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RESEARCH ARTICLE

Low Carbon Development Study of Watermelon Cultivation as an Implementation of a Green Economy

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ABSTRACT

Umbulrejo Village, Ponjong District, Gunungkidul Regency offers significant potential for dry land farming. However, the use of petrol generator-powered pumps for irrigation increases operational costs and generates environmental hazards, such as noise pollution and emissions of harmful substances including lead (Pb), carbon dioxide (CO2), carbon monoxide (CO), nitrogen oxides (NOx), and sulfur oxides (SOx). These pollutants contribute to air pollution, climate change, and health risks for the local population. To meet the agricultural sector's challenge of increasing food production by 70% by 2050 while simultaneously reducing greenhouse gas (GHG) emissions, Indonesia's solar energy potential—averaging 5.045 $kWh/m^2/day$—offers a viable solution. In Umbulrejo Village, Solar Power Plants (SPP) have demonstrated this potential by reducing GHG emissions by 3,071.78 kg of CO2 and saving IDR 3,200,000 in generator rental costs. These results illustrate how SPPs can support sustainable, low-carbon farming practices, reducing environmental impact while cutting operational expenses for farmers.

INTRODUCTION

Prolonged heat with high-temperature increases, followed by intense rainfall at the beginning of the rainy season, indicates the growing impact of climate change. Europe has experienced twice the average warming since 1980, with a global average temperature increase of 1.50°C above pre-industrial levels in 2019, making 2022 the hottest year on record (Directorate-General for Climate Action, 2023; Hansen et al., 2023).

Global warming is primarily driven by the effects of greenhouse gases (GHGs), particularly due to increasing concentrations of CO2. Fossil fuel power plants, including those that use petroleum, natural gas, and coal, are significant sources of CO2 emissions (Dewan Energi Nasional, 2023). Global efforts, including those by Indonesia, are essential to reduce GHG emissions. Indonesia has set a target to reduce its GHG emissions by 29% independently and by 41% with international support by 2030 (Angin et al., 2022).

The use of new renewable energy (NRE), such as solar energy, is increasingly encouraged. The rise in solar energy usage has been significant, driven by environmental awareness, technological advances, supportive policies, and decreasing solar technology costs. However, in 2022, the actual use of Solar Power Plants (SPP) in Indonesia was only 271.6 MW, far below the planned 893.3 MW [1].

To increase the usage of SPPG (Solar Panel Power Generator), the Yogyakarta Stiper Agricultural

Institute is collaborating with PT Virama Karya to develop a SPPG pump irrigation system in Umbulrejo Village, Ponjong District, Gunungkidul Regency. Local farmers currently use petrol-powered generators for irrigation, which raises production costs and causes environmental harm (Putri, 2017). Fossil fuel and electricity-powered irrigation increase water costs and greenhouse gas emissions. In developing countries, solar-powered irrigation is becoming popular to address these issues. A study of 1,080 wheat farmers in Balochistan, Pakistan, found that using solar-powered irrigation systems (SPIS) improved the technical efficiency of wheat production (Ullah et al., 2023). Another feasibility study assessed the adoption of solar-powered groundwater pumping systems in rural areas of South Africa, showing that the technology is financially and technically viable for enhancing water supply (Jovanović et al., 2023).

Providing irrigation with diesel pumps emits significant CO2. For example, a diesel pump in El-Bahera Province, Egypt, emits an average of 690 tons of CO2 per ton m^3 of water (El-Gafy & El-Bably, 2016). In China, emissions from irrigated agriculture range from 36.72 Mt to 54.16 Mt, with groundwater pumping contributing around 60.97% of these emissions (Zou et al., 2015). In Indonesia, emissions from small-scale agricultural cultivation on peatlands include 42.6 tons of CO2/ha/year for rubber, 35.9 tons for oil palm, and 34.4 tons for ginger plantations (Gusmayanti & Gusti Z Anshari, 2020).

