Green Manufacturing Solutions in the Development of Sustainable Agro-edutoursim in Semarang City, Indonesia

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Abstract: The agricultural sector faces significant challenges due to climate change and land conversion, threatening long-term food sustainability. This study aims to provide policy recommendations by applying the green manufacturing approach to optimize the potential of Mijen District as an agro-edutourism destination. The research began by identifying local resources in Kampung Sawah Mijen, one of the area's key agricultural tourism sites, as a basis for developing strategic solutions through sustainable innovation. Participatory Rural Appraisal (PRA) was employed to explore the community's perspectives on potentials, problems, and solutions. Meanwhile, the Multiaspect Sustainability Analysis (MSA) was employed to assess the sustainability index across six dimensions. The results show that farmers produce an average of 4.6 tons of rice per hectare per growing season, with the majority already implementing environmentally friendly agricultural practices. The sustainability index of Kampung Sawah Mijen was 50.14, with the highest score in the social aspect (69.44) and the lowest in the technological aspect (41.67). Green manufacturing practices such as converting rice straw and manure into compost, reusing aquaculture waste for irrigation, and implementing energy efficient post-harvest techniques were introduced and evaluated as part of an agro-edutourism model. These initiatives were developed collaboratively with stakeholders, including local communities, academics, business, and the media. The findings highlight the need for sustainable technological innovation. Green manufacturing provides a practical pathway to enhancing farmers' economic resilience while promoting sustainable production and education-based tourism in urban agricultural areas.

Keywords: agro-edutourism; food; innovation; sustainability

1. Introduction

Food agriculture is a critical sector essential for human sustenance and well-being. It is enshrined in the Sustainable Development Goal of Zero Hunger,

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emphasizing a global commitment to ensuring regional food security and resilience. However, the sector faces significant challenges due to climate change and land conversion. The Mijen area, located in Semarang City, Central Java, holds significant potential for development as an innovative and sustainable rice field village. This initiative is driven by the need to mitigate land conversion while enhancing the income of the farming community. Between 2016 and 2021, agricultural land in the form of raw rice fields decreased by 1,482.48 hectares, from 3,701.27 hectares to 2,218.79 hectares, due to conversion to non-agricultural uses[1]. This reduction in land area has directly contributed to a decline in rice production. Excessive use of chemical inputs, along with the impacts of climate change, plays a significant role in the decline of productivity and rice production[2].

Kampung Sawah Mijen is an agricultural area in Semarang City, Central Java, Indonesia, that offers substantial potential for development. *Kampung Sawah Mijen* serves as a tourist attraction, integrating various agricultural sub-sector functions within the area. This area was designed by combining building arrangements with open spaces, environmentally conservative management practices, and the establishment of agricultural-based educational zones. The rice fields in *Kampung Sawah Mijen* hold potential for development into an economic hub centered on food crop commodities. With this approach, the potential of local agriculture can be utilized as a tourist attraction that includes natural scenery typical of rice fields, the uniqueness and diversity of local products, the application of modern agricultural technology, and the culture of the surrounding community.

Kampung Sawah Mijen faces challenges related to productivity. Excessive use of chemicals contributes to the decline in agricultural productivity.[3]. Agricultural land management in *Kampung Sawah Mijen* requires an approach that is not only productive but also sustainable. The application of the green manufacturing concept is essential for minimizing environmental impacts, optimizing resource efficiency, and enhancing climate change adaptation.

As a part of Semarang City, Kampung Sawah reflects the broader dynamics of urban-rural interaction and agricultural transformation. Semarang presents a valuable case for examining urban food system transitions due to its strong yet distinctive agricultural base, unlike other major cities in Java[4,5]. This agricultural identity not only sustains local food production but also opens pathways for integrated sustainability initiatives such as agro-edutourism. In this context, Kampung Sawah Mijen stands out as a promising site where agricultural productivity and tourism potential intersect making green manufacturing a relevant and strategic approach to ensure sustainable development.

Green manufacturing is a production approach designed to minimize environmental impacts. This approach encompasses waste reduction, recycling, resource optimization, and the application of technology to achieve sustainable production. Green manufacturing is built upon the 5Rs concept: Repair, Reuse, Refurbish, Rebuild, and Recycle.[6]. Green manufacturing enhances economic value by reducing operational costs through energy efficiency, resource optimization, and waste reduction.[7]. Green manufacturing serves as the foundation for a circular economy, supporting the transition toward a sustainable and productive future.[8]. The green manufacturing model, integrated into the concept of sustainable agro-edutourism, is essential for improving farmers' economic welfare while preserving social and environmental systems to ensure sustainable food security.

Research on agro-edutoursim has been implemented in various locations, both in Indonesia and internationally, demonstrating its potential to blend agricultural practices with public education and community engagement. In Bali, Buana Amertha Sari Agro-tourism in Kintamani offers visitors the opportunity to engage in coffee processing and traditional farming activities[9]. While the program provides meaningful educational experiences, it has yet to incorporate structured environmental sustainability measures, such as waste management or energy-efficient systems.

A similar case is found at Sekarmukti Eco-Agro in Pangsan Village, where tourists are introduced to organic fertilizer production and aquaculture activities[10]. However, the emphasis remains on experiential learning rather than environmental innovation. Chelsea Agrotourism in Gianyar focuses on children’s participation in farming to increase agricultural interest from a young age, but lacks integration with broader sustainability frameworks[11].

In recent years, agro-edutourism has gained global attention as a strategy to integrate rural livelihoods, sustainable agriculture, and tourism-based education. In Japan, agritourism has been actively promoted through national policies to revitalize rural areas, emphasizing farm-based tourism experiences such as fruit picking, rice planting, and farm stays that immerse visitors in traditional agricultural practices[12]. In the context of Southeast Asia, traditional rice farming communities have shown that resilience in agriculture is strongly supported by intangible elements such as cultural identity, ecological knowledge, and collective memory rooted in local practices. These non-material aspects play a crucial role in sustaining farming systems, especially amid socio-environmental change[13]. In Indonesia, agro-edutourism initiatives like those in Ngestiharjo Village have integrated green industrial practices, such as composting, local food processing, and environmentally themed educational tours as part of broader sustainable development efforts[14]. Moreover, sustainable water management models based on Balinese heritage, like the Subak system, have

demonstrated how traditional ecological wisdom can inform modern efficient infrastructures[15]. Thus, the concept of agro-edutourism is intrinsically linked to green industrial practices, encompassing efforts to conserve biodiversity, preserve traditional agricultural technologies, and enhance income generation for rural communities. Its significance extends beyond economic dimensions, as it promotes environmental stewardship at the community level and supports the realization of the "act locally, think globally" principle through educational tourism grounded in sustainable land-use practices[16].

