and maintainability analysis, 2024). The maintenance of photovoltaic poverty alleviation facilities is critical for project performance, as improper or neglected maintenance will shorten efficiency and project life, potentially transforming investments into new burdens for people experiencing poverty rather than sustainable solutions (Policy evaluation and optimization, 2024).

Implementation Models and Best Practices

Diverse implementation models have emerged for delivering electricity to rural areas, with solar home systems (SHS) and village microgrids representing the two major approaches. The choice between these models depends on factors including the number of homes on the system, with the main tradeoff being between marginal cost of distribution and the cost of installing solar systems in individual houses (Rural Electrification with Solar Energy, n.d.). The World Bank has advocated for hybrid renewable-diesel systems for small villages, as pure solar electricity systems can take more than twenty years to become more economical than diesel generators, though hybrid systems can reduce fuel usage by 27% and carbon dioxide emissions by 24% (Rural Electrification with Solar Energy, n.d.).

A detailed roadmap for implementing rural electrification projects using solar PV has been developed based on participatory observation of Solar Home Systems, examining their impact, advantages, disadvantages, and operation (Urmee et al., n.d.). This holistic approach emphasizes the importance of user-centric design, context-specific solutions, and long-term sustainability planning. Successful case studies from Bangladesh's Solar Home System program and India's Solar Energy Program demonstrate that off-grid solar solutions can bring electricity to millions of rural households, reducing reliance on fossil fuels and improving energy access in underserved areas (Solar Energy's Role, 2024).

Socio-Economic Impacts and Development Outcomes

The socio-economic impacts of solar PV rural electrification extend far beyond mere access to electricity. Research demonstrates that solar energy systems enable economic empowerment through powering rural industries, enabling mechanization in agriculture, and creating new job opportunities in the installation, maintenance, and operation of renewable energy systems (Solar energy implementation in rural communities, 2025). A case study from Ghana's Ketu North District found statistically significant differences in perceptions between electrified and non-electrified communities regarding improved quality of life and enhanced economic opportunities, with access to electricity identified as a catalyst for socio-economic growth (Rural electrification as a catalyst, 2025).

In China, the implementation of large-scale photovoltaic poverty alleviation projects from 2013 to 2016 demonstrated that PV investments can significantly impact rural development, with effects being positive and significant in the year of implementation and more than twice as high in subsequent years, particularly benefiting poorer regions (Solar photovoltaic interventions, 2020). The power generated through solar PV systems can operate motors and pumps for irrigation, store agricultural products, enable school children to study at night, allow women to engage in entrepreneurial activities, contribute to better health by switching from biomass fuels to clean electricity, and provide rural communities access to telecommunications and mass media (Opportunities and challenges in setting up solar photo voltaic based micro grids, 2012).

Energy Justice and Equity Considerations

The prospects of decentralized solar energy home systems must be evaluated through the lens of energy justice to ensure equitable and sustainable transitions. Research on distributed solar photovoltaic systems in rural communities reveals that while there is high satisfaction among users, factors influencing willingness to procure additional solar power include income, education level, duration of solar use, user satisfaction, time of day for power supply, and financial support (The prospects of decentralised solar energy, 2019). Notably, freely given solar power offers limited incentives for procuring more solar power, suggesting that welfare policies using subsidies, while intended to improve quality of life for disadvantaged populations, may fail to address fundamental structural aspects of the energy system underscored by procedural justice issues (The prospects of decentralised solar energy, 2019).

Policies for distributed clean energy in emerging countries must address concurrent energy transitions and energy justice frameworks to support sustained decentralized solar transitions (The prospects of decentralised solar energy, 2019). This includes ensuring that rural electrification initiatives do not merely provide minimal electricity access but enable meaningful participation in modern economic activities and improve overall quality of life in ways that are sustainable and equitable.

Regional Variations and Adaptive Strategies

Regional differences significantly influence the effectiveness of photovoltaic rural electrification strategies. In Southeast Asia, where over 45 million people lack reliable electricity access, solar PV leads rural electrification efforts with declining costs, while biomass energy contributes up to 15% of rural energy use in Indonesia and Thailand, and small hydropower accounts for 20% of rural generation in Laos and Vietnam (Potential of renewable energy technologies, 2025). However, deployment remains hindered by upfront costs exceeding $2,500 per household for solar systems, limited technical expertise, policy inconsistencies, and socio-cultural resistance (Potential of renewable energy technologies, 2025).

