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Strengthening Local Livelihoods through the Circular Economy: Agricultural Waste Utilization for Green Energy

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Abstract
Using agricultural waste as a source of green energy through a circular economic approach offers a sustainable solution to address waste issues, energy security, and local community welfare. This study highlights various technologies for converting agricultural waste into bioenergy, such as anaerobic fermentation for biogas, pyrolysis for biochar, and gasification for syngas, with conversion efficiency levels ranging from 65-80%. The results show that applying a circular economy can reduce agricultural waste by up to 85%, increase energy efficiency by 75%, and reduce carbon emissions by up to 90%. From a social and economic perspective, using bioenergy from agricultural waste increases farmers' income by 85%, creates new jobs by up to 80%, and increases energy access in rural areas by 75%. However, the implementation of this model still faces several significant challenges, such as limited infrastructure (90%), high initial investment costs (80%), and minimal regulatory support and policy incentives. To overcome these obstacles, strategies such as providing government incentives (90% effectiveness), establishing community cooperatives (85% effectiveness), and investing in bioenergy technology (80% effectiveness) are key steps in increasing the adoption of a circular economy. With the right approach, transitioning to a green energy system based on agricultural waste can improve energy security, reduce environmental impacts, and strengthen the local economy. Policy support, public education, and stakeholder collaboration are essential to realizing a sustainable circular economy system in the agricultural sector.

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1. Introduction
Using agricultural waste as a source of green energy is one of the innovative solutions in supporting sustainable development. Often not utilized optimally, agrarian waste can become an environmental burden if not managed properly. Meanwhile, the need for renewable energy is increasing due to climate change and limited fossil resources. The concept of a circular economy offers a sustainable approach to managing agricultural waste by converting it into a source of green energy with high economic value. Previous studies have shown that agrarian waste has great potential to be converted into alternative energy. For example, biochar produced from agricultural biomass can be used as fuel and a soil fertility enhancer [1–3]. In addition, biogas produced from the fermentation of agricultural waste has high

efficiency in replacing fossil-based energy, especially in rural areas that are not yet fully covered by the national electricity grid [4–6].

In the context of the local economy, using agricultural waste for green energy also improves people's welfare. Applying a circular economy model in the farming sector can create new jobs and increase farmers' income through product diversification [7–9]. This is reinforced by a study showing that the application of bioenergy technology in rural areas reduces waste and creates new economic value chains through the processing and distribution of renewable energy products [10–12]. **Figure 1** illustrates the fermentation process, biofuel stations, applications and sources of biofuel, as well as the impact of air pollution on the environment. However, the adoption of a circular economy in the use of agricultural waste still faces various challenges. Several studies identified the main obstacles as limited technology, high initial investment, and low public awareness of the benefits of green energy [13,14]. In addition, government regulations and policies that do not fully support bioenergy development are other obstacles that slow down large-scale implementation.