Internationally, agro-edutourism has been recognized as an effective tool for promoting environmental awareness, particularly among students[17]. In addition to integrating environmentally friendly practices with educational experiences, agro-edutourism also contributes to environmental conservation while supporting the local economy[18]. Considering its urban location, the integration of green manufacturing within the agro-edutourism concept is particularly critical for Kampung Sawah Mijen. This innovation is expected to bring significant benefits to the sustainability of urban agriculture by promoting efficient resource management, reducing environmental impact, and enhancing local economic resilience[19–21].

While previous studies on agrotourism and agro-edutourism have explored cultural experiences, community participation, and the use of agricultural technologies, these aspects are often addressed in isolation. There remains a lack of integrated approaches that combine agro-edutourism with green manufacturing principles such as circular systems, resource efficiency, and environmentally friendly innovations. This study seeks to fill that gap by presenting a comprehensive model that embeds green manufacturing within an agro-edutourism framework. The model not only promotes sustainability across technological, economic, social, and environmental dimensions but also offers a practical, community-based approach to applying circular economy concepts in peri-urban agricultural settings. In doing so, this research contributes a novel and replicable pathway for aligning sustainable production with education-oriented tourism.

The model proposed in this study introduces green manufacturing as a strategic approach that not only enhances educational value but also embeds sustainability into agricultural practice. By combining learning experiences with circular systems, resource-efficient technologies, and smart irrigation, Kampung Sawah Mijen presents a more integrated and transferable model of sustainable agro-edutourism. Therefore, this study focuses on and aims to provide a green manufacturing solution by presenting a green manufacturing model in collaboration with agro-edutourism. The implementation of green manufacturing within the agro-edutourism framework in Kampung Sawah is expected to enhance the overall sustainability of Kampung Sawah Mijen.

2. Methods

This research was conducted in *Kampung Sawah Mijen*, situated in Mijen District, Semarang City, East Java, Indonesia. Semarang City was selected as the study site due to its unique position as a major urban area in Indonesia that still retains active peri-urban agricultural zones such as Kampung Sawah Mijen. Despite rapid urbanization, these green pockets present a rare and strategic opportunity to integrate sustainable agriculture, education, and green manufacturing practices. This makes Kampung Sawah Mijen not only a relevant case study, but also a potential model for other cities in Indonesia seeking to balance urban growth with environmental sustainability and food security. This research focused on analyzing the potential, challenges, and sustainability practices of the *Kampung Sawah Mijen* area to develop sustainable green manufacturing solutions.

Data were collected through field observations, semi-structured interviews, community discussions, and a review of relevant local documents. The interviews were guided by sustainability dimensions outlined in the MSA framework and were designed to explore local potentials, challenges, and practices related to agro-edutourism and green manufacturing. Field observations were conducted using structured checklists focused on farming systems, environmental practices, and infrastructure conditions in Kampung Sawah Mijen.

This research addressed issues related to land conversion, climate change, and challenges in achieving sustainable food security in Semarang City. This study employs two methodological approaches that combine qualitative and descriptive quantitative strategies. The Participatory Rural Appraisal (PRA) method represents a qualitative approach, emphasizing community involvement and local knowledge in planning and implementing area development. This method actively engages local stakeholders in the decision-making processes.[22]. The Multiaspect Sustainability Analysis (MSA) applies a descriptive quantitative approach, as it evaluates the sustainability status of activities, locations, institutions, or companies across multiple dimensions using weighted indicators and scores. This analysis was conducted using the Eximpro software, which facilitates structured assessment and visualization of sustainability dimensions. MSA supports effective and efficient decision-making by integrating multiple dimensions of sustainability[23].

The PRA approach involved 20 farmers. A total of 20 farmers participated in the PRA, corresponding to the full number of landholders actively farming in Kampung Sawah Mijen. This allows for exhaustive community input within the study area. MSA engaged multiple stakeholders involved in managing *Kampung Sawah Mijen*, including

representatives from the Semarang City Agriculture Department, Fisheries Department, and Culture and Tourism Department, as well as the chairpersons of the Ayem Tenang Farmer Group, Sidorejo Farmer Group, Ngudi Makmur Farmer Group, and the Farmer-Owned Enterprise (BUMP) Lumpang Semar, which also cultivates rice fields in the Agriculture Office Seedling Farm. The selection of respondents was conducted purposively, targeting individuals who are actively involved in the development and management of the Kampung Sawah agro-edutourism area.

In the Participatory Rural Appraisal (PRA) process, a series of community discussions with local farmers was conducted to identify key issues and development opportunities from the community's own perspective. PRA was not merely used to collect data about the community, but was conducted with and for the community. It emphasized local ownership, recognizing community members as active contributors in formulating solutions. This ensured that the outcomes, particularly the green manufacturing strategies, were contextually grounded and socially accepted.

Complementing PRA, the Multiaspect Sustainability Analysis (MSA) provided a structured and quantitative evaluation of sustainability status across six key dimensions: technological, economic, social, environmental, government support, and creative economy (tourism). Together, the findings from PRA and MSA were synthesized to construct a holistic green manufacturing model tailored to the real conditions of Kampung Sawah Mijen, further supported by relevant literature to ensure theoretical and practical alignment. The results of the PRA and MSA provided green manufacturing solutions, which were presented as recommendations to the Semarang City Government. The overall research framework of thinking are illustrated in Figure 1.

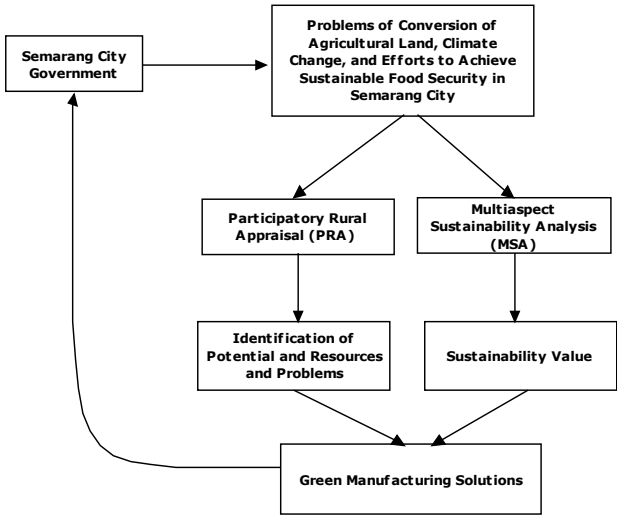

Fig. 1: Framework of Thinking

3. Results and Discussion

3.1. Potential of Kampung Sawah Mijen

The potential of Kampung Sawah Mijen was identified through a Participatory Rural Appraisal (PRA) involving multiple local stakeholders, including farmer groups, community leaders, and relevant government representatives. *Kampung Sawah Mijen* is in the southwestern part of Semarang City, Central Java Province, along RM Hadi Soebono S. Street. This area is about 19 km from the center of Semarang City. The 30-hectare rice field village is part of Tambangan Village in Mijen District, Semarang City. Between 1981 and 2020, the area recorded an average annual rainfall of 2,687 mm. The lowest annual rainfall was recorded in 1998 at 1,664 mm/year, while the highest was 3,912 mm/year. The average daily temperature reaches 30°C, while the altitude above sea level is 228.00 meters. Mijen District has the largest rice paddy harvest area in Semarang City, spanning 1.07 hectares[24]. These climatic and topographical characteristics endow the area with significant agricultural potential.