In the Amazon region, the unique geographic, climatic, and socio-economic conditions require specially tailored approaches. Isolated systems face challenges including the enormous distances involved, limited transportation infrastructure, and the need for community-based maintenance systems (Solar electrification in isolated Amazonian systems, 2024). A systematic literature review identified ten mitigation strategies aligned with Sustainable Development Goals, emphasizing the need for comprehensive and systemic analyses that consider multiple dimensions rather than addressing isolated technical or policy barriers (Solar electrification in isolated Amazonian systems, 2024).

Integration with Sustainable Development Goals

The role of solar energy in achieving the United Nations Sustainable Development Goals has received increasing attention in recent literature. Solar energy aligns with multiple SDGs, including Goal 7 (Affordable and Clean Energy), Goal 13 (Climate Action), and Goal 3 (Good Health and Well-being), while also contributing to poverty reduction, economic development, and environmental sustainability (Solar Energy's Role, 2024). Research employing city-level scenarios in China demonstrates significant variations in PV deployment across diverse goal-oriented scenarios, revealing potential conflicts or synergies between different SDGs and highlighting the need for integrated planning approaches that balance environmental, resource, and social factors (Promoting Sustainable Development Goals, n.d.).

The implementation of rural rooftop distributed photovoltaic systems plays a crucial role in energy strategies to achieve sustainable development goals, contributing to carbon peak and carbon neutrality objectives while supporting high-quality development and ecological civilization (Empirical study on sustainable energy development, 2024). However, despite technological maturity, lower costs, and supportive policies, adoption rates in many regions remain below expectations, indicating the need for more comprehensive approaches that address technical, economic, social, and policy dimensions simultaneously (Empirical study on sustainable energy development, 2024).

The literature reveals that harnessing photovoltaic mainstreaming for rural electrification presents both significant opportunities and persistent challenges. While technological advances have improved efficiency and reduced costs, successful implementation requires addressing complex socio-technical barriers, developing appropriate policy frameworks, ensuring long-term maintenance capabilities, and engaging communities meaningfully in the planning and implementation process. Future research should focus on developing scalable models, assessing environmental impacts comprehensively, creating innovative financing mechanisms, and formulating strategies to overcome adoption barriers in underserved rural communities. The synthesis of existing research emphasizes that photovoltaic rural electrification must be approached holistically, integrating technical solutions with social, economic, environmental, and policy considerations to achieve truly sustainable and equitable energy access.