Agricultural cultivation is a significant GHG emitter, necessitating urgent emission reduction efforts. Presidential Regulation Number 71 of 2011 mandates an 8 Gg CO2eq reduction in the agricultural sector. In 2017, Indonesia launched the Low Carbon Development platform to promote a green economy and reduce GHG emissions (Kurniawati Hasjanah, Uliyasi Simanjuntak, 2023).

Low-carbon development in agriculture is crucial for the livelihoods of Indonesian farmers. Large-scale farmers tend to adopt capital-intensive low-carbon technologies like new crop varieties and straw recycling, while mid-level part-time farmers prefer labor-saving or low-risk technologies. Low-level part-time farmers often opt for labor-intensive methods to overcome capital constraints (Zhao & Zhou, 2021). Adoption of these technologies is influenced by household and plot characteristics, especially for farmers with capital constraints and high-risk preferences, common among Indonesian farmers. Therefore, providing solar-powered pumps for small-scale farmers is a strategic move to promote low-carbon agriculture in Indonesia.

Factors influencing the adoption of climate-smart agriculture (CSA) practices among smallholder farmers vary, including age, gender, education, risk perception, and access to credit. In contrast, factors such as labor availability, land tenure security, extension services, agricultural training, NGO support, climate conditions, and access to information consistently have a positive impact. Climate-smart villages and civil society organizations enhance CSA adoption by improving credit access. CSA adoption increases agricultural resilience to climate change, boosts crop yields, farm income, economic diversification, and reduces greenhouse gas emissions (Ma & Rahut, 2024). This research aims to examine the effectiveness of low-carbon development in reducing GHG emissions by cultivating watermelon in Umbulrejo Village, Ponjong District, Gunungkidul Regency. This development model can be expanded by evaluating the effectiveness of SPP pump irrigation in reducing GHG emissions.

METHODOLOGY

Research Sites

The research was conducted in Sladi Hamlet, Umbulrejo Village, Ponjong District, Gunungkidul Regency, Special Region of Yogyakarta (Figure 1). The research object is a SPP pump irrigation system designed to irrigate watermelon plants, developed by INSTIPER in collaboration with State-Owned Enterprises (SOE) company PT Virama Karya.

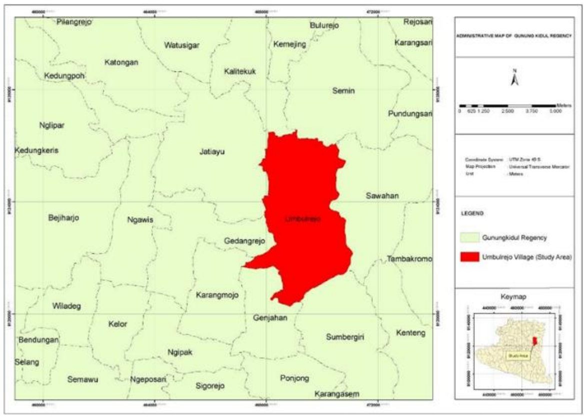

Figure 1. Reseach Location

Analysis Method

The study aimed to evaluate whether the construction of a pump irrigation system using solar power (SPP) can be categorized as low-carbon development. This evaluation is crucial to determine if the system effectively reduces greenhouse gas (GHG) emissions compared to conventional irrigation systems that rely on fossil-fuel-powered pumps. Furthermore, the analysis seeks to assess the environmental impact of implementing SPP irrigation technology in the context of sustainable agriculture. The steps involved in the analysis are as follows:

a. Analysis of Irrigation Water Supply

This analysis aims to determine the amount of water needed by watermelon plants and their water supply patterns. To achieve this, UIR (Unit Irrigation Rate) data from nearby areas with similar soil types, climate conditions, and watermelon varieties were used. The optimal water application pattern was then implemented based on plant needs, including frequency, volume, and timing.

b. Analysis of GHG Emissions from Watermelon Cultivation Irrigation Systems

This analysis focuses on emissions produced by irrigation systems that use petrol generator-powered pumps, as currently employed by farmers. It includes a comprehensive look at fuel consumption estimates. Additionally, the calculation of greenhouse gas (GHG) emissions was carried out in detail using emission factor values from previous research, referring to the IPCC 2006 guidelines refined in the 2019 Book 2 on Energy (IPCC, 2019).