Three farmer groups operate in *Kampung Sawah Mijen*: the Ayem Tenang, Sidorejo, and Ngudi Makmur Farmer Groups. These farmer groups cultivate rice crops in the rice fields with an average production of 4.6 tons per hectare. Additionally, some farmers cultivate ornamental plants, such as orchids, along with horticulture and livestock. The potential of the *Kampung Sawah* area was categorized into two main components: natural and man-made features.[25]. In ecotourism, natural and man-made features play crucial roles in attracting visitors and boosting local economies.[26]. Table 1 describes the natural features present in Kampung Sawah Mijen, whereas Table 2 describes the man-made features in the area. The potential of natural and man-made features was identified through a PRA conducted with the farmer groups.

The potential of natural and man-made features was crucial to study when planning the development of sustainable agro-edutourism and green manufacturing in *Kampung Sawah*. Agro-edutourism is a tourism concept that combines agriculture and education, aiming to provide visitors with an educational experience about sustainable farming, livestock, or aquaculture systems. At the same time, it contributes to improving the well-being of the local community through economic diversification [27,28]. Integrating these features can create a complex yet balanced development model. Natural and man-made elements were integrated by addressing local needs and applying suitable technology to promote efficient and environmentally friendly management [29].

3.2. Sustainability Analysis

MSA was used for the sustainability assessment. The sustainability assessment of *Kampung Sawah Mijen* was evaluated across six aspects: technology, economy, social,

Table 1: Natural Features in *Kampung Sawah Mijen*

Natural Features	
Rice fields	The landscape features a vast expanse of rice fields. Owl houses were strategically placed in certain areas to utilize owls for controlling rat pests.
Mountain	The *Kampung Sawah* area was located in the highlands, providing *Kampung Sawah* Mijen visitors with a view of Mount Ungaran..
Agriculture Department Garden	The Semarang City Agriculture Department Garden serves as a center for community education activities. The garden was divided into four areas: area 1 contains food and plants, area 2 contains potted fruit plants, area 3 contains horticultural collections, including chili plants, melons, and cabbages, and area 4 contains a greenhouse containing various orchid plants. This garden also acts as the main entrance to the *Kampung Sawah Mijen* area.
Livestock Areas	A livestock area was located in the Mijen rice field village, managed by local farmers.
Aquaculture Areas	The aquaculture areas comprise aquaculture ponds scattered across three locations in the *Kampung Sawah* area: (1) The Fish Seed Center (BBI), managed by the Semarang City Fisheries Department, (2) Fish therapy ponds at Soto Sawah, (3) Recreational fish ponds at the Gebyar Sumyah fishing site, a popular tourist destination for fishing.
Orchid Garden	This area boasts a large collection of orchids. Visitors can take photos or purchase orchids as souvenirs.

Table 2: Man-Made Features in *Kampung Sawah Mijen*

Man-Made Features	
Agricultural Museum	The agricultural museum in Kampung Sawah presents information related to agriculture, ranging from the 'Pranata Mangsa' calendar to agricultural tools from the past that are the heritage of the local agricultural culture. The museum supports educational activities for the community and students.
Agricultural Extension Center (BPP)	BPP serves as a center for agricultural technology information, training, and farmer coaching. The facility supports agricultural education programs and farmer group development.
Orchid Laboratory	This laboratory was used for orchid research and development to become the center of orchid innovation in Semarang City.
The Animal Health Center (Puskeswan)	The Animal Health Center (Puskeswan) provides animal health services, especially for livestock in Kampung Sawah. This facility supports livestock farming practices and food production.
Parking Areas	A large parking area capable of accommodating up to 400 vehicles provides good accessibility for visitors.
Jogging Track	A 2-kilometer jogging track starts at the Agriculture Office Garden and extends to the Orchid Garden. This path serves as an additional attraction for tourists looking to enjoy the natural atmosphere of the surroundings.
Toilets	Toilets were available in several strategic locations, such as at the Farm Service Garden, Soto Sawah, and Orchid Garden, to support visitor convenience.
Soto Sawah	A typical Kampung Sawah culinary spot serves Indonesian traditional dishes. This location serves as a culinary center with a capacity to accommodate up to 2,000 visitors per day.
The Hall at Orchid Garden	A hall with a capacity of up to 30 people that can be rented for various activities such as training, family events, or group discussions.

environment, government support, and creative economy (tourism). These dimensions reflect the multidimensional nature of sustainability and align with widely recognized frameworks such as the Sustainable Development Goals (SDGs) and the Triple Bottom Line (TBL), which emphasize the balance between economic (profit), social (people), and environmental (planet) pillars. Key elements, such as economic, social, environmental, and technological factors, have been used to assess the sustainability of food estates in North Sumatra.[30]. Validation in MSA was assessed based on the value of random iteration, with an acceptable error threshold of five[31]. Table 3 shows that the validation status met the required criteria, with an average error value of 1.97.

Table 4 displays the sustainability scores of each aspect. A score of 0-25 means unsustainable, >25-50 means low sustainable, >50-75 means sustainable, and >75-100 means very sustainable. The technological aspect has the lowest sustainability score (41.67), followed by the government support aspects (43,4), and environmental (44.33). Meanwhile, the highest score was on the social aspect of 69.44.

a. Technological Aspect

The technology aspect had the lowest score, at 41.67. The contributing indicators were the suitability of new technology to farmers' skills and the availability of new agricultural technology. Some agricultural machinery was incompatible with farmers' skill levels and the physical conditions of their land. In addition, agricultural machinery technology was still in short supply. The availability of appropriate technology that matches the skills of farmers and the location of agricultural land can optimize resources and potentially increase crop yields.[32]. In Kampung Sawah Mijen, some of the agricultural machinery provided by the government such as large tractors proved to be unsuitable for the area's narrow and irregular field layouts. Additionally, the predominantly older age of the farming population presents challenges in adopting new technologies, particularly those requiring

