

Fly Ash Innovation in Sustainable Agriculture: A Case Study of the INNDESA CSR Program by PT PLN Indonesia Power UBP Central Java 2 Adipala

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Abstract. This study aims to explore the innovative use of fly ash by PT PLN Indonesia Power UBP Central Java 2 Adipala as a natural insecticide within the INNDESA program. This is crucial as global climate change has brought food security issues to the forefront of strategic agendas for many countries, including Indonesia. Employing a qualitative case study approach, this research collected data through in-depth interviews with beneficiaries of the INNDESA program, supported by secondary data from relevant journals, mass media, program reports, and other supporting documents. The findings reveal that: (1) the utilization of fly ash in INNDESA innovation effectively replaces chemical pesticides by killing pests through abrasive mechanisms and preventing them from attacking crops, (2) the INNDESA program fosters economic improvement in communities through a circular economy system, and (3) the INNDESA program aims to establish sustainable, community-based food security as reflected in the establishment of the INNDESA Integration Forum.

Keywords: Fly Ash, Natural Insecticide, Food Security, Sustainable Agriculture.

A. INTRODUCTION

Amid ongoing global climate change, food security has undoubtedly become a strategic focus and locus for governments worldwide, including Indonesia. Partini and Sari (2022) note that food security can be considered a reflection of a nation's level of prosperity and welfare. Food security, as defined by Law No. 18 of 2012 on Food, refers to a condition where food is adequately available at the national and individual levels, characterized by sufficient quantity and quality, safety, diversity, nutritional value, equity, affordability, and compliance with religious, cultural, and societal norms, enabling a healthy, active, and productive life sustainably. From this definition, sustainability in the context of food security becomes a key concept related to national development. This aligns with Budiawati et al. (2020), who argue that robust food security is a critical factor in fostering quality human resource development, thereby facilitating the achievement of national development goals.

At present, however, food security in Indonesia faces numerous challenges. According to the 2021 Global Food Security Index (GFSI), Indonesia ranked 69th out of 113 countries (Partini & Sari, 2022). The Economist Group (2022) states that there are four primary indicators for measuring a country's food security: affordability, availability, quality and safety, as well as sustainability and adaptation. In 2022, although Indonesia's ranking improved slightly to 63rd out of 113 countries, the sustainability and adaptation indicator scored the lowest (compared to the other three indicators), at only 46 out of 100. This poses a paradox: despite Indonesia's abundance of food resources, the country remains highly vulnerable during potential food crises due to inadequate strategies in ensuring food sustainability.

In this regard, one strategic alternative to address the sustainability challenges of food security in Indonesia is the implementation of sustainable agriculture systems. Sustainable agriculture aims to reduce environmental degradation, maintain agricultural productivity,

increase farmers' income, and improve the stability and quality of rural livelihoods (Efendi, 2016). A study by Setsoafia et al. (2022) in Northern Ghana demonstrated that the full adoption of sustainable agricultural practices (such as improved seeds, soil and water conservation, and efficient fertilizers) positively impacted farmers' incomes and household food security. At the national level, Djibran et al. (2023) surveyed 250 agricultural stakeholders in Central Java and reported that 63% of respondents believed sustainable agriculture positively influenced their overall well-being, including improvements in health and quality of life.

To promote sustainable agriculture and strengthen food security in Indonesia, the CSR initiative of PT PLN Indonesia Power UBP Central Java 2 Adipala developed an innovative program called INNDESA (Inovasi Nusantara Desa Integratif Pangan). This program integrates agriculture, livestock, fisheries, as well as food processing and distribution, aiming to achieve community-based food security while adopting zero-waste principles. One of the key agricultural innovations within this program is the use of fly ash as a protective coating for horticultural crops to prevent pest attacks. Based on the Report of Analysis (RoA) conducted by PT PLN Indonesia Power UBP Central Java 2 Adipala, the chemical compounds contained in fly ash have been shown to function as both an insecticide and an alternative nutrient that supports plant growth, particularly in protecting crops from pest damage.

In line with this, Kathirvelu et al. (2020), in the book chapter *Circular Economy and Fly Ash Management*, stated that the application of fly ash in dust form at a dosage of 40 kg/ha on okra (bhendi) and brinjal plants resulted in larval and grasshopper mortality rates of 68–73%, caused by cuticular abrasion and mechanical dehydration in the insects. In this trial, fly ash functioned as an abrasive and physical barrier, adhering to the surface of leaves and pests. In another study, Ghosh and Kumar (2020) revealed that nano-fly ash technology (particles of 10–50 µm) for foliar application, i.e., the direct application of nutrients or fertilizers to plant leaves (rather than through roots), is also capable of supporting pest control without toxic residues. Therefore, it can serve as a more environmentally friendly alternative compared to chemical nutrients.