c. Low Carbon Development Analysis

This analysis aims to determine the amount of GHG emissions resulting from the operation of the PLTS pump irrigation system and compare it with conventional irrigation systems to assess its effectiveness in reducing the carbon footprint. The steps for the GHG Emission Inventory included data collection and emissions calculation. Data collection was conducted to inventory the energy and fuel consumption of a pump irrigation system, which encompassed the production, transportation, installation, and operational processes powered by fossil fuel electricity. Additionally, the operational costs of solar-powered irrigation pumps were also inventoried for comparison with the conventional pump irrigation system. Afterwards, GHG (CO2 equivalent) emissions were calculated based on the energy and fuel consumption as activity data and emissions factors, in accordance with IPCC Guidelines for National Greenhouse Gas Inventories.

RESULT

Analysis of Irrigation Water Supply

The study at the Southwest Purdue Agricultural Center analyzed watermelon yield differences between irrigated and non-irrigated fields. The irrigated field received 25.4 mm of water weekly via drip tape and mulch, while the non-irrigated field did not receive supplemental water. Results showed that the non-irrigated field had a yield reduction of approximately 5%, with the average fruit weight dropping from 7.53 kg to 7.16 kg. Fully grown watermelon plants require around 25.4 mm to 38.1 mm of water weekly during the summer, based on average reference evapotranspiration (ETo). With about one-third of the field covered with plastic mulch, this translates to a water requirement of approximately 34,260 to 51,390 liters per hectare per week (Guan, 2020).

The average monthly potential evapotranspiration (ETo) in Gunungkidul Regency is 3.57 mm/day (Khalimi & Kusuma, 2018). Research in Ngeposari Village, Semanu District, Gunungkidul Regency, found the Unit Irrigation Rate (UIR) for watermelon plants during the growth period to be 3.86 mm/day. The growth period for watermelon ranges from 80 to 110 days (Prastowo et al., 2007). Table 1 shows the detailed water supply pattern for watermelon cultivation.

Table 1. Pattern of Water Supply for Watermelon Cultivation

No.	**Planting Age**	**Water Supply**			
		Morning		**Aftenoon**	
		UIR (mm/day/hectar)	Watering period, every	UIR (mm/day/hectar)	Watering period, every
1	1 – 15 DAP	3.89	2 days	3.86	2 days
2	15 - 45 DAP	3.86	3 days	3.86	3 days
3	46 - 60 DAP	3.86	4 days	3.86	4 days
4	61 - 75 DAP	3.86	5 days	3.86	5 days
5	76 - 90 DAP	3.86	5 days		
6	91 - 110 DAP	3.86	5 days		

The watering schedule for watermelon plants is as follows:

a. For the first 15 days, water is given every 2 days, in the morning and evening.
b. From 15 to 45 days after planting (DAP), water is supplied once every 3 days.
c. From 45 to 60 days, watering is done once every 4 days.
d. From 60 to 110 days, water is given every 5 days, only in the morning.

Water Requirement and Irrigation Capacity

Water requirements are essential for optimal watermelon growth and yield. Research indicates that watermelon plants need approximately 38.6 m^3 of water per day per hectare. Using a submersible pump with a capacity of 9.6 liters/second, it takes about 1.11 hours to irrigate 1 hectare. In Sladi Hamlet, Umbulrejo Village, 184 hectares of land are available for watermelon cultivation. However, water instability and financial limitations, especially concerning renting electric-powered irrigation pumps and petrol generators, restrict agricultural activities during the dry season (USAID, 2020).

Collaboration Between Farmers and Pump Providers

Farmers and petrol generator owners established a collaboration for one planting season, which involved 278 hours of pumping: 4.5 hours per session for 52 sessions (morning and evening) and 5 hours per session for 7 morning sessions (Purboseno et al., 2023). Although previous studies set the submersible pump's capacity at 9.2 liters/second, farmers agreed to operate at 8 liters/second.

