



Integrating Renewable Energy and Rural Innovation: A Case Study of the Rumah Energi Program in Indonesia

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Abstract

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Rural innovation in Indonesia increasingly depends on access to sustainable energy solutions. Despite growing attention to renewable energy initiatives, the integration of such programs into rural development and community empowerment models remains underexplored. This study aims to analyze how renewable energy initiatives, particularly biogas and solar energy, contribute to rural innovation, community empowerment, and environmental sustainability through the Rumah Energi Program in Indonesia. Employing a qualitative case study approach, the research utilizes document analysis of Rumah Energi's annual reports (2017–2023), reviews program implementation data across multiple provinces, and synthesizes secondary literature on rural development and renewable energy transitions. The findings reveal that the Rumah Energi Program has facilitated the construction of over 29,000 biogas units, trained more than 370 farmers in bio-slurry utilization, engaged 162 construction partners, and reduced approximately 528,000 tCO₂e emissions. In addition, gender-focused initiatives, such as Pro-Women for Renewable Energy, have strengthened the participation of women farmers and local champions in rural innovation. These outcomes demonstrate that renewable energy initiatives not only mitigate environmental burdens but also generate tangible economic benefits, including household savings on LPG and fertilizers, while fostering community-driven models of sustainability. Overall, the Rumah Energi Program provides a replicable framework for integrating renewable energy and rural innovation in developing countries, and future research should explore comparative models across Southeast Asia to assess scalability, policy integration, and long-term sustainability impacts.

Introduction

Access to clean and sustainable energy has become a global development priority, particularly under the United Nations Sustainable Development Goal 7 (SDG7), which emphasizes universal access to affordable, reliable, and modern energy services by 2030 (Newell et al., 2021). Despite significant progress, around 675 million people worldwide remained without electricity access in 2021, with rural areas accounting for nearly 80% of this deficit (Raimi et al., 2022). Recent studies suggest that achieving universal electrification will require a stronger focus on decentralized renewable energy solutions, as centralized grid expansion alone is insufficient in geographically dispersed and low-income contexts ((Hargroves et al., 2023); Hafner & Tagliapietra, 2020).

The urgency of decentralized renewable energy is further amplified by the global climate agenda. Transitioning from fossil fuels to renewables not only addresses energy poverty but also contributes significantly to carbon reduction targets (IRENA, 2024). For rural communities, renewable energy technologies such as solar photovoltaic (PV), biogas, and hybrid mini-grids are increasingly recognized as viable pathways to meet basic needs while supporting broader development goals, including food security, health, and livelihoods (Marpaung et al., 2020; Bhattacharyya & Palit, 2021; Rumbayan et al., 2025). However, the long-term sustainability of such interventions depends on their integration with local socio-economic structures and innovation models rather than purely technical deployment (Salam et al., 2020).

Indonesia illustrates these global dynamics in a particularly complex manner. The government has reported an electrification ratio of 99.63% as of 2022, yet more than one million people—mostly in Eastern Indonesia—still lack reliable access to electricity, with many households experiencing only tier 1 or 2 electricity supply (Vianda & Wirawan, 2022). The geographical realities of dispersed islands, mountainous terrains, and remote agricultural areas make grid extension financially and technically unfeasible (Putri et al., 2025). Moreover, the reliance on diesel generators in rural areas remains a critical issue, as fluctuating fuel prices and logistical barriers undermine both affordability and sustainability (Rimbawati, 2025 ; Budiman, 2021).

Recent government strategies under the National Energy Policy highlight renewable energy as a priority, yet implementation challenges persist. Policy inconsistencies, limited financing mechanisms, and fragmented institutional responsibilities have slowed down the deployment of decentralized systems (Muhayatul & Umar, 2025 ; Najicha et al., 2023). As a result, despite ambitious renewable energy targets of 23% in the national energy mix by 2025, Indonesia has only reached around 14% by 2023 (IESR, 2023). This discrepancy reflects a broader tension between policy aspirations and on-the-ground realities in rural energy transitions.