Table 3: Validation of Kampung Sawah Mijen's sustainability status

No.	Aspect	Sensitivity Random Iteration
1	Technological	0,33
2	Economic	1
3	Social	1,44
4	Environmental	2,67
5	Government Support	1,4
6	Creative Economy (Tourism)	5
Total Average		1,97

Table 4: Sustainability Status of *Kampung Sawah Mijen*

No.	Aspect	Existing
1	Technological	41,67
2	Economic	52
3	Social	69,44
4	Environmental	44,33
5	Government Support	43,4
6	Creative Economy (Tourism)	50
Total Average		50,14
Status Sustainability		Sustainable

mechanical operation or digital literacy. Agricultural technology, in this context, should be understood not only as physical equipment but also as encompassing sustainable farming practices introduced through green manufacturing approaches. These include the use of compost derived from agricultural waste, energy-efficient irrigation methods, and environmentally friendly pest control systems. Despite their potential benefits, such innovations are not widely adopted, largely due to a lack of training, limited access to demonstration units, and insufficient technical support. Addressing these issues requires more locally adapted interventions, such as introducing machinery scaled for smallholder use, designing training programs that are accessible to older farmers, and fostering stronger partnerships between local community groups, government, academics, and business.

b. Economic Aspect

The economic aspect achieved a sustainability score of 52, indicating it was moderately sustainable. However, this score can be improved to a highly sustainable score by paying attention to several indicators, namely the ratio of profit to living costs from agricultural products, agricultural financing, and agricultural insurance. Farmers' profit was not sufficient to cover their living costs. On average, farmers earn a net profit of approximately IDR 2 million per month. This amount is clearly inadequate when compared to their living expenses, as the estimated cost of living per person is around IDR 2 million per month. Moreover, most farmers have an average of three dependents, further exacerbating the financial gap. The small area of cultivated land and high input costs were the reasons why farmers have not been able to achieve maximum profits. Weather and climate conditions contribute to the uncertainty of farmers' profits. Therefore, farmers need agricultural insurance. However, the agricultural insurance program had not been implemented evenly. Agricultural insurance was essential for maintaining farmers' profits, offering financial protection against risks such as adverse weather and market fluctuations. Agricultural insurance can increase agricultural productivity.[33]. In terms of farm financing, the majority of farmers rely entirely on self-financing and rarely receive assistance from the government or other financial institutions

c. Social Aspect

There is not much research on social sustainability. Social sustainability is the least explored area of research compared to the economic and environmental dimensions of sustainability[34]. The social aspect achieved the highest sustainability score at 69.44. However, important indices of social sustainability, such as the number of family members working as farmers and collaboration between farmer groups, remain underutilized. Farmers in *Kampung Sawah Mijen* were generally older, and younger generations from their families did not pursue farming careers. Farmer regeneration was key to agricultural sustainability.[35]. Instances of collaboration between farmer groups remain infrequent. Collaboration among farmer groups in *Kampung Sawah Mijen* is essential, as each group possesses unique strengths that can collectively enhance agricultural profitability.

d. Environmental Aspect

Chemical fertilizer use, aquaculture waste management, and organic fertilizer adoption were key indicators influencing the environmental sustainability score of 44.33. In Kampung Sawah Mijen, farmers had not yet completely embraced ecologically friendly farming methods. The conversion of waste into organic fertilizer was not fully optimized. Optimal waste utilization can lower agricultural input costs and mitigate environmental pollution.[36]. For any agricultural society, ensuring the well-being of the plants is crucial to achieve a greater yield[37]. The vitality and overall condition of plants significantly influence the final results of agricultural production. Therefore, the adoption of sustainable practices such as organic fertilizer use not only supports environmental goals but also directly contributes to improving plant health and agricultural productivity.

e. Government Support Aspect

The government support aspect had a sustainability score of 43.4, indicating low sustainability. Regulations to prevent land conversion in the green belt were key determinants of the government's support for the sustainability score. There was no definitive regulation

prohibiting land conversion in the green belt. Land conversion was a crucial point that could threaten the sustainability of agriculture. Land conversion can be prevented through extension activities that involve farmer groups. Farmer groups play an important role in the effectiveness of extension activities.[30].

f. Creative Economy (Tourism Aspect)

Kampung Sawah Mijen was under development. Enhancing amenities, such as hotels, internet access, restaurants, parking, toilets, and guides, can attract more tourists to *Kampung Sawah Mijen*.

The sustainability status of *Kampung Sawah Mijen* can be elevated from sustainable to highly sustainable by implementing targeted improvement scenarios. The following scenarios outline aspects that can be improved to elevate *Kampung Sawah Mijen* to a highly sustainable status, as presented in Table 5.

Here are some indicators that can be improved through scenarios:

a. Technological Aspect

Activities that can be undertaken to enhance the technological aspect include:

i. The Department of Agriculture, through agricultural extension workers and infrastructure, can organize training and assistance programs to enhance farmers' skills in using agricultural technology. Technology demonstrations can be included in these programs to improve farmers' understanding of their use. This program should be implemented regularly and consistently to ensure its success. Intensive extension programs will accelerate farmers' response to new technologies and ensure they are relevant to their local needs[38].

ii. The government collaborates with academics to continuously innovate and acquire the latest information on environmentally friendly agricultural technology. It can certainly increase farmer productivity and reduce adverse impacts on the environment as the integration of IoT-based smart agriculture systems particularly those optimized

Table 5: Very Sustainable Scenario

No.	Aspect	Existing	Scenario 1
1	Technological	41,67	77,83
2	Economic	52	85,38
3	Social	69,44	93,56
4	Environmental	44,33	75
5	Government Support	43,4	86,8
6	Creative Economy (Tourism)	50	91,75
Total Average		50,14	85,05
Status Sustainability		Sustainable	Very Sustainable