Consequently, this research aims to further examine how PT PLN Indonesia Power UBP Central Java 2 Adipala's innovation in utilizing fly ash as a coating/protective agent for plants can foster sustainable agriculture and contribute to the realization of national food security in Indonesia. In alignment with the pillars of sustainable agricultural development, this study focuses on assessing the ecological, social, and economic impacts of fly ash utilization. Given the limited number of studies on the use of fly ash as a plant protective agent, most commonly employed as a growth medium, this research is expected to provide novelty and contribute as a catalyst for the advancement of sustainable agricultural systems. Therefore, national food security can be strengthened, particularly in terms of sustainability, an indicator of food security that has recorded the lowest scores.

B. METHODS

This study employed a qualitative method with a case study approach. Qualitative research is a method designed to explore and understand phenomena based on the experiences of individuals or groups (Creswell, 2014). The purpose of this method is to gain a comprehensive picture of the social phenomena occurring within the community. In other words, this approach provides a deeper understanding of social realities, leading to a holistic interpretation of the events studied (Subadi, 2006).

Accordingly, a case study approach is employed to examine how PT PLN Indonesia Power UBP Central Java 2 Adipala's innovation in utilizing fly ash as a coating/protective agent for plants can promote sustainable agriculture and achieve food security in Indonesia.

The data used in this research consists of secondary data collected from the internal CSR reports of PT PLN Indonesia Power UBP Central Java 2 Adipala.

In addition, data from mass media, journal articles, and books related to the research topic were utilized. Data analysis was conducted through a descriptive analysis approach, which involved explaining data by means of classification and categorization to generate a systematic descriptive narrative. Data verification was carried out by presenting key data relevant to this study. Furthermore, data credibility testing was conducted using triangulation of data and sources to provide comprehensive justification for the innovation of fly ash utilization (as a plant coating) based on the literature sources gathered in this research.

C. RESULTS AND DISCUSSION

Sustainable agriculture is a holistic approach aimed at meeting present needs without compromising the ability of future generations, by maintaining a balance between soil, water, air quality, economic viability, and social equity (Sharma & Bipana, 2024). Rivai and Anugrah (2011) emphasize that sustainable agriculture is an implementation of the concept of sustainable development, which consists of three main pillars: ecological, social, and economic sustainability. The findings of this study indicate that the innovation of using fly ash in sustainable agricultural systems has a significant impact on food security, as it effectively integrates these three pillars of sustainability. Furthermore, the manifestations of sustainability across these pillars can be elaborated as follows:

1. Fly Ash Innovation as a Natural Insecticide Promoting Ecological Sustainability

The innovation of utilizing fly ash as a natural insecticide and nutrient, initiated by PT PLN Indonesia Power UBP Central Java 2 Adipala, is part of a broader program called INNDESA (Inovasi Nusantara Desa Integratif Pangan). The company is committed to advancing a zero-waste approach by repurposing various waste products from its operations, including coal combustion byproducts such as fly ash, for agricultural purposes. According to Sarkar et al. (2015), fly ash is a fine residue composed of microscopic particles generated during coal combustion in thermal power plants. It primarily consists of minerals such as silica, alumina, and metal oxides. Based on the Report of Analysis (ROA) by Sucofindo (2025), fly ash from PT PLN Indonesia Power UBP Central Java 2 Adipala contains five main mineral components: silica (20.94%), alumina (11.74%), ferric oxide (34.43%), calcium oxide (14.18%), and magnesium oxide (10.42%). Typically, fly ash is used as a soil amendment due to its alumina and calcium content.

However, PT PLN Indonesia Power UBP Central Java 2 Adipala introduced a unique innovation by utilizing its fly ash as a natural insecticide. This approach is inspired by the findings of Kathirvelu et al. (2020), which confirm that fly ash can effectively replace chemical pesticides by killing pests through abrasive mechanisms and preventing them from attacking crops. A pilot test involving the application of fly ash dust (2 kg/0.9 hectares) on rice fields owned by CSR-supported farmers demonstrated improved pest and disease resistance. While the results are not yet statistically significant, they have motivated the farmers to adopt this technique on a larger scale.