International literature in the last five years has emphasized that rural energy innovation cannot be separated from local governance, financing, and community participation. For example, Ahl et al., (2022) analyzed decentralized renewable energy systems in Sub-Saharan Africa and found that long-term success depends more on institutional and financial models than on technology alone. Similarly, (Murshed et al., 2021) demonstrated in South Asia that integrated approaches linking renewable energy with agriculture and local entrepreneurship generate more sustainable outcomes than stand-alone electrification projects. These findings underline a critical research gap: renewable energy must be examined within broader frameworks of rural innovation and circular economy practices.

Another emerging theme in the literature is the role of social innovation and co-creation in rural renewable energy projects. Mayer et al., (2024) emphasized that energy transitions are not merely technical shifts but also political and social processes shaped by local agency. Case studies in Nepal and Bangladesh have shown that community-led renewable energy models foster stronger ownership, enhance local skills, and ensure better financial sustainability compared to donor-driven interventions (BEHERA et al., 2022; Islam et al., 2025). Yet, there remains a lack of studies analyzing how these integrative models operate in Southeast Asia's diverse socio-geographical contexts, particularly Indonesia.

In Indonesia, recent scholarship has highlighted several persistent gaps. IESR (2022) stressed that energy planning remains dominated by centralized, top-down approaches, with insufficient attention to community needs and participatory mechanisms. Putri et al., (2025) found that renewable energy adoption in rural Java was often hindered by institutional fragmentation and inadequate maintenance structures, leading to system failures. Likewise, Situmeang et al., (2022) showed that biogas programs in Central Java delivered significant environmental benefits but faced challenges in scaling due to financial and institutional barriers. These findings suggest that while technological feasibility is established, the main barriers lie in governance and integration with local innovation ecosystems.

One dimension that remains underexplored in Indonesian renewable energy research is the integration of gender and inclusivity into rural innovation models. Recent studies have demonstrated that gender-responsive energy programs enhance both adoption rates and community impacts. For instance, Clancy and Feenstra (2020) argued that women's leadership in renewable energy projects not only improves household energy security but also fosters entrepreneurial activities and social resilience. Similar findings in Southeast Asia highlight that inclusive governance mechanisms are crucial for equitable and sustainable transitions (Zafarullah & Azmat, 2024). However, in Indonesia, few empirical studies have analyzed how gendered approaches intersect with decentralized renewable energy.

The Rumah Energi Program provides a unique lens to address these gaps. Established to promote biogas and solar-based rural energy, the program has built over 29,000 biogas digesters, trained more than 370 farmers in bio-slurry utilization, and engaged over 162 construction partners by 2023, resulting in an estimated

reduction of 528,781 tCO₂e emissions (Rumah Energi, 2023). Unlike many energy projects, Rumah Energi explicitly links renewable energy with circular economy practices through productive bio-slurry use in agriculture, reducing dependence on chemical fertilizers and enhancing food security.

Moreover, Rumah Energi's initiatives such as Pro-Women for Renewable Energy integrate gender empowerment into the energy transition, fostering participation of women farmers, entrepreneurs, and local champions. These efforts echo global calls for inclusive innovation in renewable energy systems and highlight the importance of embedding social justice within energy transitions (Sharma et al., 2025). This holistic model situates energy as both a technical and socio-economic enabler, demonstrating its potential to catalyze village-level innovation.

Beyond its immediate achievements, the Rumah Energi case has broader implications for Southeast Asia, where similar challenges of rural electrification, agricultural dependence, and climate vulnerability exist. Comparative studies in the Philippines, Vietnam, and Cambodia underscore the importance of scaling decentralized renewable energy through integrated governance and financing mechanisms (Hadpakdee, 2025). Examining Indonesia's experience therefore provides valuable lessons for designing replicable and scalable models of rural energy innovation in the region.

Despite increasing scholarly attention to renewable energy transitions in Indonesia, existing studies remain largely fragmented and technologically focused, offering limited understanding of how renewable energy can be systematically integrated into rural innovation ecosystems. Most research emphasizes electrification rates, technical feasibility, or policy targets, but few explore the socio-institutional dynamics that enable renewable energy to foster innovation, entrepreneurship, and circular economy practices at the village level. Moreover, gender and inclusivity dimensions—critical for ensuring equitable and sustainable energy access—are seldom embedded within analytical frameworks of rural energy development. This study addresses these gaps by investigating how the Rumah Energi Program operationalizes an integrated model that combines renewable energy deployment, local innovation, and gender empowerment, thus contributing new empirical evidence to the Indonesian rural energy literature and offering insights for broader Southeast Asian contexts.