Conceptual Framework

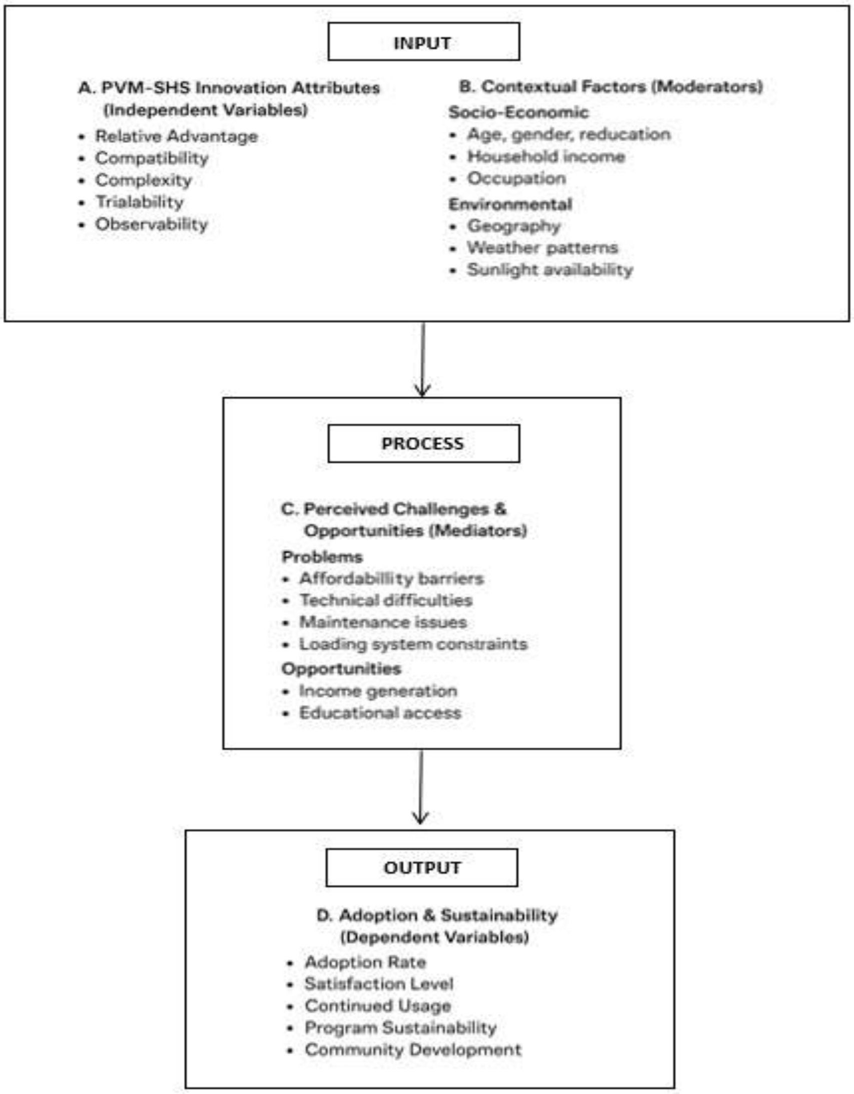

Figure 1: Perceived Conceptual Framework of the Study

Chapter 3
METHODOLOGY

This chapter discusses the research design, rationale of qualitative, sampling procedure, and data analysis.

Research Design

The questionnaire employs a qualitative approach, using open-ended questions to collect rich, descriptive data. This design allows respondents to share their thoughts, feelings, and experiences in detail, providing a deeper understanding of the issues.

Rationale for Qualitative Method

An in-depth understanding of lived experiences and contextual barriers qualitative; the Diffusion of Innovation framework demands statistical measurement of adoption factors alongside nuanced exploration of perceptions; and the complex rural context necessitates both breadth (how many, how much) and depth (why, how) of understanding.

Component

Participants: Purposive sampling of 3-4 key informants including community elders or barangay officials, PVM-SHS users with varying success levels, and a local business owner utilizing the system.

The questionnaire is divided into five sections:

Demographic & Household Info: Gathers background information on respondents, including age, gender, occupation, and income level.

Obstacle: Explores challenges faced by respondents in using PVM-SHS, such as performance issues, maintenance, and affordability.

Monetary: Investigates financial barriers, costs, and affordability of PVM-SHS.

Benefits: Examines the benefits of PVM-SHS, including economic, social, and environmental advantages.

Community-level Benefits: Assesses the impact of PVM-SHS on community development, education, and household expenses.

Data Analysis: The qualitative data will be analyzed using thematic analysis, involving: **Coding:** Identifying patterns and themes in respondents' answers. **Categorization:** Grouping similar themes and concepts together. **Interpretation:** Drawing meaning from the data, highlighting key findings, and implications.

Ethical Considerations

The study will secure informed consent from all participants, maintain confidentiality through data anonymization, obtain barangay clearance, coordinate with COTELCO, and respect cultural sensitivities of the indigenous community.

Chapter 4
PRESENTATION, ANALYSIS AND INTERPRETATION OF DATA

This chapter presents the findings derived from the mixed-methods investigation of the Photovoltaic Mainstreaming Solar Home System implementation in Sitio Tibok, Barangay Bacong, Tulunan, Cotabato. The data encompasses both quantitative measurements through structured surveys and qualitative insights gathered from open-ended responses. Five PVM-SHS recipient households participated in this study, providing comprehensive perspectives on their experiences, challenges, and opportunities associated with the program.

Demographic Profile of Respondents

The demographic characteristics of the five respondents reveal a community composition representative of rural agricultural settings in Mindanao. The respondent group consisted of three males and two females, with ages ranging from 28 to 54 years old, yielding a mean age of 43 years. This age distribution indicates that the PVM-SHS program primarily serves middle-aged household heads who are in their productive years and actively engaged in livelihood activities.