Kathirvelu et al. (2020) recommend an optimal application rate of approximately 40 kg/hectare for fly ash dust as an insecticide, with the best timing being midday after dew has evaporated. Hariprasad (2020) further suggests that combining 40 kg/hectare of fly ash dust with herbal extracts such as turmeric or chili enhances its pest-control efficacy, achieving up to 73% mortality rates for pests like leaf caterpillars, grasshoppers, and brown planthoppers, without posing health risks.

Through this innovation that supports sustainable agricultural systems, the prospects for food security are strengthened, particularly by prioritizing ecological sustainability. By

definition, ecological sustainability refers to the capacity of activities to preserve natural resources, biodiversity, and the overall carrying capacity of the environment (Putra et al., 2025). Currently, agricultural practices in Indonesia face severe environmental challenges due to the widespread and intensive use of chemical inputs. Agriculture, which has become almost entirely dependent on chemical fertilizers and pesticides, is gradually becoming a threat to human well-being (Hammada, 2024).

Furthermore, Sinambela (2024) highlights that the chemical pesticide residues sprayed onto crops leave harmful traces on agricultural produce, posing significant health risks to humans. Alarmingly, pesticide residue levels in Indonesian agricultural products have already exceeded the government's Maximum Residue Limit (MRL), which is set at 2.00 ppm. This situation is highly concerning if no alternative innovations are developed to address the issue. In this context, the innovation by PT PLN Indonesia Power UBP Central Java 2 Adipala, utilizing fly ash (industrial waste) processed into natural insecticides, emerges as a crucial solution to the threats posed by chemical pesticides. This initiative stands out as the first of its kind in Cilacap Regency and within PT PLN Indonesia Power UBP Central Java 2 Adipala compared to similar companies utilizing fly ash. This innovation advances ecological sustainability by applying the zero-waste principle, transforming industrial waste into environmentally beneficial products, and producing environmentally friendly outputs (natural insecticides) that contribute to the preservation of biodiversity.

2. INNDESA Program: Enhancing Community Economy through a Circular Economy System

According to Kirchherr et al. (2017), a circular economy is an economic system designed to close the life cycle of products, with a primary focus on reducing, reusing, and repairing materials throughout the production, distribution, and consumption processes. The main objective of a circular economy is to maximize the use of production materials while balancing economic growth with environmental and natural resource conservation (Purwanti, 2021). The circular economy concept addresses concerns about the sustainability of production by ensuring the continuous availability of natural resources. The transition to a circular economy is particularly critical for Indonesia, as it promises numerous positive impacts for both environmental conservation and future development across various sectors (Coordinating Ministry for Economic Affairs of the Republic of Indonesia, 2021). The paradigm shift among businesses from a linear to a circular economy, focusing on environmental and resource sustainability, has been widely encouraged by the government.

The Ellen MacArthur Foundation (2013:7), which popularized the concept of the circular economy, identifies three core principles: first, designing out waste so that consumed products can be recycled and reintroduced into the production cycle; second, separating short-term and long-term waste streams; and third, relying on renewable energy sources to minimize dependence on non-renewable energy (MacArthur, 2013). Meanwhile, principles outlined in Low Carbon Development Indonesia emphasize reducing waste and pollution, maintaining the utility of products and materials for as long as possible, and regenerating natural systems (Ministry of National Development Planning/Bappenas, 2024). Collectively, these definitions highlight that circular economy processes prioritize both environmental and economic sustainability.

In the agricultural development context, this entails a transition from conventional farming to renewable and sustainable agricultural practices (Hamdir & Nurhasanah, 2021). The circular economy concept can be applied to sustainable agriculture as both emphasize environmental preservation and resource continuity. Nikolaienko (2019) asserts that the circular economy model is one of the most effective approaches to conserving resources and materials, thereby enabling continuous economic growth (Latif, 2022). In this context, a

circular economy system can be integrated into sustainable agriculture by reconfiguring production and consumption patterns among actors within the supply chain.

By adopting the circular economy concept, PT PLN Indonesia Power UBP Central Java 2 Adipala, through the INNDESA program, implements a sustainable agricultural system. This program integrates multiple farmer groups into a supply chain designed to achieve food security through cross-sectoral waste utilization. The company repurposes fly ash as a natural insecticide and as a construction material for seedling houses, which can be utilized by local communities in their agricultural activities. The use of company fly ash by farmers represents a waste-design approach or the recycling of waste as a resource reintroduced into the agricultural production of rice and secondary crops. Furthermore, within the program’s supply chain, mushroom cultivation waste (baglog) is also utilized as an alternative fuel source (sawdust) by the company.