Against this background, this study aims to examine the Village Innovation Model Based on Renewable Energy through the case of the Rumah Energi Program in Indonesia. It contributes to the literature by addressing three main research gaps: (1) the need to integrate renewable energy with rural innovation and circular economy frameworks, (2) the lack of empirical evidence on gender-responsive renewable energy initiatives in Indonesia, and (3) the limited analysis of replicable models that can inform regional policy and practice. By combining document analysis of program reports (2017–2023) with secondary literature synthesis, this

paper seeks to demonstrate how renewable energy can move beyond electrification to become a foundation for sustainable and inclusive rural transformation.

Method

This study employs a qualitative approach using the case study method. The case study was chosen because the research focuses on an in-depth examination of the Rumah Energi Program as a model of village innovation based on renewable energy in Indonesia. This approach allows the researcher to understand the interrelation between technical, social, economic, and institutional aspects that influence both the success and challenges of the program, while also providing insights into how such a model can be replicated in broader contexts.

A document-based research design was selected because the primary data sources consist of program archives, policy documents, academic publications, and statistical data. According to (Creswell & Creswell, 2017) and (Hollweck, 2015), document studies represent a valid strategy in qualitative research as they are able to record events, policies, and practices within specific contexts in a systematic and academically testable manner.

The population of this research comprises all documents, reports, data, and literature discussing the implementation of renewable energy, particularly within the framework of rural innovation in Indonesia. From this population, the sample was determined using purposive sampling, namely the selection of data based on relevance and alignment with the research objectives. This technique was chosen because not all documents or publications are directly related to the study's focus. The research sample consists of official reports of the Rumah Energi Program from 2017 to 2023, including annual reports, program achievements, and internal evaluations; national and regional energy policy documents such as the National Energy Policy (KEN), the National Energy General Plan (RUEN), and the Regional Energy General Plan (RUED); academic publications in the form of journal articles, research reports, and policy briefs discussing renewable energy, rural innovation, circular economy, and gender; as well as official statistical data issued by both national and international institutions such as Statistics Indonesia (BPS), the International Renewable Energy Agency (IRENA), and the Institute for Essential Services Reform (IESR).

Data collection techniques were conducted through document study and literature review. Program reports, policy documents, academic publications, and statistical data were accessed through official databases, institutional websites, and public archives. In this study, documents are positioned as primary text-based data since they serve as the main sources of analysis rather than merely complementary materials.

The research tools employed in this study include Zotero and NVivo. Zotero functions as reference management software used to organize literature, store citations, and manage bibliographies to ensure that the writing process is systematic

and in line with academic standards. Meanwhile, NVivo serves as qualitative data analysis software, enabling the researcher to conduct coding, classification, and thematic analysis of the documents, reports, and articles used as data sources. The research materials include program reports, energy policy documents, scholarly articles relevant to renewable energy, rural innovation, the circular economy, and gender, as well as statistical data from BPS, IRENA, and IESR.

Table 1. Coding Matrix of Thematic Categories in the Rumah Energi Case Study

Main Theme / Category	Sub-Categories	Examples of Coded Data (Sources)	Analytical Focus
Renewable Energy Implementation	Biogas adoption, Solar PV initiatives, Hybrid systems	Rumah Energi Annual Reports (2018–2023), IRENA data	Assessing contribution to rural electrification and emission reduction
Rural Innovation	Agricultural productivity, Local entrepreneurship	Program evaluation documents, Journal articles (Marpaung et al., 2020)	Understanding innovation linkages between energy and livelihood systems
Circular Economy Practices	Bio-slurry utilization, Waste-to-resource initiatives	Internal program reports, BPS agricultural data	Evaluating energy-agriculture integration and resource efficiency
Gender and Inclusivity	Women farmers' participation, Pro-Women initiative	Pro-Women for Renewable Energy reports, Clancy & Feenstra (2020)	Analyzing gendered empowerment in energy innovation models
Institutional and Governance Aspects	Policy alignment, Local partnerships	RUEN, RUED, IESR reports	Examining policy coherence and local institutional engagement

Source: Author's NVivo qualitative data analysis (2025)

The study was conducted in the form of a desk study, with data collection carried out online and through institutional archives available to the public. The duration of the research is planned for six months, from February to July 2025, encompassing the stages of preparation, data collection, analysis, and report writing.