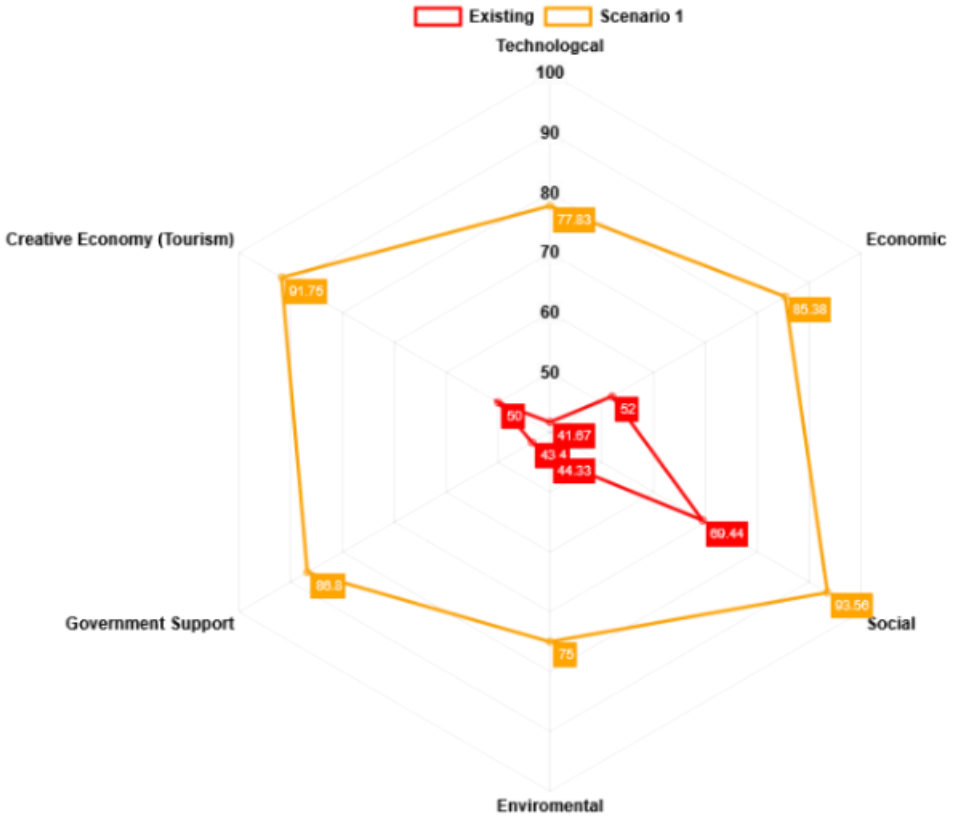

Fig. 2: Sustainability Graph

using adaptive algorithms has been shown to significantly enhance efficiency, reduce energy consumption, and improve sustainability in agricultural practices39).

iii. Providing incentives for farmers who were willing to implement environmentally friendly agricultural technology.

b. Environmental Aspect

Activities that can be carried out to enhance environmental aspects include:

i. Reducing farmers' dependence on chemical fertilizers by providing organic fertilizer subsidies was a key initiative.
ii. Conducting regular mentoring for farmers on environmentally friendly agriculture
iii. The marketing process needs to be introduced into to environmentally friendly marketing process
iv. Utilize waste treatment technology. Sustainable agricultural practices that adopt a zero-waste production system and optimize local resources can facilitate green manufacturing in agro-ecotourism areas like *Kampung Sawah Mijen*[40)].

c. Government Support

Activities that can be undertaken to enhance aspects of government support include:

i. The government provides targeted financial support to encourage farmers to adopt sustainable eco-agriculture practices. Financial support can be in the form of grants or incentives for farmers. This will certainly have an impact on reducing environmental pollution and increasing the production efficiency of rice farmers in *Kampung Sawah Mijen*[41)].
ii. The Semarang City government should enact regulations with strict sanctions to prevent the conversion of paddy fields. The government should also involve local communities in green belt monitoring to prevent land conversion. Strict regulations and supervision from local communities can reduce the conversion of paddy fields and maintain the sustainability of *Kampung Sawah Mijen*.
iii. The government can support farmers by providing environmentally friendly agricultural machinery for land cultivation and post-harvest activities.

d. Creative Economy (Tourism) Aspect

Activities that can be undertaken to enhance the creative economy (tourism) aspect include:

i. Develop infrastructure to meet the needs of tourists. High-quality facilities can encourage repeat visits to Kampung Sawah Mijen.
ii. Strengthen the Tourism Awareness Group (*Pokdarwis*) Tambangan to serve as the primary driver of creative economic development in Mijen Rice Fields Village's agro-edu-tourism sector
iii. Organizing creative events centered on culture, environment, and education to promote sustainable tourism in *Kampung Sawah Mijen*.

e. Economic Aspect

Activities that can be undertaken to improve the economic aspect include:

i. Improve agricultural production efficiency by utilizing green manufacturing practices to increase crop yields.
ii. Optimize agricultural inputs by converting waste into organic fertilizer[42)].
iii. Enhance market access for agricultural products to increase their selling value.
iv. Providing agricultural insurance to guarantee rice yields for agricultural uncertainties, such as weather or pests, and plant disease attacks.

f. Social Aspect

Activities that can be undertaken to improve environmental aspects include:

i. Develop a farmer regeneration program by engaging younger generations and offering incentives to those pursuing farming careers.
ii. Promote a positive perception that attracts young farmers who work as farmers as a promising job in farming as a viable and rewarding career.
iii. Farmer group leaders can collaborate in the development of agriculture in *Kampung Sawah Mijen*. Each farmer group has its own uniqueness. The Ayem Tenang Farmer Group plays a role in the management of soto sawah, so it has the potential to become the main market for other farmer groups. The Ngudi Makmur Farmer Group plays a role in livestock management, so it has the potential to become a provider of fertilizer from livestock manure for other farmer groups. The Sidorejo Farmer Group plays a role in orchid garden management, which can be an added value for other farmer groups.

Based on the results, this research recommends a model to enhance sustainability in Kampung Sawah Mijen as an agro-edutourism area. This model aligns with the principles of green manufacturing, which emphasize energy efficiency, the use of environmentally friendly materials, and waste recycling to reduce environmental pollution.[43)]. The model integrates agriculture, livestock, aquaculture, and the local market within a circular economic system. This approach improves efficiency, minimizes waste, and utilizes renewable energy sources, thereby creating an economic ecosystem that reduces waste and emissions at the source.[44)].

3.3. Green Manufacturing Solutions

Although green manufacturing is frequently addressed in broad terms, this study gives a concrete application of the concept in the agricultural setting of Kampung Sawah Mijen. Green manufacturing here is more than just theoretical principles; it is practically represented through the integration of low impact, resource efficient processes

throughout the production system. These include converting rice straw and livestock manure into organic fertilizer, using rice husk as biomass energy, reusing aquaculture effluent for smart irrigation, and implementing environmentally friendly post-harvest technology. These methods are consistent with the 5R (Reduce, Reuse, Recycle, Refurbish, and Repair) framework and reflect circular economy ideas. By embedding these actions within both the production and educational aspects of the agro-edutourism model, the case study demonstrates how green manufacturing can be implemented as a tangible, replicable system for sustainable rural development.