The discrepancy was due to the unstable water discharge from dug wells, requiring longer operational hours than initially calculated to ensure sufficient water for the plants, as detailed in Table 2.

Table 2. Provision of water for watermelon cultivation 5.6 Ha (8 Shoulder)

No.	Planting Age		Water Supply			
			Morning		Aftenoon	
		Period for water supply, every	Debit(lt/sec)	Delivery Time (hours)	Debit(lt/sec)	Delivery Time (hours)`
1	1 - 15 DAP	2 days 8 times	8	4.5	8	4.5
2	15 - 45 DAP	3 days 10 times	8	4.5	8	4.5
3	46 - 60 DAP	4 days 5 times	8	4.5	8	4.5
4	61 - 75 DAP	5 days 4 times	8	4.5	8	4.5
5	76 - 90 DAP	5 days 3 times	9	5.0		
6	91 - 110 DAP	5 days 4 times	9	5.0		

Analysis of GHG Emissions from Watermelon Cultivation Irrigation Systems

The study focused on assessing the greenhouse gas (GHG) emissions specifically associated with the irrigation systems used in watermelon cultivation, primarily powered by gasoline generators. The emissions were calculated based on operational hours, fuel consumption, and the carbon emission factors linked to gasoline use. The findings are detailed below:

a. Operational hours and fuel consumption:

1. The irrigation system used a submersible pump, powered by a gasoline generator (3 kVA, 3000 watts), which perated for a total of 278 hours over the entire cultivation period.

2. The operation of the pump varied across different growth stages, reflecting the varying water needs of the watermelon plants.

3. Table 3 provides a detailed breakdown of the operational hours during different planting stages, showing how water requirements change throughout the crop cycle.

Table 3. Operating Hours for Petrol Generator Engines

No.	Planting Age		Operation of Gasoline Generator Engines			
			Morning		Afternoon	
		Number of Operations	Operating Time (hours)	Total Operating Time (Hours)	Operating Time (hours)	Total Operating Time (Hours)
1	1 - 15 DAP	8	4.5	36	4.5	36
2	15 - 45 DAP	10	4.5	45	4.5	45
3	46 - 60 DAP	5	4.5	22.5	4.5	22.5

4	61 - 75 DAP	4	4.5	18	4.5	18
5	76 - 90 DAP	3	9	5.0		
6	91 - 110 DAP	4	9	5.0		
			Total	156.5		121.5
Number of Operational Hours for Gasoline Generator Engines					278	

b. Fuel requirements:

1. The total gasoline consumption for the 278 operational hours was calculated to be 231.67 liters, reflecting the energy required to sustain irrigation throughout the growing season.

2. Table 4 presents the detailed fuel requirements based on different planting stages, showing a comprehensive view of energy usage patterns.

Tabel 4. Fuel Requirements for Operational Petrol Generators

No.	Planting Age	Fuel Requirements for Gasoline Generator Engines			
		Morning		Aftenoon	
		Number of Operations	Gasoline Consumption (Lt)	Number of Operations	Gasoline Consumption (Lt)
1	1 - 15 DAP	36.00	30.00	36.00	30.00
2	15 - 45 DAP	45.00	37.50	45.00	37.50
3	46 - 60 DAP	22.50	18.75	22.50	18.75
4	61 - 75 DAP	18.00	15.00	18.00	15.00
5	76 - 90 DAP	15.00	12.50		
6	91 - 110 DAP	20.00	16.67		
			130.42		101.25
Total Gasoline Consumption (lt)				231.67	
Gasoline factor emissions (CO_2 kg/lt)				2.32	
Total Gasoline GHG Emissions (kg)				535.16	

c. GHG emissions calculation:

1. The CO2 emission factor for gasoline was identified as 2.31 kg per liter (IPCC, 2019).

2. Using this emission factor, the direct CO2 emissions from the gasoline generator throughout the cultivation period were calculated to be 535.16 kg.

3. The study also accounted for additional emissions from the processes of fuel exploration, production, processing, and marketing, bringing the total GHG emissions to 3,071.78 kg CO2.

