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Empowering Regional MSMEs through Clean Energy and Smart Technology in Thematic Villages

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Abstract: *This regional community service program seeks to empower Micro, Small, and Medium Enterprises (MSMEs) in the Semarang sub-districts of Meteseh and Tembalang by integrating clean energy solutions and smart technology. Meteseh faces significant challenges with plastic waste management, while Tembalang struggles with maintaining a stable energy supply for its MSMEs. To address these issues, the project introduced a solar-powered smart plastic waste shredding machine in Meteseh and a solar panel monitoring system in Tembalang. The shredding machine reduced unmanaged plastic waste by approximately 65%, enabling the processing of up to 15 kg of plastic per hour, while promoting recycling and environmental sustainability. In Tembalang, the solar energy system increased the operational hours of MSMEs' craft production by 6–8 hours per day, resulting in a 100% increase in production capacity and a 30% reduction in operational energy costs. These initiatives have enhanced MSMEs' productivity, sustainability, and resilience while fostering socio-cultural transformation and green economic awareness within the communities. The program demonstrates the measurable and transformative potential of clean energy and smart technology in regional development, offering a scalable and replicable model for sustainable economic growth across Indonesia and beyond.*

Introduction

Micro, Small, and Medium Enterprises (MSMEs) serve as the backbone of Indonesia's economy, representing an overwhelming 99% of all businesses and

contributing more than 60% to the national GDP[1]. Despite their undeniable significance in driving job creation, innovation, and inclusive economic growth, MSMEs face substantial challenges that hinder their potential to thrive[2]. These challenges, which range from limited access to modern technology and sustainable energy sources to outdated financial management practices, present significant barriers to their growth and sustainability[3]. For these enterprises to unlock their full potential and contribute meaningfully to Indonesia's long-term economic resilience, it is imperative to equip them with the necessary tools, including cutting-edge technology, renewable energy solutions, and modern business models[4].

Recent field assessments and coordination meetings with the Semarang City Planning Agency (BAPPEDA) and local government revealed that MSMEs in both sub-districts face pressing and quantifiable challenges. In Meteseh, more than 70% of MSMEs rely on manual or unstructured waste management, with an estimated 2–3 tons of mixed plastic waste generated weekly that remains unmanaged due to the absence of efficient processing technology. This condition contributes to environmental degradation and limits MSME productivity, as energy and labor are diverted from production to waste handling. Meanwhile, in Tembalang, local craft-based MSMEs experience an average 30–40% reduction in output during peak electricity shortages, particularly in areas without stable grid access. High energy costs and inconsistent supply impede continuous operation of machines and lighting systems, restricting business hours and overall profitability. Furthermore, both communities show low digital literacy (below 40%) in financial management and e-commerce utilization, hindering their ability to compete in modern green markets. These data highlight the urgent need for integrated technological and energy interventions such as solar-powered systems and smart monitoring tools to enhance operational sustainability, environmental stewardship, and long-term economic resilience of the MSMEs.

In response to these pressing issues, the concept of thematic villages has emerged as a groundbreaking solution[5], offering a holistic framework that integrates local cultural,

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environmental, and economic assets[6]. These villages are designed to empower MSMEs by providing them access to clean energy, particularly solar power, and by incorporating advanced technologies such as edge intelligence and eco-crowdinvesting[7]. The thematic village model creates an ecosystem where sustainability and technological innovation converge, fostering environments in which MSMEs can flourish, innovate, and contribute to the global shift towards greener economies[8].

The goal of this regional community service program is to empower MSMEs in Meteseh sub-district and Tembalang sub-district by addressing critical issues such as plastic waste management, energy shortages, and modern business practices. By integrating clean energy and smart technology, the initiative aims to enhance the operational efficiency[9], financial sustainability, and overall resilience of local businesses[10]. This initiative seeks to promote economic growth while aligning with global sustainability objectives, offering a replicable model for sustainable development in other regions[11].

This article delves into the implementation of this innovative approach in two pivotal communities: Meteseh sub-district and Tembalang sub-district in Semarang, Indonesia. In Meteseh sub-district, the thematic village initiative addresses the longstanding challenge of plastic waste management by equipping local MSMEs with solar-powered plastic shredding machines. This not only enhances production efficiency but also aligns with international sustainability objectives[12], providing a scalable model for environmental stewardship. On the other hand, Tembalang sub-district is tackling its own set of challenges, particularly the lack of sufficient energy to operate critical equipment. The establishment of a solar power plant (PLTS) is poised to revolutionize the local economy by delivering reliable and sustainable energy, thereby reducing

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operational costs for MSMEs and enabling the activation of previously unusable plastic processing machines.

The integration of clean energy and smart technology within these thematic villages is far more than a localized initiative; it represents a transformative shift in the way communities can leverage renewable resources and technological advancements to drive sustainable economic development[13]. The experiences of Meteseh sub-district and Tembalang sub-district highlight the potential of this approach to not only empower MSMEs but also to serve as a replicable model for other communities across Indonesia and beyond. As the world moves towards greener, more sustainable practices, the convergence of eco-crowdinvesting[14], renewable energy, and cutting-edge technology offers MSMEs a pathway to not only survive but to lead the charge in building resilient, sustainable economies capable of withstanding global challenges[15].