Data analysis was performed using content analysis and thematic analysis methods. The process includes data reduction by selecting relevant information, coding data according to key categories—namely renewable energy, rural innovation, circular economy, and gender and inclusivity—presenting the data in a thematic matrix and interpreting the findings to construct a framework for a renewable energy-based village innovation model.

To ensure the validity of the research results, source triangulation was employed by comparing various program reports, policy documents, academic literature, and statistical data, along with data triangulation through the integration of information from program reports, policies, and scholarly publications to reinforce consistency of findings. The entire research process was documented in the form of an audit trail to ensure traceability and supported by peer debriefing, namely discussions with academics or renewable energy experts to test the accuracy of the interpretations.

In conducting the thematic analysis, NVivo 14 software was utilized to manage and code the collected documents systematically. All textual data—including program reports, policy documents, and academic publications—were imported into NVivo and organized into source folders according to their type. The coding process began with open coding, where key phrases and concepts related to renewable energy, rural innovation, circular economy, and gender were identified. Subsequently, axial coding was conducted to connect categories and subcategories, allowing the identification of interrelations among technical, social, economic, and institutional themes. Finally, selective coding was used to refine and integrate the main themes into a conceptual model of village innovation based on renewable energy. To enhance analytical transparency, a research flowchart illustrating the overall analytical process and a coding matrix showing the relationship between categories and data sources were developed using NVivo's visualization tools.

Results

Renewable Energy Integration in Rural Development

The Rumah Energi Program (2017–2023) recorded notable progress in promoting renewable energy solutions tailored for rural contexts in Indonesia. A key achievement was the construction of over 29,000 biogas digesters across different provinces, which significantly expanded access to decentralized energy systems (Rumah Energi, 2023). These digesters provided not only household-level energy for cooking but also supported broader community needs, particularly in agricultural villages where energy access had been limited.

Based on program evaluation documents, the deployment of biogas digesters contributed to an estimated reduction of 528,781 tCO₂e emissions during the period under review (Rumah Energi, 2023). This demonstrates the dual benefits of the program: addressing rural energy poverty while contributing to Indonesia's climate mitigation commitments under the Nationally Determined Contributions (NDCs).

The environmental dimension is therefore central to the program’s long-term relevance.

Table 1. Summary of Achievements of the Rumah Energi Program (2017–2023)

Key Indicator	Achievements 2017–2023
Total beneficiaries	148,360 individuals (29,473 households)
Installed biogas digesters	29,411 units across 20 provinces in Indonesia
Training beneficiaries	33,761 individuals
Farmers trained in bio-slurry	376 farmers
Installed solar PV systems	67 units + 1 rooftop solar PV
Solar Dryer House units	2 units
Incubated enterprises	243 enterprises
Cooperative partners	69 cooperatives
Development partners	162 partners
Carbon emission reduction	528,781 tCO ₂ e

Energy–Agriculture Nexus

In addition to its environmental contributions, the program enhanced energy security at the village level. Many communities in Eastern Indonesia had previously relied on costly and unreliable diesel generators. The introduction of biogas and solar units reduced dependency on imported fossil fuels, thereby strengthening local resilience against fuel price volatility (Kabeyi & Olanrewaju, 2022). The integration of renewable energy technologies with agricultural productivity stands out as one of the program’s most innovative dimensions. The use of bio-slurry, a by-product of biogas digesters, was promoted as organic fertilizer. Farmers reported improvements in soil quality, higher crop yields, and reduced reliance on chemical fertilizers (Marpaung et al., 2020). This represents a clear energy–agriculture nexus.