The green manufacturing processes developed in Kampung Sawah Mijen are visualized as a closed-loop system in Figure 3. This Figure serves as a labeled summary of the green manufacturing cycle, illustrating how agricultural, aquacultural, and livestock components interact through resource recycling, energy reuse, and integrated production flows. It highlights the core elements of circular economy principles applied within the agro-edutourism model. Figure 3 illustrates the relationships between several key sectors, including:

a. Cultivated Crops in Kampung Sawah Mijen

The primary crop cultivated was rice. The harvested rice was processed at the rice milling unit (BUMP Lumpang Semar) to produce rice for consumption. In addition to rice, there were also crops grown for livestock feed and horticultural products, which can be sold at the farmers' market. The agricultural waste, such as rice straw, can be converted into organic fertilizer and biomass.[45,46]. The use of partial organic fertilizer substitution has been shown to reduce methane (CH_4) emissions by up to 36.95%, global warming potential (GWP) by up to 31.29%, and contributing to more sustainable rice cultivation practices[47].

b. Rice Milling (BUMP Lumpang Semar)

BUMP Lumpang Semar absorbs the harvest from the rice fields. The rice milling unit at *BUMP Lumpang Semar* has a production capacity of 2–3 tons of rice per day. The processed rice can be sold directly at the farmers' market and supplied to Soto Sawah. The rice husk waste from milling can be used as fertilizer for crops and processed into biomass.

c. Livestock Barn

The livestock barn produces milk and meat, which are sold at the farmers' market. Additionally, livestock manure can be used as fertilizer and biomass, supporting sustainability within the system.[48].

d. Aquaculture

The aquaculture sector produces fish fry and consumable fish products. Fish from aquaculture serve as a menu item at Soto Sawah and can also be sold at the farmers' market. Recycled wastewater from aquaculture was used as one of the irrigation sources for rice farmers. The irrigation

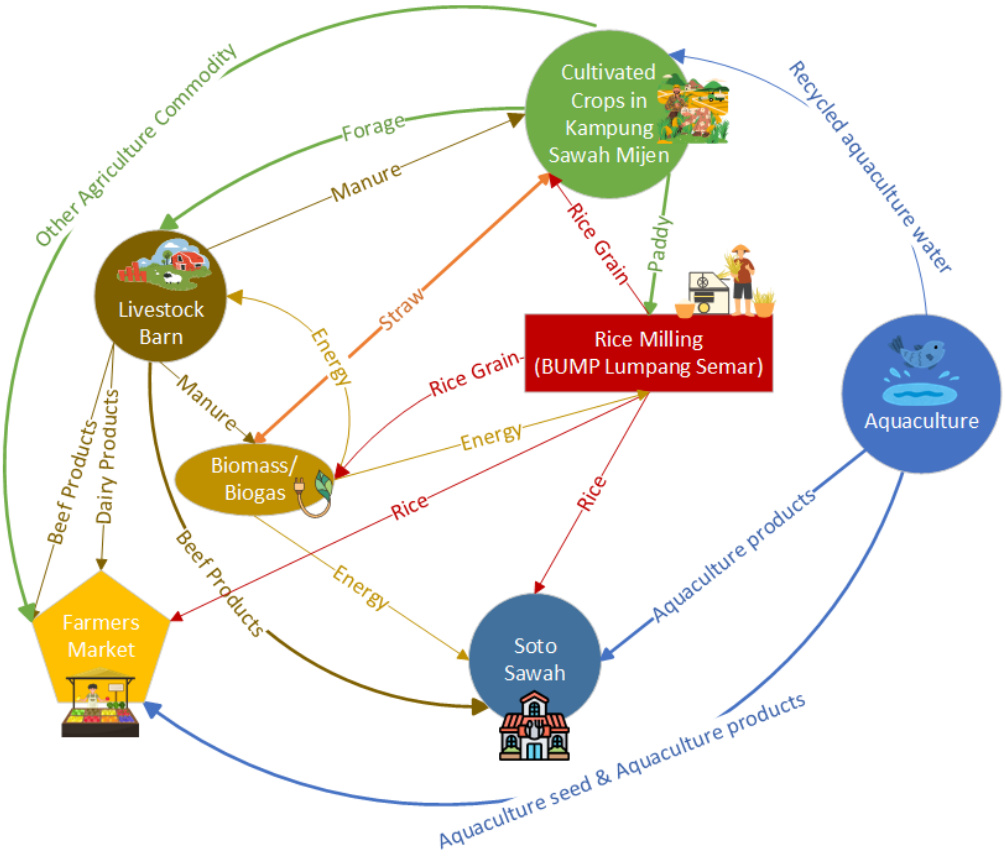

Fig. 3: Green Manufacturing Model

system adopts the concept of smart farming. Biomass can be converted into energy that can power irrigation pumps. The smart farming concept can improve resource efficiency.[49]. The use of aquaculture wastewater for irrigation aligns with the concept of Water-Saving Irrigation (WSI), contributing to water conservation and significantly enhancing water use efficiency (WUE). WSI practices significantly reduced carbon dioxide (CO_2) emissions by approximately 8% (lnRR = −0.084, 95% CI: −0.139 to −0.028) and methane (CH_4) emissions by around 42% (lnRR = −0.551, 95% CI: −0.640 to −0.462). In addition, GWP and greenhouse gas intensity (GHGI) decreased by about 29% and 39%, respectively, highlighting the potential of WSI to mitigate climate change impacts[50]. Integrating WSI with nutrient-rich aquaculture effluents as organic liquid fertilizer offers further benefits by partially replacing synthetic fertilizers, potentially lowering N_2O emissions, and promoting the productive reuse of organic waste. This approach not only saves water but also contributes to greenhouse gas mitigation and circular resource management in agriculture.

e. Soto Sawah (Restaurant)

Soto Sawah, a culinary spot within the agro-edutourism area, uses locally sourced ingredients. Organic waste from the Soto Sawah restaurant was returned to the agricultural sector or converted into biomass, creating an efficient closed-loop system. Utilization of *soto sawah* waste helps reduce organic waste disposal to the Jatibarang landfill, which is a landfill in Semarang City. Research shows that organic waste produces large greenhouse gas emissions in Semarang City.[51].

f. Farmers Market

The farmers market serves as the main distribution hub for agricultural, livestock, and aquaculture products generated from this system. It supports sustainability by improving the economic well-being of the local community.

The application of green manufacturing practices, particularly through the reuse of agricultural waste, can also offer economic benefits for farmers. A case example from Kampung Sawah Mijen compares two farmers: one who utilizes on-farm organic waste (Farmer 1), and another who does not (Farmer 2). Farmer 1 applies compost made from agricultural waste on a 0.9-hectare plot, incurring a fertilizer cost of IDR 600,000. In contrast, Farmer 2 relies entirely on purchased chemical fertilizers for a 0.35-hectare plot, with a cost of IDR 520,000. When normalized per hectare, the organic-waste-based approach results in a cost of approximately IDR 666,667/ha, whereas the use of chemical fertilizer reaches around IDR 1,485,714/ha. This indicates that utilizing agricultural waste as fertilizer can reduce input costs by about 55%, while also contributing to waste reduction and improved soil health. These findings provide early support for the economic feasibility of green manufacturing practices in smallholder farming systems.