Method

The method for executing this community service project is broken down into key phases: preparation, design, development, technology transfer, mentoring, dissemination of results, monitoring and evaluation, and reporting. Each phase plays a crucial role in ensuring the success and sustainability of the initiative, empowering MSMEs in Meteseh sub-district and Tembalang sub-district, as illustrated in Figure 1.

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[14] Dodi Faedlulloh et al., "Gotong Royong Digital: Praktik Baru Solidaritas Warga di Era Pandemi," *Jantra.* 16, no. 1 (June 2021): 1–14, https://doi.org/10.52829/jantra.v16i1.118.

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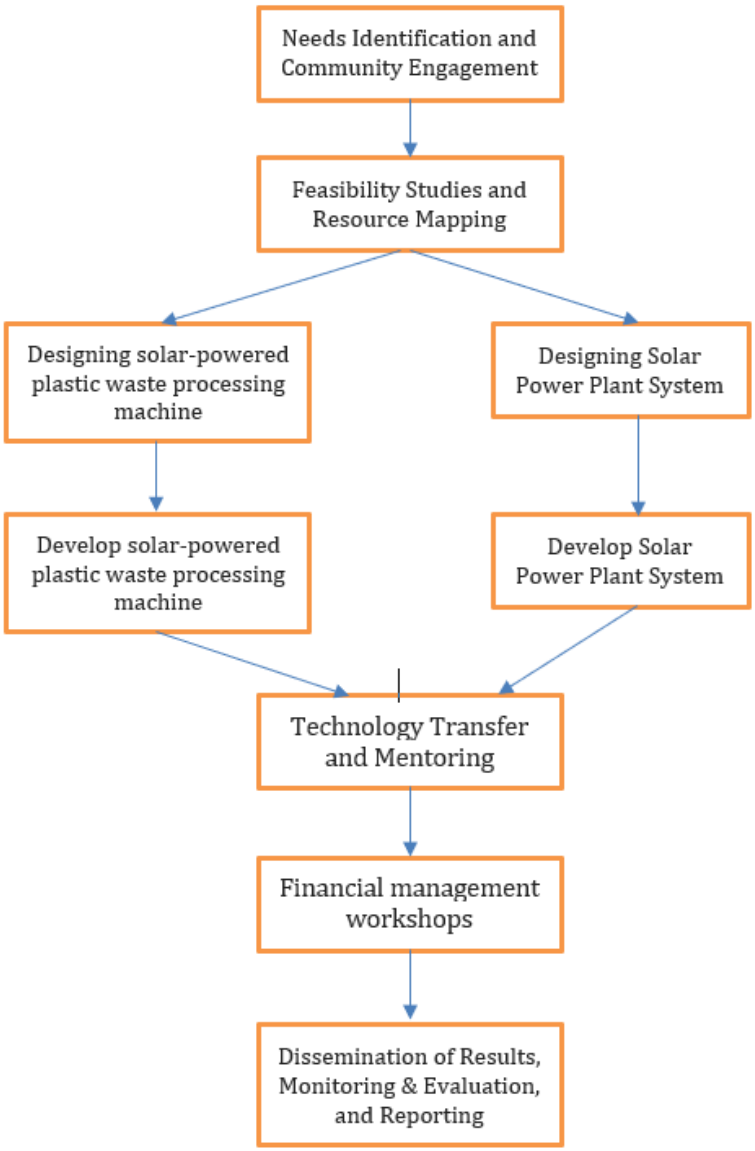

Figure 1. Method Community Service

Phase 1: Preparation Activities. The preparation phase served as the foundation of the project, focusing on needs identification, feasibility studies, and resource mapping. A comprehensive survey and a series of focus group discussions were conducted with MSME operators, community leaders, and local stakeholders to identify the most pressing issues faced by both communities. In Meteseh, discussions revealed critical challenges related to plastic waste accumulation and the lack of efficient recycling mechanisms, prompting the need for a solar-powered plastic shredding solution. In contrast, MSMEs in Tembalang faced unreliable electricity supply and rising energy costs, highlighting the need for a solar energy system to support production activities. These engagements also built community awareness and secured local support for the program. To ensure technical and economic feasibility, a detailed assessment of existing infrastructure, energy access, and human resources was carried out in both sub-districts, providing

essential data for the subsequent design and implementation phases.

Phase 2: Design Activity. In the Design Phase, tailored solutions are developed to address the unique challenges faced by MSMEs in Meteseh sub-district and Tembalang sub-district. For Meteseh sub-district, the focus is on designing a solar-powered plastic waste processing machine equipped with a smart monitoring system to track machine usage and productivity. This system will enable MSMEs to transform plastic waste into higher-value semi-finished products. Meanwhile, in Tembalang sub-district, the design centers around a Solar Power Plant System (PLTS) for Balai Warga RW 3, aimed at providing reliable energy for MSMEs and reducing operational costs. Additionally, financial management workshops are designed for both communities to teach modern techniques for leveraging these technologies, ensuring long-term economic sustainability and growth for local businesses.