4. Table 3 provides a comprehensive breakdown of the emission sources.

Table 5. Analysis of the emission load of the watermelon cultivation irrigation system

	Emission Sources	Reference Value	CO_2 GHG Emissions

No.		Value	Unit	Value	nit
1	Amount of gasoline burned (lt)	231.67	lt		
2	Direct CO_2 GHG emissions	2.31	kg/lt	535.16	kg
3	Specific gravity of gasoline	0.73	kg/lt	169.12	kg
4	Emissions from exploration and production processes	1.95	kg/kg	329.78	kg
5	Emissions from processing processes	1.009	kg/kg	170.64	kg
6	Amount of gasoline burned (lt)	11.04	kg/kg	1,867.07	kg
	Total GRC CO_2 Emissions			3,071.78	kg

Low carbon development analysis

The agricultural sector plays a crucial role in global food production but is also a major contributor to greenhouse gas (GHG) emissions, making it highly vulnerable to the impacts of climate change. As the world aims to meet 70% of global food needs by 2050, it is essential to develop this sector within a Low Carbon Development framework to balance productivity and sustainability (Solidaridad, 2023) Low-Carbon Agriculture: A Forward-Looking Approach To Farming. Key findings and strategies are outlined below:

a. The agricultural sector is a significant contributor to GHG emissions and faces challenges due to climate change. It is expected to meet 70% of global food needs by 2050, requiring development within a Low Carbon Development framework.

b. Research on low-carbon construction identified 21 influencing factors, with key influences being incentive policies, regulations, awareness, market and management support, technology, and economic factors.

c. Low Carbon Development aims to harmonize economic and environmental policies, allowing farmers to continue their activities while protecting the environment.

d. Indonesia's solar energy potential is high, with an average radiation intensity of 4.8 kWh/m^2/day, providing opportunities for solar power plant (SPP) development (Laksana et al., 2021)

e. The agricultural sector's shift to renewable energy, such as solar power, can help reduce GHG emissions. In Umbulrejo village, petrol generator-powered irrigation will be replaced with solar panels, reducing CO2 emissions.

f. Solar Power Plants (SPP) consist of solar modules, controllers, batteries, inverters, and other components, designed to operate off-grid for independent energy supply.

g. The initial phase of SPP development in Umbulrejo will cover 5.8 hectares, similar to the area previously served by petrol pumps. Due to funding limitations, the system currently operates for 4 hours daily.

h. Expanding SPP services can reduce GHG emissions, support sustainable agriculture, and enhance food security. Integrating renewable energy with sustainable practices promotes environmentally friendly rural development.

i. Climate change severely affects agriculture, especially in tropical regions dependent on rain-fed farming, posing a threat to food security. Increasing agricultural growth is essential to alleviate poverty and meet food demands.

j. Expanding SPP services and planting areas will not only reduce GHG emissions but also increase carbon absorption and promote economic benefits.

k. Although the agricultural sector has not achieved the target of reducing CO2 emissions by 26% (2014–2018), continued efforts are needed to implement low-carbon development at the farmer level, ensuring food security and mitigating the impact of peak emissions (Firmansyah, 2022).

DISCUSSION

The transition to Low Carbon Development in agriculture is essential to tackle climate change and ensure food security. Solar power integration offers a sustainable alternative to fossil fuels, reducing greenhouse gas emissions and fostering eco-friendly practices. In Umbulrejo village, Solar Power Plants (SPP) have effectively replaced petrol-powered irrigation, cutting CO2 emissions. However, funding constraints limit their expansion, highlighting the need for investment.

Solar-powered irrigation lowers fuel costs, reduces carbon footprints, and benefits regions with abundant sunlight. The case in Umbulrejo shows that even small-scale adoption brings significant environmental gains. Despite these successes, limited funding restricts operational hours due to fewer panels and batteries.

By using solar energy, farmers avoid fuel price volatility and reduce environmental impact. Sadawarti et al., (2021) found that solar irrigation improves water use efficiency, reducing water use by 30% compared to traditional methods (Sadawarti et al., 2021). Gothandam et al., (2023) noted that solar systems provide reliable energy, especially in off-grid areas, enhancing productivity and economic stability (Gothandam et al., 2023).