Beyond its economic potential, the adoption of green manufacturing practices also plays a vital role in enhancing the experiential and educational dimensions of agro-edutourism. Agro-edutourism is a tourism concept that combines agriculture and education, aiming to provide visitors with an educational experience about sustainable farming, livestock, or aquaculture systems. At the same time, it contributes to improving the well-being of the local community through economic diversification. Integrating these features can create a complex yet balanced development model. Natural and man-made elements were integrated by addressing local needs and applying suitable technology to promote efficient and environmentally friendly management.

These educational experiences are enhanced through the application of green manufacturing practices, such as waste recycling, energy-efficient irrigation, and the reuse of organic materials. Visitors not only observe but also participate in these environmentally friendly processes, making sustainability both visible and tangible. The integration of green manufacturing practices into agro-edutoursim activities in Kampung Sawah Mijen is realized through experiential learning and demonstration-based tourism. For instance, visitors are introduced to the processes of converting agricultural waste into organic fertilizer, recycling rice husk into biomass, and using smart farming systems for irrigation. These practices are not only implemented by the farmer groups but also showcased to tourists through guided tours, educational signage, and interactive demonstrations. Through this approach, Kampung Sawah Mijen serves as a living classroom that allows visitors to learn firsthand about sustainable agriculture and circular production systems, thereby strengthening the educational component of agro-edutourism with practical green manufacturing applications.

The implementation of green manufacturing practices not only contributes to sustainable agricultural production but also strengthens the quality and depth of the agro-edutoursim experience. Conversely, agro-edutourism serves as an effective platform to promote and disseminate green manufacturing concepts to the broader public. This mutual relationship creates a reinforcing loop where sustainability practices support tourism, and tourism, in turn, educates and encourages wider adoption of sustainable practices. Thus, green manufacturing and agro-edutourism are inherently interlinked, forming a synergistic model for sustainable rural development.

The complex system that integrates various aspects within Kampung Sawah Mijen requires a metaheuristic and artificial intelligence-based approach to ensure long-term sustainability and address increasingly complex challenges. Metaheuristic algorithms, particularly those enhanced by artificial intelligence, have demonstrated high flexibility

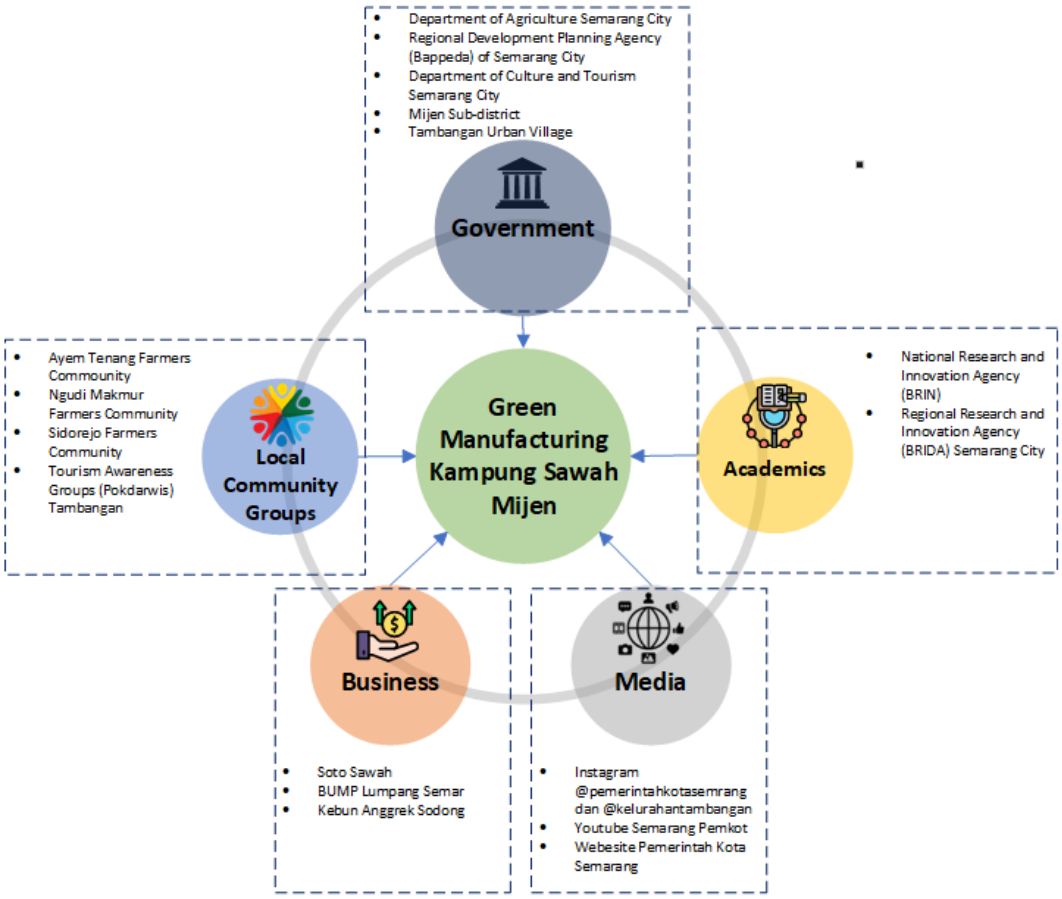

Fig. 4: Pentahelix

and efficiency in solving multi-objective problems in dynamic environments[52,53]. These capabilities offer promising potential for future applications in sustainable production and planning contexts. However, further in-depth research is needed to examine the practical implementation and contextual relevance of metaheuristic algorithms in the integration of green manufacturing systems with agro-edutourism.