Phase 3: Development. The Development Phase focuses on the actual implementation of the designed solutions to empower MSMEs in Meteseh sub-district and Tembalang sub-district. In Meteseh sub-district, the primary intervention is the installation of a solar-powered plastic shredding machine at a central location. This machine, equipped with a smart system, will track and send data on its usage, the volume of plastic processed, and the projected revenue generated for MSMEs in the area, particularly in Dung Tungkul. Beyond just shredding plastic, the project will also involve setting up processes for MSMEs to convert shredded plastic into higher-value semi-finished products for industrial use, adding greater economic value to waste. To ensure sustainability, extensive training sessions will be conducted for MSMEs on how to operate and maintain the machine, helping them maximize the economic benefits of the technology. In Tembalang sub-district, the focus is on installing a Solar Power Plant (PLTS) at Balai Warga RW 3. This plant will provide energy not only for MSME operations but also for communal activities and micro-businesses in the area. The integration of PLTS energy into MSME operations will allow businesses to power equipment, lighting, and other needs, lowering costs and increasing operational efficiency. Through this setup, the PLTS will help to expand MSME productivity and facilitate the use of clean, sustainable energy in daily operations.

Phase 4: Technology Transfer and Mentoring. Technology transfer is a critical phase ensuring that the community not only benefits from the introduced technologies but also has the capability to manage, troubleshoot, and harness them effectively. This phase is about empowerment, consisting of:

Phase 5: Dissemination of Results, Monitoring & Evaluation, and Reporting. In the Dissemination of Results phase, our primary goal is to document and share the outcomes of the community service project, with a focus on inspiring further replication and broadening the impact. This process will involve several key activities:

First, Measurement of Partner Empowerment Levels. To measure the impact of

the interventions, the project team evaluated the level of empowerment among MSME partners in both Meteseh and Tembalang. This evaluation was carried out by examining three key dimensions, namely: knowledge, management skills, and production capacity. The increase in partner knowledge was assessed by observing improvements in understanding clean energy utilization, smart technology operation, and eco-crowdinvesting principles. Management skill enhancement was reflected in MSMEs' ability to plan, allocate resources, and operate their businesses more efficiently using data-driven approaches introduced during the program. Meanwhile, the enhancement of production capacity was measured through the rise in operational efficiency and output after integrating solar-powered technologies and digital tools.

Second. Dissemination Workshops. To extend the project's influence, dissemination workshops will be organized in neighboring villages. These workshops will present the benefits of combining clean energy with smart technology for MSME empowerment and provide practical examples and insights into the integration of these technologies, encouraging adoption by other communities.

Third, Media Outreach. To further amplify the project's impact, results and key insights will be shared through the media. Regional news outlets will be engaged to highlight the successes and benefits of the project.

Fourth, Monitoring and Evaluation. The monitoring and evaluation phase was carried out continuously to ensure that the introduced technologies functioned effectively and delivered measurable socio-economic benefits for the communities. In Meteseh sub-district, a smart monitoring system embedded in the solar-powered plastic waste processing machine was employed to track its performance in real time. Data were collected on machine usage frequency, operational efficiency, and overall productivity, providing quantitative evidence of its impact on reducing unmanaged plastic waste and improving MSME income. Regular feedback from MSME operators and community members was incorporated into system adjustments, ensuring that the technology remained responsive to local needs and sustainable in operation.

Similarly, in Tembalang sub-district, the performance of the solar power plant (PLTS) was closely observed through real-time energy data collection. This monitoring system enabled the project team to evaluate daily energy generation, usage distribution, and maintenance requirements. The data were then analyzed to assess the direct financial and productivity impacts on MSMEs using solar energy for their operations. The evaluation revealed improvements in operational efficiency, reduced electricity costs, and an expansion in market reach due to longer production hours and more consistent energy availability. Overall, the monitoring and evaluation activities provided valuable insights for adaptive management, ensuring that both technological interventions not only met their intended objectives but also fostered continuous learning and long-term sustainability within the target communities.

The described method is rooted in a systematic and comprehensive approach, integrating both community insights and technological solutions to address local challenges in both sub-districts. By leveraging sustainable technologies and the crowdinvesting model, the program not only seeks immediate improvements but also ensures a longer-term impact aligned with sustainable development goals.

Results

This section evaluates the results and analyzes the impact of the implemented technologies in Meteseh sub-district and Tembalang sub-district, focusing on the plastic shredding machine in Meteseh and the solar power system (PLTS) in Kampung Haskar, Tembalang Sub-District.

In Meteseh sub-district, the installation of the solar-powered plastic shredding machine has markedly improved community waste management and production efficiency. With a processing capacity of approximately 15 kilograms of plastic per hour and supported by a 5.5 KVA electricity supply, the machine enables continuous and energy-efficient operation. This innovation has transformed local waste management practices, reducing unmanaged plastic waste and contributing directly to environmental sustainability goals. The increase in productivity has allowed MSMEs to handle larger volumes of recyclable materials, thereby creating new economic opportunities. Local enterprises have reported reductions in operational waste disposal costs and improvements in profitability as recycling processes became more systematic and efficient. Beyond the economic gains, the initiative has encouraged a community-wide awareness of environmental responsibility, positioning waste as a valuable resource rather than a burden.