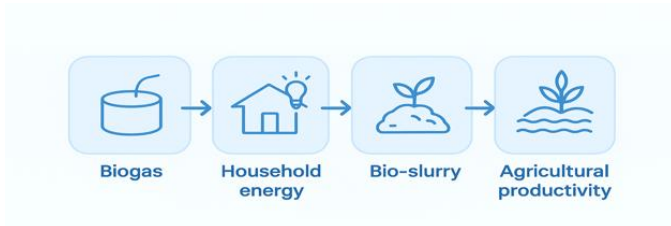


Figure 1. Flowchart of the Biogas Cycle:
Household Energy → Bio-slurry → Agricultural Productivity
Source: Author’s analysis.

Training activities organized between 2018 and 2022 involved more than 370 farmers who were introduced to bio-slurry management and application methods (Rumah Energi, 2023). Such capacity-building measures ensured that renewable energy adoption was accompanied by knowledge transfer and long-term skill

development. The findings underscore that technological deployment alone is insufficient without local capacity building.

Solar energy also played a complementary role in rural development. Although biogas digesters were the main focus, small-scale solar PV systems were introduced in selected pilot villages to provide electricity for productive activities such as water pumping and food processing (Vianda & Wirawan, 2022). These hybrid solutions suggest that integrating multiple renewable energy technologies can enhance community resilience. The review of national policies (KEN, RUEN, and RUED) indicates a strong commitment to expanding renewable energy, with a national target of 23% in the energy mix by 2025. However, only 14% had been achieved by 2023 (IESR, 2023). The Rumah Energi Program findings highlight that while policies provide an enabling framework, implementation at the local level often encounters governance and financing barriers (Muhayatul & Umar, 2025).



Figure 2. Map of Biogas Digestor Distribution by Province, 2017-2023.
Source: Adapted from Rumah Energi's Website.

Governance and Implementation Challenges

Institutional fragmentation remains a significant challenge. Responsibilities for energy policy, agriculture, and rural development are often divided among multiple ministries and agencies, which can lead to overlaps and inefficiencies (Najicha et al., 2023). The program's decentralized approach demonstrates that effective coordination at the village level can sometimes compensate for these structural gaps. Overall, the integration of renewable energy into rural development through the Rumah Energi Program provides a holistic model where energy is not an isolated technical intervention but a driver of agricultural improvement, environmental sustainability, and community empowerment. These findings suggest that replication of such models in Southeast Asia could yield significant benefits, provided that policy frameworks and financing mechanisms are adapted to local contexts.

Rural Innovation, Circular Economy, and Inclusivity in Renewable Energy Programs

The Rumah Energi Program highlights the strong integration of renewable energy with rural development, especially through circular economy practices. One of the most significant innovations is the use of bio-slurry, which reduces dependence on chemical fertilizers and supports more sustainable farming systems. This practice illustrates how renewable energy projects can extend beyond energy supply and create tangible agricultural benefits for rural communities.

The program's training initiatives have reached more than 370 farmers, equipping them with the knowledge and skills to maximize bio-slurry use in their farming activities. Such capacity building not only supports productivity but also fosters local knowledge-sharing networks, ensuring that innovation is diffused across communities. The emphasis on training reflects the program's holistic approach, where technology deployment is accompanied by social learning and empowerment.

Circular Economy and Local Entrepreneurship

Local entrepreneurship has also emerged as a key outcome of renewable energy adoption. The integration of renewable energy systems into rural contexts has generated a range of socio-economic opportunities, extending far beyond household-level electrification. Access to stable and affordable energy has enabled rural communities to explore productive activities such as agricultural processing, water pumping, and the development of bio-based products. These activities have provided a foundation for new forms of rural entrepreneurship, where farmers and community groups are no longer merely consumers of energy but active participants in energy-driven economic ecosystems. The Rumah Energi Program has thus facilitated the emergence of local innovation clusters that align energy access with livelihood improvement.