Table 1. Utilization of Waste in the INNDESA Program

Type of Waste	Utilization in Production
Fly Ash	Natural insecticide and raw material for the construction of shallot seedling houses.
Mushroom Baglog Waste	Alternative fuel (sawdust)
Rice Agricultural Waste	Rice husk biobriquettes

Processed by researchers, 2025

A circular economy represents a mutually beneficial model (mutualistic symbiosis) for all stakeholders in Indonesia, aiming to promote economic growth, address environmental changes, and create new employment opportunities simultaneously (Shimomura & Qibthiyah, 2020). The INNDESA program exemplifies this mutualistic symbiosis between the company and surrounding communities by utilizing corporate waste to support agricultural activities. Beyond this, the company has also developed the food-processing sector, thereby providing broader benefits to the community. The implementation of a circular economy concept in the agricultural sector has generated significant impacts, such as job creation and improved community economic conditions.

Table 2. Income of INNDESA CSR Program Beneficiaries

Group	Income Before/Month	Income After/Month
Rice and Secondary Crop Farmers	IDR 2,300,000,-	IDR 4,530,000,-
Agricultural Processing Group	IDR 0-	IDR 2,300,000,-
Mushroom Cultivation Farmers	IDR 0-	IDR 3,450,000,-

Processed by researchers, 2025

3. Realizing Community-Based Sustainable Food Security

Agriculture is a sector with a strategic role in national economic development. It is also crucial for maintaining global food security and ensuring adequate food availability for the growing world population (Harahap & Anis, 2023). However, various challenges such as rapid economic growth, climate change, and environmental degradation have eroded conventional agriculture. This has resulted in reduced productivity, declining natural resource quality, and further economic setbacks for farmers. Hence, sustainable agricultural development is essential for achieving long-term food security.

Sustainable agricultural development not only emphasizes economic outcomes and food supply but also the preservation of the environment and natural resources. Agricultural development is key to achieving food security, as it contributes to food availability and stabilization (Yudha et al., 2023). Furthermore, agricultural development aims to increase farmers’ income and living standards, expand employment opportunities, and foster a modern, efficient, and resilient agricultural sector (Silaban & Sugiharto, 2016). Sustainable agriculture emerges as an antithesis to conventional agriculture, focusing not only on land productivity for

economic gains but also on the long-term sustainability of natural resources (including agricultural land).

Putri et al. (2023) state that strategies for sustainable agricultural development also involve the implementation of Corporate Social Responsibility (CSR) programs and community assistance, which are the responsibility of companies to ensure the welfare of surrounding communities and the environment (Salawati et al., 2024). PT PLN Indonesia Power UBP Central Java 2 Adipala introduces a sustainable agricultural system to buffer-zone communities, most of which possess extensive potential for productive agricultural land. According to the 2023 social mapping report by PT PLN Indonesia Power Central Java 2 Adipala PGU (Spectrum CSR Solution, 2023), most buffer-zone villages have productive farmland ranging from 200 to 500 hectares. However, these communities face challenges in agricultural land management, including irrigation or drainage issues, weather fluctuations, and rain-fed farming systems.

Sustainable agricultural development aims to increase farmers' income and living standards, create job opportunities, and enable agriculture to become advanced, efficient, and resilient (Silaban & Sugiharto, 2016). The INNDESA program is a form of corporate social responsibility by PT PLN Indonesia Power UBP Central Java 2 Adipala, based on community needs assessments. This program is a strategic initiative that integrates various food production sectors into a village-based, integrated system, employing innovative approaches and zero-waste principles.

The development of sustainable agricultural systems is a critical step toward achieving long-term food security (Siregar, 2023). This aligns with the Sustainable Development Goals (SDG) point 2 (Zero Hunger), which aims to end hunger, achieve food security, improve nutrition, and promote sustainable agriculture. The implementation of INNDESA by PT PLN Indonesia Power UBP Central Java 2 Adipala represents a tangible realization of sustainable agricultural development, with the ultimate goal of community-based food security. The program positively impacts the productivity of buffer-zone agricultural land through the utilization of fly ash and the advancement of a circular economy system. PT PLN Indonesia Power UBP Central Java 2 Adipala's interventions include training programs, the application of appropriate technologies, strengthening of village economic institutions, and the development of local food distribution networks.