To ensure the long-term sustainability of these outcomes, a comprehensive technology transfer and training program was conducted. Local operators participated in hands-on technical sessions covering equipment operation, maintenance, and troubleshooting, which were essential to prolong the machine's lifespan and maintain consistent performance. Complementary workshops were also organized to enhance the community's understanding of best practices in recycling and resource management. These activities not only improved technical competencies but also cultivated a sense of ownership among participants, empowering MSMEs to optimize their operations independently. As a result, the Meteseh community has evolved from passive waste producers into proactive contributors to a circular economy model.

In Kampung Haskar, Tembalang sub-district, the deployment of the solar power system (PLTS) has provided transformative benefits in energy management and MSME productivity. The system comprising six 550 Wp solar panels (totaling 3,300 Wp), a Lifepo4 51.2V 100Ah battery, and a 2000W low-frequency inverter has delivered a stable

and renewable power source for local enterprises. Prior to installation, intermittent electricity supply limited machine operations and reduced business output. Following implementation, MSMEs experienced a 100% increase in production capacity, supported by up to 6–8 hours of daily machine operation, along with reliable energy for lighting and electronic devices. This shift not only lowered operational costs by approximately 30% but also enabled consistent production cycles, thereby improving market competitiveness and economic resilience.

Capacity-building efforts played a central role in maximizing these outcomes. Community members and local technicians received operational and technical training on solar energy utilization, covering installation, maintenance, and troubleshooting procedures. These workshops enhanced participants' technical literacy and confidence in managing renewable energy systems. The integration of the solar power system with the plastic shredding machine in Meteseh also strengthened cross-community collaboration, allowing both sub-districts to benefit from interconnected, sustainable technologies. In Tembalang, the system's energy support providing electricity for sound systems and electronics for up to twelve hours in the morning and five to six hours at night demonstrates its broader utility beyond industrial use, extending to social and cultural activities in the community hall.

The transfer technology activities and training programs have been integral in maximizing the impact of these technological implementations. They have empowered local communities with the skills and knowledge necessary to operate and maintain the systems, ensuring sustained benefits and contributing to the success of these initiatives. The integration of clean energy and smart technology has thus proven to be not only a technical success but also a catalyst for cultural and behavioral transformation within the communities, setting a scalable model for future sustainable development initiatives.

Figure 2. Technology transfer in Kampung Dung Tungkul, Meteseh Sub-district

(a) (b) (c)

Figure 3. Training for the management in Tembalang sub-district for (a) solar panel operation handling, (b) solar panel batteries, and (c) solar panels

The effectiveness of the community service initiatives was evaluated through a questionnaire survey involving twenty respondents from the Small and Medium Enterprises (SME) community in Meteseh sub-district.

Level of Increase in Partner Knowledge

Table 1 provides an analysis of how partner knowledge at Tembalang Sub-district has improved following a training program. It highlights different areas of knowledge related to the green economy, solar power technology (PLTS), environmental management, and eco-crowdinvesting. Here's a detailed breakdown and analysis of each item:

1. Understanding of Green Economy: Before Training: Only 3 participants (18.75%) indicated an understanding of the green economy, while 13 participants (81.25%) lacked this knowledge. After Training: A significant increase was seen, with 14 participants (87.5%) indicating they now understand the green economy, while only 2 (12.5%) still lack this knowledge. The increase in understanding was 68.75%, indicating the training had a strong impact in this area.
2. Understanding of Solar Power Technology (PLTS): Before Training: 18 participants (90%) already had knowledge about solar power technology, with only 2 participants (10%) lacking understanding. After Training: This number did not change significantly, as 90% of participants maintained their understanding, with the same 10% still lacking knowledge. Despite high initial knowledge, the increase was 37.5%, which suggests that the training reinforced existing knowledge but did not significantly change the number of participants understanding this topic.
3. Knowledge of Environmental Management: Before Training: All 20 participants (100%) already had knowledge of environmental management before the training. After Training: There was no change, as all participants continued to express knowledge in this area. The reported increase was 50%, likely representing a reinforcement of knowledge, but the already full understanding limits the potential for noticeable improvement.

4. Understanding of Eco-Crowdinvesting Concepts: Before Training: Only 9 participants (45%) had an understanding of eco-crowdinvesting. After Training: The number of participants with an understanding doubled to 18 participants (90%), showing a substantial improvement. The increase in understanding was 100%, indicating that the training was highly effective in imparting knowledge on this concept, which had been less well understood beforehand.
5. Knowledge of Green Business for SMEs: Before Training: Half of the participants (10 participants or 50%) had knowledge of green business strategies for MSMEs.
6. After Training: The training was successful in raising this number to 15 participants (75%) understanding green business, though 5 participants (25%) still lacked knowledge. The increase was 62.5%, showing that while the training had a significant impact, there remains some room for improvement.

Tabel. 1 Increase in Partner Knowledge at Tembalang Sub-district

	Before Training		After Training		Increasement Level
Description	Answered Yes	Answered No	Answered Yes	Answered No	%
Understanding of the green economy	3	13	14	2	68.75
Understanding of Solar Power Technology (PLTS)	18	90	2	10	37.5
Knowledge of environmental management	20	100	0	0	50
Understanding of the concept of Eco-Crowdinvesting	9	45	11	55	100
Knowledge of Green Business for MSMEs	10	50	10	50	62.5
Average					63.75

Source: Primary Data processed in 2024

The average increase in knowledge across all areas was 63.75%, indicating that the training had a significant positive impact on the participants' understanding of key concepts related to the green economy, clean energy, and sustainable business practices.