Farmers and rural entrepreneurs utilized bio-slurry to diversify crops, improve yields, and develop small-scale agricultural enterprises. The utilization of bio-slurry—a nutrient-rich by-product of biogas digesters—has proven to be one of the most successful innovations in linking renewable energy with agriculture. In several provinces, farmers applied bio-slurry as an organic fertilizer to restore soil fertility, improve water retention, and reduce the cost burden of chemical inputs. As a result, agricultural productivity and product quality both increased, allowing rural entrepreneurs to explore new market opportunities such as organic farming and integrated livestock-crop systems. These transformations show how energy interventions, when locally embedded, can trigger wider economic linkages that extend to environmental and social benefits.

These innovations created new income streams, strengthening rural economies and local resilience. By linking renewable energy access with agricultural productivity and entrepreneurship, the Rumah Energi Program has cultivated an

ecosystem of innovation at the village level. This ecosystem encourages collaboration between farmers, cooperatives, and local enterprises, fostering knowledge exchange and collective problem-solving. In addition, the development of value chains based on renewable energy products has contributed to income diversification and reduced vulnerability to external shocks, such as fluctuating fuel prices or market instability. Ultimately, these findings underline that renewable energy initiatives can evolve into a foundation for inclusive rural transformation—where technology, economy, and community empowerment reinforce one another within a sustainable development framework.

Gender Inclusion and Empowerment

The Pro-Women for Renewable Energy initiative demonstrates a deliberate strategy to integrate gender into rural energy innovation. Women farmers and entrepreneurs actively participated not only as end-users of energy but also as innovators applying it in productive activities. Compared to earlier donor-driven projects, this initiative promoted stronger ownership among women, empowering them to take leadership roles in their communities and enhancing local resilience.

However, challenges remain in mainstreaming gender within rural renewable energy initiatives. Reports indicate that cultural barriers and limited access to financing still constrain women's participation. Although inclusivity was prioritized, these structural issues highlight the need for more systematic gender-sensitive governance to support long-term scalability and impact. Without addressing these barriers, the full potential of women's contributions in renewable energy and agriculture may remain untapped.

Governance and Policy Gaps

From the triangulation of program documents, policies, and academic literature, several key lessons emerge. The energy–agriculture nexus proves central: renewable energy projects achieve greater sustainability when directly linked to local agricultural practices. In addition, governance gaps remain a challenge, as ambitious national policies are often hindered by fragmented institutional responsibilities and limited financial mechanisms when translated into rural contexts.

Another emerging trend is the importance of community ownership. Programs that emphasize co-creation, participation, and capacity building show stronger adoption and long-term sustainability compared to purely technical interventions. At the same time, gender empowerment consistently emerges as a transformative factor, amplifying both adoption rates and the broader social impact of renewable energy projects. Yet, achieving this requires confronting entrenched cultural norms and structural barriers.

Table 2. Innovations, Impacts, and Challenges in the Rumah Energi Program

Key Aspect	Program Findings	Positive Impacts	Challenges
Circular Economy (Bio-slurry)	Utilization of bio-slurry as organic fertilizer	Reduced dependence on chemical fertilizers; supported sustainable farming	Limited distribution and large-scale adoption by farmers
Capacity Building	>370 farmers received training	Knowledge transfer; formation of knowledge-sharing networks	Need for continuity and sustained technical support
Local Entrepreneurship	Farmers/SMEs developed bio-slurry-based businesses and integrated farming	Income diversification; fostered village innovation ecosystems	Limited access to markets and financing
Gender and Inclusivity	<i>Pro-Women for Renewable Energy</i> program: women involved in energy & enterprises	Strengthened women's leadership; enhanced community resilience	Cultural barriers; women's limited access to financing
Governance & Policy Support	National policies support (KEN, RUEN, RUED), but local implementation gaps	Provided regulatory framework for renewable energy	Institutional fragmentation; inadequate financial mechanisms
Community Ownership	Participatory and co-creation approaches	Stronger adoption; higher program sustainability	Need for stronger cross-sectoral coordination

Source: Processed from Rumah Energi Program Reports (2017–2023), author's analysis.

The Rumah Energi Program demonstrates how renewable energy can evolve beyond its traditional role of electrification to become a driver of rural innovation, agricultural transformation, and social inclusion. Its integration of circular economy principles and gender-sensitive approaches positions it as a potential model for

replication in other parts of Southeast Asia. Nonetheless, persistent challenges in governance, financing, and cultural dynamics must be addressed to enable scalability and ensure that renewable energy truly serves as a catalyst for inclusive and sustainable rural development.