In terms of occupational profile, the respondents demonstrated diverse economic activities characteristic of rural communities. Two respondents identified themselves as farmers, reflecting the agricultural base of Sitio Tibok, while the others engaged in entrepreneurial ventures including store ownership, small business operations, and youth leadership roles. This occupational diversity suggests that the PVM-SHS program serves households with varying economic activities and livelihood strategies.

The civil status distribution revealed that four respondents were married while one was single, indicating that the program predominantly benefits family households. Regarding monthly household income, three respondents reported earnings below PHP 5,000, while two respondents indicated income in the PHP 5,000-10,000 range. Notably, no respondents reported monthly household incomes exceeding PHP 10,000, underscoring the economically challenged circumstances of the community. This income profile aligns with national poverty indicators for remote rural areas and validates the program's targeting of underserved populations living below or near the poverty threshold.

Table 1. Demographic Profile of Participants (N=5)

Respondent	Age	Gender	Occupation	Civil Status	Monthly Income (PHP)
1	41	Male	Farmer	Married	<5,000
2	28	Male	Youth Leader	Single	<5,000
3	47	Female	Store Owner	Married	5,000-10,000
4	54	Female	Entrepreneur	Married	<5,000
5	45	Male	Farmer	Married	5,000-10,000

1. That obstacles in promoting PVM-SHS in rural communities.

While the benefits assessment revealed unanimous satisfaction, the challenges section presents a more nuanced picture, with respondents expressing varying levels of concern across different challenge dimensions. Data provides valuable insights into the most pressing obstacles facing PVM-SHS adoption and sustained utilization in the community.

1.1 Most Critical Challenges

The challenge commonly narrated was the limitation of the PVM indicating that respondents perceive the current system capacity as insufficient for their household needs. This was followed closely by concerns about system failure during cloudy or rainy days, which directly impacts the reliability and consistency of the service. These two challenges are intrinsically related to the technical limitations of solar photovoltaic systems and the geographical and climatic context of the community.

1.2 Moderate Challenges

Several challenges received moderate ratings, these include difficulty in swiftly calling for repair services, and perceptions that PVM service is not efficient due to unreliable sunlight. In the most common adverse technical issues, the maintenance and repair challenge is particularly noteworthy, as it suggests potential gaps in the technical support infrastructure necessary for sustained system operation. The knowledge gap regarding sustainable development contributions indicates that while users appreciate the immediate practical benefits, they may not fully recognize the broader environmental and developmental significance of renewable energy adoption.

2. The monetary obligations affect the promotion and continuity of the program.

Interestingly, several challenges that might have been anticipated as significant received relatively low assessments. The cost of PVM load was not perceived as a major obstacle, suggesting that despite economic constraints, households find the loading fees manageable or worthwhile given the benefits received. Similarly, loading system accessibility and the loading affordability were not identified as major problems. Most notably, the perception that PVM is inadequate to household needs received unsignificant concerns to respondents.

The comparison with kerosene costs revealed that respondents do not perceive PVM as significantly more expensive than traditional energy sources. This finding is particularly important because it suggests that economic barriers to PVM adoption and sustained use are not as prohibitive as might be expected in a low-income community. The moderate rating indicates that while PVM does require monetary investment, it is not perceived as unreasonably costly compared to the alternative of kerosene lamps, which involve ongoing fuel expenses.

3. The role can PVM-SHS play in promoting socio-economic growth and improving the living standards to attain sustainable development in the underserved areas.

The open-ended responses provided rich contextual understanding of the quantitative findings, revealing the lived experiences and perspectives of PVM-SHS users in their own words.

3.1 Biggest Benefits Experienced

When asked about the biggest benefit experienced from PVM-SHS, respondents emphasized several interconnected themes.

Extended productive hours: Multiple respondents highlighted the ability to continue important activities even during nighttime, with one noting the capacity to "extend important activities even during nighttime" and another emphasizing "we can extend our small livelihood activities even during nighttime.”

Business enablement: The production of livelihood items was mentioned, with respondents noting that "bamboo bags and sticks can extend until night," indicating that the system supports artisanal and manufacturing activities.