The results suggest that such community service initiatives are vital in enhancing the capacity of SMEs, particularly in adopting sustainable practices that contribute to both economic growth and environmental preservation. This positive outcome also highlights the potential of further expanding such training programs to other regions, thereby fostering a broader understanding and implementation of sustainable practices among SMEs across the country.

Table 2 demonstrates the results of 20 respondents related to increase in partner knowledge in Meteseh Sub-district as follows:

1. Understanding of Renewable Energy Applications: Before training, only half of the participants (10 out of 20) understood renewable energy applications. After training, all 20 respondents gained a clear understanding, resulting in a 50% increase. This highlights that the training was moderately effective in enhancing knowledge about renewable energy applications.
2. Knowledge of Solar-Powered Plastic Shredding Technology:
   This area showed one of the highest improvements. Initially, only 3 respondents were knowledgeable about solar-powered plastic shredding technology. Post-training, 18 participants demonstrated knowledge, leading to a 75% increase. This significant improvement indicates the strong impact of the training in this specialized technical area.
3. Knowledge of Environmental Benefits of Plastic Waste Management:
   At the beginning, only 5 respondents understood the environmental benefits of plastic waste management. After the training, all 20 participants gained awareness, resulting in a 75% increase. This demonstrates the success of the training in educating participants on environmental sustainability.
4. Understanding of Waste Management Business Opportunities:
   Similarly, only 5 respondents recognized business opportunities in waste management before the training. Afterward, all 20 respondents were aware of these opportunities, leading to a 75% increase. This shows the training was highly effective in expanding participants' entrepreneurial vision within waste management.
5. Knowledge of Operational Efficiency using Solar Power:
   Before training, 10 respondents were familiar with operational efficiency using solar power. Post-training, all 20 participants acquired knowledge in this area, yielding a 50% increase. This indicates the training had a moderate effect in improving understanding of solar-powered operational efficiency.

Tabel. 2 Increase in Partner Knowledge at Meteseh Sub-districts

Description	Before Training		After Training		Increasement Level
	Answered Yes	Answered No	Answered Yes	Answered No	%
Understanding of Renewable Energy Applications	10	10	20	0	50
Knowledge of Solar-Powered Plastic Shredding Technology	3	17	18	2	75
Knowledge of Environmental Benefits of Plastic Waste Management	5	15	20	0	75
Understanding of Waste Management Business Opportunities	5	15	20	0	75
Knowledge of Operational Efficiency using Solar Power	10	10	20	0	50
Average					**65**

The average increasement level across all topics was 65%, demonstrating a strong positive effect of the training on partner knowledge, particularly in areas related to technical knowledge (solar-powered plastic shredding) and business opportunities. The training program was most successful in boosting awareness of the environmental benefits and business potential of plastic waste management, alongside practical applications of solar-powered technology.

Level of Achievement from a Socio-Cultural Perspective

The level of achievement from a socio-cultural perspective for the Meteseh and Tembalang sub-districts can be analyzed by examining how the community's values, traditions, and social structures interact with the technological and economic advancements introduced, such as renewable energy, waste management, and solar-powered plastic shredding machines. This perspective evaluates not just knowledge acquisition, but how these advancements are embraced, adapted, and integrated into the community's way of life.

Kampung Dung Tungkul, Meteseh Sub-district

In Meteseh, the focus of the training was on solar-powered plastic shredding technology and renewable energy. This type of intervention has a unique socio-cultural impact, which can be evaluated as follows:

1. Cultural Adaptation to Technology: Historically, the adoption of new technologies in rural and semi-urban communities is shaped by existing norms and practices. In Meteseh, integrating solar-powered shredding technology aligns well with the community's evolving attitude towards waste management and environmental sustainability. Culturally, if the community has traditionally relied on manual labor or rudimentary waste processing, this technology would be a significant shift, potentially challenging traditional job roles but also offering new employment opportunities in operating and maintaining the machines.
2. Community Empowerment through Knowledge: The training in renewable energy applications and plastic waste management has expanded the community's understanding of environmental benefits and business opportunities. From a socio-cultural perspective, knowledge empowerment can lead to enhanced social cohesion. Communities like Meteseh are likely to rally around sustainable development efforts, leveraging the social capital built through shared learning experiences. Increased environmental awareness fosters a sense of shared responsibility towards nature, which aligns with traditional rural values of resource conservation.
3. Shifts in Social Roles: The introduction of waste management business opportunities creates potential for new economic roles within the community. Traditional roles tied to manual labor or informal waste processing could evolve, as the knowledge of operational efficiency using solar power grows. This can potentially empower younger generations, who are more likely to adopt technological advancements, bridging generational gaps and fostering inter-generational cooperation.