Discussion

The findings of this study indicate that the Rumah Energi Program successfully combines renewable energy access with agricultural productivity, advancing rural development goals in Indonesia. This aligns with earlier studies emphasizing that rural energy systems generate stronger outcomes when integrated into local livelihoods rather than being limited to electrification (Soussi et al., 2024). The adoption of biogas digesters, combined with productive applications such as bio-slurry use, illustrates the energy–agriculture nexus as a transformative pathway for sustainable rural growth. This confirms the working hypothesis that community-based renewable energy programs are most effective when coupled with socio-economic development activities.

A central contribution of the program is the widespread application of bio-slurry as an organic fertilizer, which demonstrates the successful application of circular economy principles in rural contexts. By reducing dependence on chemical fertilizers and promoting ecological farming practices, the program resonates with global discourses that emphasize waste-to-resource models as drivers of sustainability (Awad, 2023). Nevertheless, the scalability of such practices remains debated in the literature, as institutional fragmentation and financial constraints often limit adoption beyond pilot programs (Greenhalgh et al., 2017). This suggests that enabling conditions at both governance and market levels are essential for replicating circular practices across broader regions.

The program's focus on training—reaching over 370 farmers—further reinforces the importance of capacity building in strengthening adoption. As Peters et al. (2019) highlight, renewable energy interventions achieve more durable outcomes when embedded within community-based learning and innovation systems. By fostering local knowledge-sharing networks, the Rumah Energi Program enhances both technical competence and social capital. This validates the assumption that capacity building is not merely a supplementary activity but a cornerstone of program sustainability. It also reflects a shift from donor-driven interventions toward approaches that emphasize co-creation and community ownership.

The integration of gender considerations through the Pro-Women for Renewable Energy initiative introduces an important dimension of inclusivity. Unlike earlier projects where women were primarily positioned as passive beneficiaries, this program actively involved them as entrepreneurs and leaders. Such participation strengthens adoption rates and builds local resilience. However, structural barriers persist, particularly limited access to financing and entrenched cultural norms, which echo challenges identified in other gender–energy studies

(Raman et al., 2025). These findings highlight the dual reality of progress and constraint in gender mainstreaming within rural renewable energy initiatives.

From a policy perspective, the program aligns with Indonesia's National Energy Policy (KEN) and National Energy General Plan (RUEN), which target a 23% renewable energy mix by 2025 (Ministry of Energy and Mineral Resources (MEMR), 2017). Yet, the evidence also reveals persistent implementation gaps at the local level, primarily caused by fragmented institutional responsibilities. These governance issues mirror findings from (Nugroho et al., 2022), who argue that weak coordination between national and regional stakeholders undermines energy policy execution in Indonesia. Consequently, while the program operates within a supportive national framework, its local impact depends on addressing institutional bottlenecks and creating innovative financing schemes.

Another significant finding is the role of renewable energy in fostering rural entrepreneurship. Farmers and small-scale entrepreneurs leveraged bio-slurry for crop diversification and improved yields, creating additional income streams. This reflects the broader argument that renewable energy can catalyze local innovation ecosystems when linked with productive activities (Guzman et al., 2024). However, differing viewpoints caution that commercialization of renewable energy by-products may exacerbate inequalities if access to resources remains uneven (Baker et al., 2014). This underscores the need for inclusive governance mechanisms to ensure that benefits are distributed equitably across communities.

The debate over scalability also emerges strongly in this study. While some scholars argue that localized renewable energy projects face inherent limitations due to resource and governance constraints (Cloke et al., 2017), the Rumah Energi Program demonstrates that integration with agriculture and entrepreneurship enhances both sustainability and replication potential. This finding supports the emerging consensus that energy transitions must be embedded within broader socio-economic systems rather than pursued as isolated technical interventions (ESMAP, 2020). The implications extend beyond Indonesia, positioning the program as a potential model for Southeast Asia.