Convenience for daily family activities: One respondent stated the benefit as "longer time for family bonding to talk about important things before dinner. Students can study," emphasizing both social cohesion and educational dimensions.

Early morning operations: The ability to "extend the operation of my small store in the evening and open it early in the morning because we are illuminated by PVM" demonstrates how the system enables expanded business hours.

Improved academic performance: Better lighting and access to power for learning devices have led to improved grades and academic outcomes. Extended study hours with reliable lighting, students can study longer and complete homework assignments more easily.

Research data reveals a comprehensive picture of PVM-SHS implementation in Sitio Tibok. The findings demonstrate the open-ended narratives confirming substantial benefits alongside manageable but significant challenges.

The challenge data presents a more nuanced picture, with weather dependency, system capacity limitations, and maintenance accessibility emerging as the primary obstacles. Notably, the relatively low ratings for cost-related challenges suggest that the program's load-based payment model has achieved a reasonable balance between sustainability and affordability for this low-income community. However, responses reveal that even relatively low-rated challenges can have substantial real-world impacts on user experience, particularly during prolonged rainy periods or when maintenance issues arise.

The unanimous strong agreement across all benefit dimensions provide rich, contextual detail about how PVM-SHS transforms daily life. The extension of productive hours, educational opportunities for children, enhanced security, and support for livelihood activities emerge as interconnected benefits that collectively elevate household welfare and community development potential.

The community-level assessment indicates moderate institutional support and information availability, with significant room for improvement in local technical capacity. The suggestions for enhanced promotion strategies emphasize education, multi-stakeholder engagement, and peer advocacy, all of which align with best practices in community-based renewable energy adoption.

Overall, the data strongly supports the conclusion that PVM-SHS has been successful in delivering meaningful benefits to recipient households in Sitio Tibok, while also revealing specific areas where programmatic improvements could enhance sustainability, expand adoption, and deepen impact. The findings provide actionable insights for program refinement and scaling, addressing the study's core research questions about obstacles, monetary obligations, and socio-economic development potential.

Chapter 4

SUMMARY, CONCLUSION, AND RECOMMENDATION

Summary

This study investigated the challenges and opportunities associated with harnessing the Photovoltaic Mainstreaming Solar Home System for rural electrification in Sitio Tibok, Barangay Bacong, Tulunan, Cotabato. Employing qualitative research gathered from five PVM-SHS recipient households through structured questionnaires and open-ended responses.

The demographic profile revealed a community of middle-aged household heads engaged primarily in agricultural and small-scale entrepreneurial activities, with monthly household incomes predominantly below PHP 10,000. This economic profile underscores the program's targeting of underserved populations living at or near poverty thresholds.

Regarding benefits, the study found unanimous strong agreement across all measured dimensions. Respondents affirmed that PVM-SHS made significant contributions to daily routines, provided reliable lighting, enabled children's education after dark, improved household safety and security, facilitated gadget charging, sustained small business activities, boosted self-esteem, and improved overall living conditions. These findings demonstrate that the program successfully delivers on its core value propositions and creates multidimensional positive impacts.

The challenge assessment revealed more nuanced findings. The most significant obstacles identified were system capacity limitations and performance degradation during cloudy or rainy weather. Moderate challenges included difficulties accessing repair services, knowledge gaps about sustainable development contributions, and perceptions of inefficiency due to weather dependence. Notably, cost-related challenges received relatively low ratings, suggesting that the program's payment model is perceived as manageable despite economic constraints.

Respondents emphasized the transformative impact of extended productive hours, particularly for small businesses and children's education. The primary obstacle consistently identified was weather dependency, which affects system performance during the region's prolonged rainy season. Suggestions for improvement centered on enhanced information dissemination, improved technical support infrastructure, and community-based promotion strategies.

Respondents identified opportunities for community development through improved living conditions, enhanced economic activities, educational advancement, and increased security. Effective promotion strategies suggested included multi-stakeholder engagement, community campaigns, geographic expansion, and peer-to-peer advocacy.