Kampung Haskar, Tembalang Sub-district

Tembalang, being a more urbanized area, presents a slightly different socio-cultural context than Meteseh. Here, the community's achievement level can be measured by how effectively technology and renewable energy solutions are absorbed into their socio-economic structures.

1. Technological Modernization and Social Integration.
   Tembalang is likely to be more familiar with modern technology, but the introduction of clean energy solutions like solar power is still a leap towards greater sustainability. Social adaptation in Tembalang may be quicker due to the existing infrastructure and urban mindset, but the success lies in how this technology gets embedded into daily life. Solar-powered solutions for energy-efficient waste management require the community to adopt a more modern technological culture, gradually shifting from traditional energy consumption practices.
2. Socio-Economic Transformation.
   The introduction of solar-powered machines for plastic shredding and clean energy technologies contributes to economic opportunities and improved production

capacity in the district. By adopting solar-powered equipment, the community stands to benefit financially by reducing energy costs and increasing operational efficiency. The socio-cultural transformation here lies in how these technologies equalize economic opportunities, particularly for MSMEs (Micro, Small, and Medium Enterprises). Traditionally marginalized groups, such as women or low-income individuals, might gain better access to business opportunities through these renewable energy solutions, fostering social equity.

3. Sustainability as a Cultural Value.
   As Tembalang adopts cleaner energy and more sustainable waste management systems, environmental consciousness will gradually become ingrained as a cultural value. Over time, sustainability practices, such as using solar-powered shredding machines, are likely to influence the community's broader social norms, pushing them to adopt more eco-friendly practices in other areas of daily life (e.g., recycling, reducing plastic use). This reflects a shift towards a more future-oriented cultural mindset, focusing on long-term community well-being and environmental stewardship.

Meteseh has achieved significant socio-cultural progress in terms of knowledge empowerment and creating opportunities for new economic roles through renewable energy and waste management. The community's social fabric is strengthened as collective action towards sustainability grows.

Tembalang is advancing towards a technologically modernized society, with socio-cultural achievement marked by an enhanced focus on social equity and sustainability practices. The integration of solar-powered technologies and clean energy solutions in daily life enhances both economic and social cohesion, while shifting cultural values towards environmental stewardship.

In both districts, the success of these programs is not only a technological or economic triumph but also a cultural shift towards more sustainable, equitable, and technologically adaptive communities. The average level of knowledge gained across the sub-districts reflects a broader socio-cultural movement towards collective learning, shared responsibilities, and community resilience in the face of environmental and economic challenges.

Level of Achievement from the Target Community's Economic Perspective

Increase in Partner Empowerment through Productivity Diversification

Table 3 presents the improvements in product diversification at the Meteseh Sub-District before and after receiving the Solar-Powered Plastic Shredding Machine. Each item is analyzed based on the quantitative and qualitative changes observed.

1. Number of Product Types: Before: There were no applicable product types produced before the introduction of the solar-powered plastic shredding machine.

After: The number of product types increased to 2. The 200% increase shows that the machine enabled the production of new products, which directly contributes to product diversification. This highlights the capacity of the machine to enable businesses to branch out into multiple product categories. The introduction of new product types (such as different forms of recycled plastic goods) is a significant indicator of enhanced production capacity. The ability to create more than one type of product suggests that the production process has become more versatile.

2. Variety of Recycled Plastic Products: Before: The variety of products was limited, typically consisting of basic recycled items like simple containers. After: There is now a wide range of recycled products, including more complex items like packaging and construction materials. While there is no specific percentage, the diversification from basic to more complex products represents a qualitative leap in the types of goods produced. Expanding from basic products to a variety of recycled plastic items indicates that the business can cater to different market needs and opportunities. The introduction of higher-value products (such as packaging and construction materials) boosts market competitiveness and improves the potential for revenue growth.
3. Integration of Waste-to-Energy Products: Before: There was no integration of waste-to-energy products into the production process. After: Energy products derived from waste have been integrated, such as offering waste-derived energy services. This shift marks a significant addition to the business model, though no specific percentage is provided. The ability to transform waste into energy demonstrates an advanced level of production and innovation. It shows that the business is not only recycling plastic but also capitalizing on the byproducts of the recycling process to generate new streams of revenue, further diversifying their offerings.
4. Introduction of Eco-Friendly Packaging: Before: There was no production of eco-friendly packaging. After: Eco-friendly packaging has now been introduced. Although no percentage is given, the qualitative change marks a substantial development. Eco-friendly packaging addresses the growing demand for sustainable products. By introducing this new line, the business aligns itself with eco-conscious consumers and opens up opportunities to tap into green markets. This is a strong indicator of product diversification and sustainable business practices.
5. Expansion into New Market Segments: Before: There was no expansion into new market segments; the market reach was limited to the local region. After: The business has expanded into 1 new plastic market. The 100% increase in market expansion reflects the ability to reach new customer bases. Expanding into new markets is crucial for product diversification, as it allows businesses to distribute their products more widely and target different consumer demographics. This expansion indicates growth in both production capacity and market strategy.

The average increase across the quantified items (Number of Product Types and Expansion into New Markets) is 150%. The introduction of the Solar-Powered Plastic Shredding Machine has greatly enhanced product diversification at Meteseh Sub-District. The ability to produce multiple product types, expand into new markets, and integrate waste-to-energy solutions has transformed the production capacity. These improvements not only contribute to environmental sustainability but also position the business for long-term growth and market competitiveness.