Based on the result, this research recommends solutions to improve collaboration involving various stakeholders in supporting *Kampung Sawah Mijen*. Figure 4 describes a collaborative ecosystem involving various key stakeholders in supporting green manufacturing solutions in *Kampung Sawah Mijen*. The model integrates environmental sustainability, local community empowerment, and strategic sectors such as government, farmer groups, businesses, academia, and media. The roles of each element in supporting green manufacturing solutions were detailed as follows:

a. **Government:** The government serves as a policy maker and infrastructure provider to facilitate the implementation of green manufacturing solutions.
   i. The Semarang City Department of Agriculture manages the Mijen Rice Field Village area (Regulator and facilitator; provides land, technical support, and policy).
   ii. The Regional Development Planning Agency (Bappeda) of Semarang City, which was responsible for planning and overseeing the development of *Kampung Sawah Mijen* (Regional planning; integrates agro-tourism into local development plans).
   iii. The Semarang City Department of Culture and Tourism, which was tasked with fostering a sustainable creative economy through tourism in *Kampung Sawah Mijen* (Regional planning; integrates agro-tourism into local development plans)
   iv. The Government of Mijen District and Tambangan Village serve as local area authorities responsible for managing the region
b. **Local Farmers Community:** The local community was the main actor in the realization of a sustainable *Kampung Sawah*. Key community groups that contribute significantly include:
   i. Three farmer groups were key contributors to the success of green manufacturing, as they played a central role in its implementation in Kampung Sawah Mijen. Processing agricultural waste was a fundamental green manufacturing practice that promotes sustainable resource efficiency[54]. Strong social capital can encourage collective action of the three farmer groups to implement green

manufacturing practices, such as agricultural waste processing, which ultimately supports the development of agro-tourism in Kampung Sawah Mijen.[55].

ii. *Pokdarwis* have a role in promoting the concept of environmentally friendly educational tourism based on green manufacturing. The rice paddy farming tourism concept promoted by *Pokdarwis* serves as a sustainable development model by integrating eco-friendly practices, resource conservation, and socio-economic improvements for local communities[56].

c. Academics: Universities and research institutions provide technical assistance, training, and technological innovations to support agriculture and green manufacturing. The existence of research and development was very crucial in encouraging and strengthening environmentally friendly technology to realize green manufacturing in Kampung Sawah Mijen[57]. The National Research and Innovation Agency (BRIN) and the Regional Research and Innovation Agency (BRIDA) of Semarang City design green manufacturing solutions for *Kampung Sawah Mijen's* tourism sector. This collaboration includes:

i. Research to improve energy efficiency and waste management,
ii. Education to the local community regarding environmentally friendly technology,
iii. Support for the design of a sustainable agro-edutoursim concept.

In the context of Kampung Sawah Mijen, the National Research and Innovation Agency (BRIN) could play an important role during the implementation phase by contributing research-based innovations tailored to the needs of smallholder farmers. This may include developing technologies for composting agricultural waste, low-cost irrigation systems, or other resource-efficient farming solutions that align with green manufacturing principles. At the local level, the Regional Research and Innovation Agency (BRIDA) of Semarang City can act as an intermediary institution, helping to translate national research outputs into practical applications. BRIDA's involvement is particularly relevant in ensuring that innovations are contextually appropriate, well-integrated with local agricultural practices, and responsive to the specific challenges faced by farmers in Kampung Sawah. Through coordination with farmer groups and local government units, BRIDA helps bridge the gap between science and on-the-ground implementation, making the transition to more sustainable farming approaches more feasible and inclusive.

d. Business: Business actors play a role in supporting and driving an economy based on green manufacturing. Circular economy-based business concepts can realize sustainable development[58]. Elements that play a role include:

i. Soto sawah can absorb environmentally friendly agricultural products. Then, the waste produced can be reprocessed to be utilized for agriculture.
ii. *BUMP Lumpang Semar* can absorb the rice harvest, strengthen value chains, promote eco-products, apply circular practices.
iii. The orchid garden can be a spot of ornamental plant conservation that uses the concept of green manufacturing.

e. Media: The media promotes agro-edutoursim and supports the implementation of green manufacturing. Media roles include:

i. Dissemination of information on the benefits of green manufacturing practices,
ii. Increase public awareness about the importance of environmental sustainability.
iii. The media also supports branding *Kampung Sawah Mijen* as an icon of eco-friendly tourism in Semarang City.

The green manufacturing model in Figure 4 emphasizes the following principles

Introducing innovation or agricultural business to the farming community is not easy. This requires high perseverance, tenacity, and patience so that the welfare improvement program of the organization or farmers can be realized, namely introducing alternative commodities with high economic value. The need for mature planning and strategy in managing agribusiness will be a good mitigation in solving various obstacles and problems that certainly occur in the field[59]. The model in Figure 4 emphasizes a pentahelix collaboration involving five elements in society, namely government, academia, local communities, business, and media. This synergy and collaboration can advance sustainable green manufacturing by increasing resource efficiency, reducing environmental impact through waste recycling, and enhancing the welfare of local communities.

Despite its strong potential, the implementation of green manufacturing in Kampung Sawah Mijen is not without its challenges. One of the main trade-offs lies in the need to balance traditional farming practices with the introduction of sustainable technologies. While green manufacturing promotes principles such as efficiency and circularity, many local actors are still accustomed to conventional methods. This creates a learning curve, where shifting mindsets and building technical capacity take time and patience.

Financial constraints also present a major limitation. For many smallholder farmers and community enterprises, accessing the capital needed for infrastructure improvements such as composting facilities, solar-powered irrigation, or waste-to-energy systems is not easy. Without targeted financial support or government incentives, the adoption of green practices risks being

limited in both scope and long-term impact.

The urban setting adds another layer of complexity. Although Kampung Sawah remains an active agricultural area, it exists within a rapidly developing city. Competing demands for land particularly from housing and infrastructure development raise concerns about the long-term security and availability of space for farming and tourism activities.

Even so, these challenges are not barriers, but rather opportunities for deeper collaboration. By strengthening the pentahelix model engaging government, academia, business, local community groups, and the media, these issues can be addressed more holistically. This approach supports not only shared responsibility, but also innovation and resilience, making green manufacturing in Kampung Sawah Mijen a practical and adaptable model for other cities facing similar transitions.

Several agro-edutourism initiatives from other regions and countries have been discussed in the introduction as points of comparison. However, most of them focus mainly on educational activities or traditional farming, and have not fully integrated green manufacturing practices. This study fills that gap by offering a model that combines agro-edutourism with green manufacturing, aiming to promote sustainability through circular systems, efficient resource use, and environmentally friendly innovations.

4. Conclusion

This study shows how combining community-based insights through Participatory Rural Appraisal (PRA) with structured assessment using Multiaspect Sustainability Analysis (MSA) can support the development of a green manufacturing model in Kampung Sawah Mijen. The model offers practical ways to improve sustainability in agro-edutourism by optimizing local resources and encouraging collaboration among stakeholders.

The green manufacturing model developed in this research responds to key challenges such as environmental pressure, limited government support, and the need for better technology. More importantly, it is built on local participation, making it relevant to the community and easier to implement.

Looking ahead, this model has strong potential to be adapted in other agro-edutourism areas, especially in urban-fringe regions facing similar issues like land conversion or food insecurity. With the right support from government, business, and local communities, this approach can be scaled and replicated in other parts of Indonesia or Southeast Asia.

Future research can explore how this model impacts long-term sustainability, such as reducing emissions or saving water, and how it works in different locations with different conditions.

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