Conclusion

Based on the comprehensive analysis of data, this study concludes the following in relation to the research questions:

The primary obstacles in promoting PVM-SHS in Sitio Tibok are technical and infrastructural rather than economic or social. Weather dependency emerges as the most critical challenge, with system performance degradation during cloudy and rainy conditions creating reliability concerns. The limited capacity of PVM units relative to household energy needs represents another significant obstacle, though interestingly, respondents simultaneously perceive the system as adequate for essential needs. The geographic isolation of the community compounds these challenges by hindering timely access to maintenance and repair services, revealing gaps in technical support infrastructure.

Importantly, commonly anticipated obstacles such as high costs, cultural resistance, or lack of interest were not strongly evident in the data. This suggests that the program has successfully addressed basic economic and social barriers to adoption, though technical limitations and support infrastructure remain areas requiring attention.

The monetary obligations associated with PVM-SHS do not appear to significantly hinder program promotion or continuity. The cost of PVM load received a relatively low challenge rating and respondents did not perceive PVM as substantially more expensive than traditional kerosene-based lighting. This finding is particularly significant given the low-income profile of recipient households, suggesting that the load-based payment model has achieved an appropriate balance between program sustainability and affordability.

PVM-SHS plays a substantial and multifaceted role in promoting socio-economic growth and improving living standards in Sitio Tibok, contributing to sustainable development across multiple dimensions:

Economic Development: The system enables extended operating hours for small businesses and income-generating activities, directly expanding economic opportunities. Respondents consistently reported that PVM-SHS allows them to sustain and improve small business activities, with specific examples including store operations and artisanal production (bamboo bag and stick making). The ability to recharge essential gadgets further supports economic participation in an increasingly digital economy.

Educational Advancement: Universal acknowledgment that PVM-SHS enables children to study after dark represents a critical pathway for long-term human capital development and intergenerational poverty reduction. This educational benefit directly supports Sustainable Development Goal 4 (Quality Education) and creates foundations for future socio-economic mobility.

Health and Safety: Improved nighttime safety and security, combined with elimination of indoor air pollution from kerosene lamps, contribute to household health and well-being. These benefits align with

SDG 3 (Good Health and Well-being) and create enabling conditions for other development activities.

Social Development: The psychosocial benefit of enhanced self-esteem and reduced marginalization contributes to social inclusion and community dignity. Respondents emphasized how access to modern energy services makes them feel less isolated and more connected to broader development processes.

Environmental Sustainability: While not the primary benefit articulated by respondents, PVM-SHS contributes to climate change mitigation through renewable energy adoption, supporting SDG 13 (Climate Action) and SDG 7 (Affordable and Clean Energy).

The convergence of these benefits demonstrates that PVM-SHS functions as an enabling infrastructure that catalyzes development across multiple domains simultaneously. Rather than providing electricity as an end in itself, the system creates conditions for education, economic activity, health improvement, and social inclusion—all fundamental dimensions of sustainable development.

In conclusion, the Photovoltaic Mainstreaming Solar Home System represents a successful rural electrification intervention in Sitio Tibok that has delivered substantial and meaningful benefits to recipient households. While technical challenges related to weather dependency and system capacity require attention, and infrastructure for maintenance support needs strengthening, the program has effectively addressed economic and social barriers to adoption. Most significantly, PVM-SHS plays a catalytic role in promoting multidimensional sustainable development, creating pathways for economic advancement, educational improvement, and enhanced quality of life in this remote, underserved community. The program's demonstrated contributions to eight Sustainable Development Goals validate its significance as a model for inclusive, sustainable rural electrification that can be scaled to benefit additional off-grid communities across the Philippines and beyond.

Recommendation

Based on the findings and conclusions, the following recommendations are proposed for various stakeholders:

For Government Agencies and Policy Makers

Enhance System Specifications: Consider upgrading PVM-SHS units with higher capacity batteries and more efficient solar panels to address system limitation concerns and improve performance during low-sunlight conditions. Conduct feasibility studies on hybrid systems that could supplement solar with alternative renewable sources during extended cloudy periods.

Establish Local Technical Support Infrastructure: Develop a cadre of community-based technicians through training programs, ensuring timely maintenance and repair services. Consider partnership models with local organizations or cooperatives to create sustainable technical support systems that reduce dependency on external service providers.