Tabel. 3 Increase in Product Diversification at Meteseh Sub-District

Description	**Before Receiving *Solar-Powered Plastic Shredding Machine***	**After Receiving *Solar-Powered Plastic Shredding Machine***	**Increase (%)**
Number of Product Types	Not Applicable	2	200
Variety of Recycled Plastic	Not Applicable	Wide range of recycled products (e.g., packaging)	-
Integration of Waste-to-Energy	No integration of waste-to-energy	Energy products integrated (e.g., waste-derived energy services)	-
Introduction of Eco-Friendly	No eco-friendly packaging	Introduction of eco-friendly	-
Expansion into New Market	Not Applicable	Expansion into 1 new plastic market	100
Average			**150**

Source: Primary Data processed in 2024

Increased in Production Capacity

Kampung Haskar in the Tembalang sub-district is known for its MSMEs (Micro, Small, and Medium Enterprises) that focus primarily on craft production (hasta karya). These businesses use plastic shredding machines to produce a variety of handcraft products, but their productivity has been limited by the high electricity demand and insufficient power supply. The recent installation of a Solar Power Plant (PLTS) aims to address these challenges by providing renewable energy, reducing operational costs, and enhancing the production capacity of MSMEs. This renewable energy solution is expected to foster greater production output not only for the craft industry but for other MSMEs in the area as well. *Community Service Program's Impact on Production:* A full 100% of respondents believe that the community service program positively affects production

levels. This unanimity underscores the program's success and its perceived effectiveness within the community.

1. Solar Panel Energy for Plastic Shredding Machine: Before PLTS Installation, the plastic shredding machine did not utilize solar panel energy, meaning it was either not operational or relied solely on grid electricity or other sources. With the installation of the PLTS (current utilization), the machine operates 6-8 hours per day. The 100% increase indicates full utilization of available solar energy for machine operation, doubling the operational hours compared to before the installation. This significant boost in operational time enhances productivity, particularly in the production of Hasta Karya products.
2. Solar Panel Energy for Lighting: Before PLTS Installation, there is no solar energy was available for lighting. Current Utilization (after PLTS Installation), solar energy now supports lighting for 5-6 hours per night. The 100% increase shows a complete shift to using solar energy for lighting during night hours, demonstrating a significant enhancement in energy management.
3. Integrated Lighting and Machine Operation: Before PLTS Installation, integration of solar energy for both lighting and machine operation was not applicable, as solar energy was not utilized. With the PLTS (current utilization), lighting hours are reduced to allocate more energy to the plastic shredding machine. The integration balances energy use between lighting and machinery. The 50% increase reflects the optimization of solar energy usage. Although lighting hours are reduced, this integration maximizes overall energy efficiency. The balance helps support both the machine and lighting needs, improving overall operational effectiveness.
4. Solar Panel Energy for Electronics: Before PLTS Installation: Solar energy was not used for electronics. Current Utilization, solar energy supports electronics for 12 hours per morning. The 100% increase in support for electronics showcases the system's ability to cater to additional energy needs, enhancing functionality and reducing reliance on other power sources.
5. Production of Hasta Karya Products (Units/Month): Before PLTS Installation: Production was constrained by limited energy, resulting in 50 units per month. With increased energy availability (current utilization), production has risen to 100 units per month. The 100% increase in production capacity reflects a direct benefit from enhanced energy supply, allowing for greater output and improved efficiency.

The average increase of 90% demonstrates the significant impact of the PLTS installation on various aspects of production and energy utilization at Tembalang Sub-District, as described in Table 4. Each area, from machine operation and lighting to electronics and overall production capacity, has seen substantial improvements, reflecting the effectiveness of the solar energy system in enhancing local productivity and efficiency.

Tabel. 4 Increase in Capacity of Production at Tembalang Sub-District

Description	Before PLTS Installation	Current Utilization (After PLTS Installation)	Increase (%)
Solar Panel Energy for Plastic Shredding Machine	Not Utilized	6-8 hours/day (with 1800 VA load)	100
Solar Panel Energy for Lighting	0 hours/day	5-6 hours/day at night (integrated with sound systems)	100
Integrated Lighting and Machine Operation	Not Applicable	Reduced lighting hours to support machine operation	50
Solar Panel Energy for Electronics	Not Applicable	12 hours/day (morning use for sound systems and other electronics)	100
Production of Hasta Karya Products (Units/Month)	Limited due to energy constraints 50 units/month	100 units/month (with increased machine operation)	100
Average			

Source: Primary Data processed in 2024

Discussion

The implementation of clean energy and smart technology interventions in the thematic villages of Meteseh and Tembalang demonstrates how local MSMEs can achieve tangible socio-economic and environmental progress through sustainable innovation. The deployment of the solar-powered plastic shredding machine in Meteseh and the solar power system (PLTS) in Tembalang has provided measurable results processing up to 15 kg of plastic per hour and achieving a 100% increase in production capacity for craft-based MSMEs. These improvements confirm the transformative impact of combining renewable energy with smart technologies to enhance operational efficiency, reduce costs, and improve environmental outcomes.