In the regional context, comparative studies indicate that community-based renewable energy initiatives succeed when backed by strong governance and financing frameworks. The findings of this research add to that discourse by showing how gender and circular economy dimensions further enhance program resilience and adoption. Indonesia's experience thus offers valuable lessons for countries in Southeast Asia facing similar challenges in rural electrification, agricultural modernization, and inclusive development. These insights also highlight the importance of adapting community-based models to diverse cultural and institutional contexts across the region.

Future research should prioritize longitudinal studies on the environmental and agricultural impacts of bio-slurry utilization. While current evidence highlights short-term gains, long-term data on soil fertility, crop diversification, and food

security would provide stronger validation of the program's outcomes. Such studies could also assess how bio-slurry contributes to the resilience of local farming systems against climate variability, offering critical insights into its role in sustainable agriculture. This direction would bridge the current knowledge gap and deepen understanding of circular economy applications in rural areas.

In addition, methodological innovations such as life-cycle assessment (LCA) could be employed to capture the full environmental benefits and trade-offs of biogas systems (Ingrao et al., 2019). LCAs can provide holistic insights into greenhouse gas reductions, nutrient cycling, and waste management, thus complementing socio-economic analyses. Incorporating such assessments into future research would strengthen the evidence base for policy advocacy and donor engagement. This would also align with broader academic debates on measuring sustainability in rural renewable energy transitions.

This study also underscores the importance of interdisciplinary approaches in renewable energy research. As shown by the Rumah Energi Program, technical interventions cannot be separated from social, economic, and governance dimensions. Future studies should therefore integrate multiple perspectives—including gender, community ownership, and policy alignment—to capture the complexity of rural energy transitions. Multi-stakeholder collaboration, particularly between government agencies, local communities, and development partners, will be key to scaling up successful models.

The Rumah Energi Program illustrates how renewable energy can go beyond electrification to catalyze rural innovation, entrepreneurship, and social inclusion. By embedding circular economy practices and integrating gender empowerment, the program provides a replicable model for Southeast Asia. Yet, challenges remain, including governance fragmentation, financing gaps, and cultural barriers. Addressing these issues will be crucial for scaling impact and ensuring long-term sustainability. This discussion therefore contributes to both academic debates and practical policy dialogues on the transformative potential of renewable energy in rural development.

Conclusions

This study has shown that the Rumah Energi Program plays a vital role in advancing renewable energy integration in rural Indonesia. Beyond electrification, the program has successfully connected energy initiatives with agriculture, local livelihoods, and community capacity building. The adoption of bio-slurry for farming reflects circular economy principles, while the training of farmers strengthened local knowledge-sharing networks and resilience.

The program's gender-inclusive approach through the Pro-Women for Renewable Energy initiative highlights the transformative role of women in rural energy innovation. Women were engaged not only as energy users but also as entrepreneurs and community leaders, contributing to stronger governance and

ownership. However, cultural and financial barriers continue to limit inclusivity, emphasizing the need for systematic gender-sensitive governance frameworks.

At the policy level, the program aligns with Indonesia's renewable energy targets, but gaps remain in local implementation due to fragmented institutional responsibilities and limited financial mechanisms. Addressing these challenges requires stronger governance, innovative financing, and cross-sectoral coordination to ensure rural communities fully benefit from national energy ambitions.

Overall, the Rumah Energi Program demonstrates that renewable energy can be a driver of sustainable rural development when integrated with agriculture, entrepreneurship, and gender empowerment. Its model offers valuable lessons for Southeast Asia and other regions pursuing decentralized renewable energy transitions. Future research should further assess the long-term impacts of bio-slurry use, community ownership, and policy frameworks to strengthen the scalability and sustainability of such initiatives.

Declarations

No ethical issues have arisen during the study, and all procedures followed comply with the ethical standards.

Authors contribution

All authors contributed substantially to this research. Contributions include the design of the methodology, data collection and analysis, as well as drafting the main manuscript. All authors also reviewed, provided critical feedback, and approved the final version of the manuscript for publication.

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Data availability

All data used in this study are derived from publicly accessible documents, official reports, and publications. Supporting data are available through the official website of Yayasan Rumah Energi at the following link: <https://www.rumahenergi.org/laporan>.

Declaration of interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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