Expand Program Coverage: Scale up PVM-SHS distribution to additional off-grid communities, prioritizing areas with similar profiles to Sitio Tibok. Develop clear criteria and transparent processes for community selection and household eligibility to ensure equitable access.

Strengthen Policy Frameworks: Enact or enhance legislation supporting rural electrification through renewable energy, including provisions for sustainable financing, technical standards, and long-term program sustainability. Integrate PVM-SHS and similar programs into broader rural development strategies and align with national commitments to Sustainable Development Goals.

Develop Tiered System Options: Create multiple PVM-SHS tiers with varying capacities and price points to accommodate diverse household needs and financial capacities. This flexibility could address the tension between affordability and system adequacy.

For Distribution Utilities (COTELCO)

Implement Comprehensive User Education Programs: Develop and deliver systematic training on PVM-SHS operation, maintenance, and troubleshooting. Include modules on renewable energy benefits, sustainable development contributions, and optimal system utilization to address knowledge gaps identified in the study.

Establish Efficient Loading and Maintenance Systems: Create mobile loading stations or partner with local stores to reduce geographic barriers to system reloading. Develop predictive maintenance schedules and rapid response protocols to minimize downtime and enhance user satisfaction.

Monitor and Document Impact: Implement systematic data collection on system performance, user satisfaction, and development outcomes. Use this data to demonstrate program effectiveness to stakeholders and identify areas for continuous improvement.

Facilitate Peer Learning Networks: Organize regular community meetings where experienced PVM-SHS users can share best practices, troubleshooting strategies, and success stories with newer recipients or potential adopters. This peer-to-peer learning model can enhance knowledge transfer and program promotion.

Consider Flexible Payment Models: Explore options for graduated payment schemes, seasonal adjustments, or community-based bulk loading arrangements that could further reduce financial barriers while maintaining program sustainability.

For Community Members and Local Leaders

Actively Promote PVM-SHS Adoption: Community leaders and current beneficiaries should serve as advocates for the program, sharing their positive experiences with potential recipients. Organize community information sessions highlighting concrete benefits and addressing common concerns.

Form User Associations: Establish PVM-SHS user groups to facilitate collective learning, coordinate maintenance services, negotiate better terms with service providers, and amplify community voice in program decision-making.

Maximize System Benefits: Explore creative ways to leverage PVM-SHS for community development, such as establishing community charging stations, supporting cottage industries that require electricity, or creating study centers for children.

Engage in Program Improvement: Provide continuous feedback to COTELCO and government agencies on system performance, challenges encountered, and suggestions for improvement. Active community participation in program refinement can enhance relevance and effectiveness.

For Future Research

Conduct Longitudinal Studies: Implement multi-year research tracking PVM-SHS impacts over time, including educational outcomes for children, business growth trajectories, and evolving user satisfaction. Longitudinal data would provide stronger evidence of long-term development impacts.

Expand Geographic Scope: Replicate this study in other PVM-SHS communities across different regions of the Philippines to identify common patterns and context-specific variations. Comparative analysis could inform program adaptation to diverse settings.

Investigate Economic Impacts Quantitatively: Conduct detailed economic analysis measuring income changes, business revenue growth, and cost savings attributable to PVM-SHS. Cost-benefit analysis would provide concrete evidence of economic returns on investment.

Explore Environmental Impacts: Quantify carbon emission reductions, fossil fuel displacement, and other environmental benefits of PVM-SHS at scale. This data could strengthen the program's alignment with climate change mitigation goals.

Study Technical Innovations: Research optimal system configurations for different climatic conditions, hybrid renewable energy systems, and emerging battery technologies that could address identified technical limitations.

Examine Gender Dimensions: Investigate differential impacts of PVM-SHS on women and men, exploring how electrification affects gender roles, women's economic opportunities, and household decision-making dynamics.

Implementation of these recommendations by relevant stakeholders can enhance the effectiveness, sustainability, and scalability of the Photovoltaic Mainstreaming Solar Home System program, ultimately contributing to the achievement of total rural electrification and sustainable development in the Philippines. The success observed in Sitio Tibok demonstrates the viability of PVM-SHS as a model for off-grid rural electrification, warranting continued investment, refinement, and expansion to benefit additional underserved communities nationwide.

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