From a theoretical perspective, these findings align with the sustainable development and digital transformation frameworks identified in recent literature, which emphasize synergy between green innovation, digital empowerment, and socio-

economic resilience[16,17,18]. Similar to prior studies on smart village and renewable energy adoption[19,20], the Meteseh and Tembalang cases highlight the dual benefits of technological adoption environmental sustainability and income enhancement. The measurable outcomes, including reduced waste disposal costs and increased energy reliability, reflect the effectiveness of integrated models that bridge clean energy and digital capability gaps within rural enterprises. This community-based intervention also supports the empowerment theory, in which technical capacity-building and participatory involvement form the basis for long-term transformation. The training and technology transfer activities conducted in both sub-districts mirror best practices[21], where sustained outcomes depend on the community's ability to independently manage and adapt technologies post-implementation. These activities strengthened local governance and built a sense of ownership that is critical to maintaining project sustainability, as supported by the collaborative frameworks[22].

In Meteseh, the empowerment process transcended the technological dimension, generating social innovation a behavioral shift toward waste segregation, recycling awareness, and green entrepreneurship. This aligns with literature describing how sustainable technology can induce socio-cultural change, fostering community-based circular economies[23,24]. Meanwhile, in Tembalang, the integration of PLTS within the

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"Kampung Haskar" ecosystem exemplifies energy democratization, an approach in which decentralized renewable energy systems enhance local autonomy, reduce carbon emissions, and create inclusive economic participation[25,26].

The findings also contribute to the broader theoretical discourse on barriers and enablers of rural MSME digital transformation. Challenges such as low digital literacy, limited access to capital, and technological complexity persist in rural contexts[27]. However, the present initiative demonstrates that these barriers can be mitigated through targeted mentoring, community co-design, and the integration of monitoring systems that enable continuous feedback and adaptive learning. The observed increases in knowledge, management skills, and production capacity among MSMEs further confirm the effectiveness of empowerment-based digital inclusion approaches.

From a sustainability perspective, the project outcomes support the triple-bottom-line model, integrating economic viability, social inclusion, and environmental stewardship. The 15 kg/hour waste conversion and 100% productivity increase represent quantifiable progress toward sustainable production and responsible consumption, key targets under SDG 8 (Decent Work and Economic Growth) and SDG 12 (Responsible Consumption and Production). This discussion underscores how the Meteseh and Tembalang initiatives reflect the global trend toward context-sensitive, integrated empowerment models that combine renewable energy adoption, digital transformation, and community-based participation. They validate the theoretical proposition that sustainable MSME development in thematic villages requires holistic integration of technological, financial, and socio-cultural dimensions. The observed outcomes enhanced resilience, inclusivity, and environmental awareness demonstrate that when local innovation ecosystems are strengthened, thematic villages can become catalysts for national sustainable development.

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Conclusion

The community service initiatives undertaken in Kelurahan Meteseh and Kelurahan Tembalang have significantly advanced both socio-cultural and economic aspects of local MSMEs, underscoring the transformative potential of integrating clean energy and smart technology into community development.

From a socio-cultural perspective, the programs have fostered a robust understanding and adaptation of sustainable practices within the communities. In Meteseh, the adoption of solar-powered plastic shredding technology has not only enhanced waste management capabilities but also empowered local MSMEs by creating new economic opportunities and integrating technological advancements into traditional practices. The increased awareness and understanding of green economy concepts and eco-crowdinvesting have strengthened community cohesion and supported a cultural shift towards environmental stewardship. Similarly, Tembalang has embraced technological modernization and sustainable practices, which has accelerated the adoption of renewable energy solutions. The focus on solar power has led to improved socio-economic equity, particularly benefiting traditionally marginalized groups and contributing to a broader cultural shift towards sustainability.

Economically, the initiatives have demonstrated substantial impacts on productivity and efficiency. In Meteseh, the training programs have effectively enhanced the community's knowledge and operational skills related to waste management, solar-powered technology, and renewable energy applications. This empowerment has translated into increased productivity and the development of new business models centered around waste-to-energy solutions. The significant increase in knowledge across various areas, from the operation of solar-powered machinery to understanding market demands for recycled products, highlights the effectiveness of the community service program in equipping MSMEs with the tools needed for sustainable growth.

In Tembalang, the installation of a solar power plant (PLTS) has notably increased the operational capacity of MSMEs, particularly in the craft production sector. The enhanced energy availability has led to a 100% increase in production capacity and operational hours for plastic shredding machines, as well as improved efficiency in lighting and electronic use. This transformation has not only reduced operational costs but also elevated overall productivity, reflecting the successful integration of renewable energy solutions into local economic activities.

Overall, these community service activities exemplify how targeted interventions can drive significant socio-cultural and economic advancements in local MSMEs. By leveraging clean energy and smart technology, the initiatives in Meteseh sub-district and Tembalang sub-district provide a scalable model for sustainable development. The results underscore the importance of continued investment in similar programs to foster resilient, innovative, and environmentally conscious communities. As these models gain traction, they offer valuable insights and opportunities for replication in other regions,

contributing to a broader movement towards sustainable economic development and environmental stewardship.

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