Green economy and low-carbon agriculture

The green economy framework emphasizes growth that is inclusive, sustainable, and environmentally friendly. In agriculture, this translates into practices that lower GHG emissions, conserve resources, and enhance biodiversity without compromising productivity. Renewable energy, particularly solar power, plays a key role in this transition, as it reduces dependency on fossil fuels, which are subject to price volatility and environmental regulations.

In Indonesia, the push for a green economy has led to the implementation of solar-powered irrigation systems, particularly in areas like Gunungkidul. According to Firmansyah (2022), the government's low-carbon development strategy highlights the need for renewable energy in agriculture to mitigate climate impacts and ensure food security. Similar strategies have been seen globally. For instance, Solidaridad (2023) emphasizes the integration of renewable energy in farming to promote sustainable agriculture while reducing carbon emissions. Their reports suggest that low-carbon agriculture can increase economic resilience for farmers by minimizing energy costs and improving sustainability.

Economic benefits and green agriculture initiatives

Green economy initiatives in agriculture not only address climate concerns but also stimulate local economies. The introduction of solar-powered irrigation systems has proven effective in reducing farmers' operational costs while enhancing productivity. Aziz et al. (2021) found that solar-powered irrigation systems in rural Indonesia significantly cut costs and reduced reliance on fossil fuels, which is crucial in managing the financial viability of smallholder farms (Aziz et al., 2021). By utilizing solar energy, farmers can avoid the price fluctuations of fossil fuels and invest their savings in other farming improvements. This is consistent with findings from other regions, such as India, where Singh et al. (2019) reported that solar-powered systems reduced energy expenses by 40%, allowing farmers to reinvest savings, thereby boosting productivity (Kumar et al., 2022).

Expanding the reach of SPP services and increasing the areas under cultivation can further support food security by ensuring a consistent water supply, even during dry spells, thus making agriculture more resilient. Pereira et al. (2019) emphasized that equipping farmers with the skills to operate and maintain solar systems could generate local employment, fostering economic development while contributing to environmental sustainability (Pereira, 2000). Moreover, Mahato et al. (2022) showed that implementing training programs and financial incentives led to a 75% increase in solar irrigation adoption, highlighting the effectiveness of supportive policies in driving green agricultural growth.

Collaborative approaches to low-carbon agriculture

The success of SPP systems in Umbulrejo illustrates the potential of cooperative farming, where farmers collectively share resources and manage water distribution. This model has proven effective in reducing energy consumption by 42% and GHG emissions by 52%, indicating that collaborative approaches can yield both cost savings and environmental benefits. Li et al., (2021) found that cooperative farming reduced operational costs and made advanced irrigation technologies more accessible to smallholder farmers (Li et al., 2021). Zhang et al., (2023) observed similar successes in China, where shared solar irrigation systems improved water efficiency by 35% and lowered individual costs by 50% (Zhang et al., 2023).

Furthermore, Chen et al. (2024) emphasized the importance of low-carbon development strategies through collaborative models, even outside the agricultural sector (Chen et al., 2024). Their study on Chinese coal enterprises demonstrated how collective efforts in carbon emission accounting and performance evaluation led to more efficient resource management and reduced emissions. Applying similar strategies in agriculture, such as cooperative farming models for solar irrigation, can help streamline the adoption of green technologies, making them more feasible for smallholder farmers by distributing costs and operational responsibilities. This collaborative approach can effectively support the broader transition to low-carbon agriculture, enhancing sustainability while improving economic viability for rural communities.

Global examples of green agriculture

Adopting solar-powered irrigation has transformed agricultural productivity in several countries, reducing costs and enhancing water efficiency. A study by the International Water Management Institute (Chen et al., 2024) reported that solar-powered pumps in India reduced irrigation costs by 50% and significantly increased crop yields. Similarly, Atieno et al. (2013) found that Kenyan farmers experienced a 60% decrease in energy costs and a 25% increase in annual crop yields after adopting solar irrigation systems (Ndede-Amadi, 2013). These examples underscore the scalability of low-carbon agricultural practices, demonstrating that they can effectively address climate change while boosting economic stability in rural areas.