Presidential Regulation No. 59 of 2017 outlines Sustainable Development Goal (SDG) 2, which ensures sustainable food production systems and the application of resilient agricultural practices that enhance production and productivity, help maintain ecosystems, strengthen adaptive capacity to climate change, extreme weather, droughts, floods, and other disasters, and progressively improve soil and land quality. In alignment with this, the INNDESA program has established a sustainable food production system by empowering farmers and local communities through activities spanning upstream to downstream stages.

At the upstream level, PT PLN Indonesia Power UBP Central Java 2 Adipala empowers rice, corn, and secondary crop (shallots, chili) farmers as well as mushroom cultivators. In the process stage, the company utilizes fly ash as a substitute for chemical pesticides and as a construction material for shallot seedling houses. At the downstream stage, the company empowers women, primarily housewives, through activities that process agricultural products into food products.

As previously mentioned, the INNDESA program aims to achieve community-based sustainable food security. Agricultural institutional innovation plays a crucial role in efforts to achieve food security (Gusya et al., 2024). The company established the INNDESA Integration Forum Group as a form of institutional innovation that integrates the food production sector. By involving young farmers, leveraging digital technology, and establishing responsive

institutions, the company has implemented innovative approaches to optimize food production and ensure sustainable food availability. Furthermore, the program has fostered new social partnerships between community groups, village and district governments, educational institutions, and the company, thereby strengthening networks that support the program’s long-term sustainability.

In addition, the INNDESA program seeks to ensure the inclusion of vulnerable groups in the agricultural sector. Vulnerable groups in rural development often refer to marginalized communities, people with disabilities, women, and the poor (Sunesti, 2023). The company involves vulnerable groups to actively participate in all program activities. Gidley et al. (2010) emphasize that social inclusion consists of three levels: access, participation, and empowerment. The INNDESA empowerment program emphasizes the active participation of vulnerable groups (the poor, the elderly, people with disabilities, female heads of households, the unemployed, and former migrant workers) by providing them with access to facilities, information, and sustainable agricultural services.

Table 3. Target Groups and Support Services in the INNDESA Empowerment Program

Vulnerable Group	Number	Condition Before	Condition After
The Poor	45 people	Dependent solely on agricultural production.	Integrated into cross-sector food systems that support sustainable agriculture.
Elderly	20 people	Elderly group in Buton Village had no income.	Empowered through secondary crop cultivation training, increasing household income.
Women of Productive Age	10 people	Had no productive activities or income.	Earn additional income through agricultural product processing.
Former Migrant Workers	10 people	- Lack of financial and entrepreneurial skills. - No income.	Able to cultivate mushrooms using technology-based farming systems, thereby increasing income.
People with Disabilities	2 people	Had no productive activities or income.	Earn income from secondary crop cultivation.
Unemployed	10 people	Had no productive activities or income.	Gained income from IoT-based agricultural activities.

D. CONCLUSION

The INNDESA program implemented by PT PLN Indonesia Power UBP Central Java 2 Adipala is an innovative empowerment initiative in sustainable agricultural systems. This program has had significant social, economic, and environmental impacts on surrounding communities. The use of fly ash as a natural insecticide effectively addresses issues of agricultural land sustainability that arise from chemical pesticide use. Fly ash as a natural insecticide has proven effective, demonstrating increased plant resistance to pests and diseases. The use of natural insecticides on community farmland also extends soil productivity by preserving soil nutrient content.

Furthermore, fly ash, an industrial by-product, has been successfully processed to realize a circular economy within the INNDESA empowerment program. The company has actively involved the community in establishing a circular economy in sustainable agriculture through the reprocessing of agricultural waste. Rice farming waste is converted into rice husk

biobriquettes for use in secondary crop farming, while mushroom baglog waste is processed into alternative fuel (sawdust) for the company's operations. The circular economy concept in sustainable agriculture has positively impacted local economic growth and job creation.

The INNDESA program supports SDG 2 (Zero Hunger), which emphasizes sustainable food production systems and resilient agricultural practices that enhance production and productivity. PT PLN Indonesia Power UBP Central Java 2 Adipala has developed a sustainable food production system by empowering farmers and local communities through activities that span the entire agricultural value chain. The active participation of communities, particularly vulnerable groups, reflects the program's inclusive approach in realizing sustainable food availability.

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