Moreover, Lipper et al. (2019) highlight the concept of Climate Smart Agriculture (CSA), which integrates sustainable technologies, such as solar-powered irrigation, to build resilience against climate change impacts (Lipper et al., 2017). Their study emphasizes that CSA practices not only increase productivity and enhance water use efficiency but also contribute to the reduction of greenhouse gas emissions. These approaches demonstrate that scalable, eco-friendly solutions can support food security while promoting sustainable agricultural development, which is crucial for the economic stability of rural communities. By adopting such practices, farmers can better adapt to climate variability, ensuring long-term resilience and sustainability.

Policies supporting a green economy in agriculture

Transitioning to low-carbon alternatives requires coordination among farmers, policymakers, researchers, and the private sector. Policies that incentivize clean energy adoption, such as subsidies for solar pump installations or tax rebates for renewable energy investments, can significantly accelerate this shift. UNEP (United Nations Environment Programme, 2021) emphasizes that integrating renewable energy into agriculture can reduce global agricultural emissions by 20%, advocating for robust policy frameworks to promote clean energy adoption.

Financial support mechanisms, including green financing, micro-loans, and grants, are essential to encourage farmers to invest in solar-powered systems by alleviating the burden of high initial costs. Such measures not only make clean technologies more accessible but also support the broader goals of a green economy by fostering sustainable agricultural practices.

Siagian et al. (2024) further highlight the economic benefits of sustainable land management practices, such as agroforestry, which enhance carbon sequestration and provide financial incentives for farmers (Siagian et al., 2024). Their study suggests that policies promoting agroforestry can create new income streams through carbon credits and green financing, demonstrating how environmental conservation can be integrated with economic development. This approach aligns with broader efforts to promote a green economy, showing how the agricultural sector can balance productivity with sustainability.

Additionally, Houssam et al. (2023) emphasize the importance of government-led incentives and international cooperation in promoting the adoption of green technologies, including renewable energy and sustainable farming practices (Houssam et al., 2023). They argue that a supportive policy environment is crucial for integrating low-carbon technologies into agriculture, helping developing nations achieve sustainable growth. Effective coordination across sectors can thus drive the widespread adoption of low-carbon technologies, ensuring economic and environmental sustainability.

CONCLUSION

The implementation of the PPS pump irrigation system in Umbulrejo Village, Ponjong District, Gunungkidul Regency, has demonstrated significant environmental and economic benefits by reducing the operation of petrol generator pumps by 79.28%, effectively decreasing GHG emissions in watermelon cultivation by 3,071.78 kg CO2. This substantial reduction in emissions contributes to the broader goal of mitigating climate change impacts and aligns with global sustainability targets. Furthermore, the use of PPS pumps has proven economically advantageous for farmers. Increased profits from reduced operational costs and enhanced efficiency mean that economic and environmental interests are not in conflict but mutually reinforcing. This synergy illustrates how Low Carbon Development successfully integrates into the agricultural sector, promoting sustainable farming practices while boosting farmer incomes. The transition to renewable energy sources, such as solar power, exemplifies the implementation of the Green Economy at the grassroots level. This approach addresses immediate energy needs and fosters long-term sustainability and resilience in the agricultural community. To maximize these benefits, it is crucial to expand the capacity of PPS and enhance the irrigation network systems in line with initial design specifications. These improvements will further amplify the reduction of GHG emissions from the energy generation sector, solidifying the role of renewable energy in achieving environmental and economic goals. In conclusion, the PPS pump irrigation system in Umbulrejo Village can serve as a model for other regions, demonstrating the potential of renewable energy solutions in transforming agricultural practices. By continuing to invest in and develop these systems, we can pave the way for a more sustainable and prosperous future for farmers and the environment.

Conflicts of interest

There are no conflicts to declare.

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