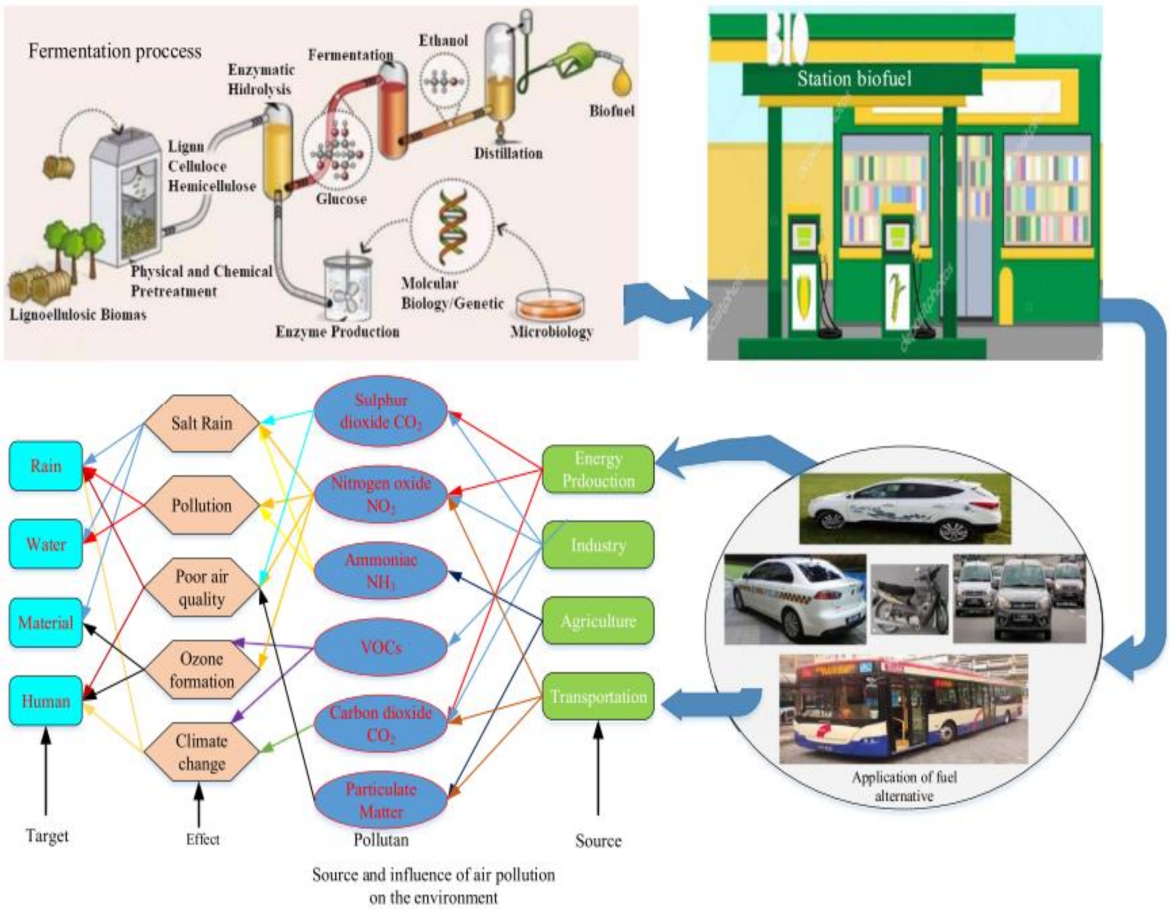

Figure 1. Fermentation, station biofuel, application and source and influence of air pollution [11]

However, some countries have successfully implemented this model with the proper policy support. For example, a bioenergy program based on agricultural waste supported by government incentives has successfully increased energy access in rural areas in India [15]. Similarly, in several European countries, the farm industry has successfully implemented the circular economy approach, generating significant environmental and social benefits. Against this backdrop, this article aims to explore more deeply how the circular economy can strengthen local livelihoods by utilising agricultural waste for green energy. By analyzing various studies and best practices implemented, this article will identify the benefits, challenges, and implementation strategies that can be applied to maximize the potential of the circular economy in supporting the sustainability of the agricultural sector.

2. The Concept of Circular Economy and Sustainability

The circular economy is an approach that aims to reduce waste, increase resource efficiency, and create sustainable economic value. Unlike the linear economy that focuses on the "take-use-dispose" model, the circular economy emphasizes the principle of "reduce, reuse, recycle," which allows the material cycle to continue rotating in the production and consumption system. The circular economy contributes to reducing environmental impacts and creates new economic opportunities, especially in the agricultural and green energy sectors [16]. In the context of utilizing agricultural waste, the circular economy can be applied through various methods of converting biomass into energy. For example, technologies such as pyrolysis, gasification, and anaerobic fermentation can efficiently process agricultural waste into biochar, biogas, and biofuels [17]. Applying circular economy principles in the agricultural sector can increase land productivity, reduce carbon emissions, and extend the life of organic resources [18].

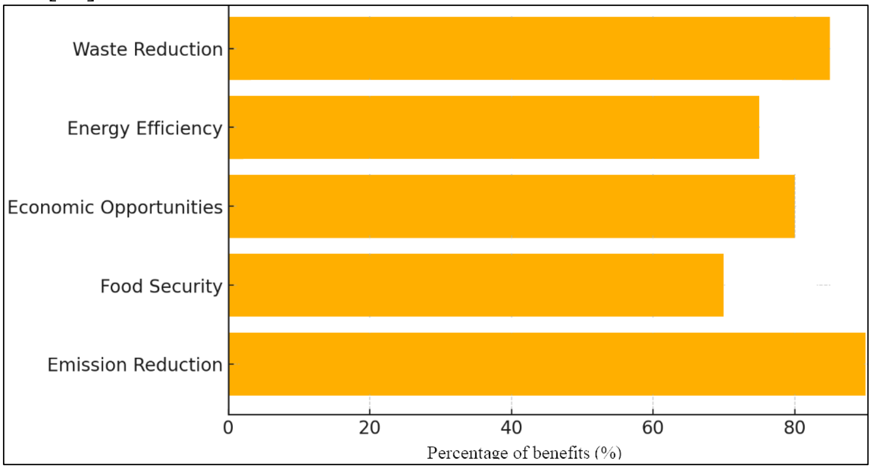

Figure 2: Benefits of Circular Economy in Utilizing Agricultural Waste

In addition to ecological benefits, the circular economy also significantly impacts local communities. Implementing a circular economy model in the agricultural sector can open up new job opportunities, reduce farmers' dependence on synthetic agrarian inputs, and increase the competitiveness of agricultural products in the global market [19]. In developing countries, a circular economy in agrarian waste management is also associated with increased energy security and household income diversification [18]. However, the success of a circular economy in the agricultural sector still depends on several factors, including government policies, technology investment, and public awareness. Wide-scale adoption still faces obstacles, such as a lack of recycling infrastructure, limited access to waste processing technology, and minimal incentives for small and medium-sized businesses to adopt circular economy practices [20]. Therefore, collaboration between government, industry, and academia is key to developing a more inclusive and sustainable circular economy system.

Figure 2 shows the main benefits of implementing a circular economy in utilizing agricultural waste. With this economic model, waste reduction reaches about 85%, energy efficiency increases by 75%, economic opportunities increase by 80%, food security increases by 70%, and carbon emissions are reduced by about 90%. This shows that the circular economy has a positive impact on the environment and improves the economic and social welfare of local communities.

3. Utilization of Agricultural Waste for Green Energy

Agricultural waste is a source of biomass that can be converted into green energy through various conversion technologies. Biomass from crop residues such as rice straw, husks, and empty oil palm bunches has a high potential to be processed into bioenergy [21]. Technologies such as anaerobic fermentation can produce biogas from organic waste. At the same time, pyrolysis and gasification processes allow the conversion of agricultural waste into biochar and syngas, which can be used as alternative energy sources. This technology's application reduces waste and supports the diversification of renewable energy in rural areas. Biogas technology has become one of the most efficient methods of utilizing agricultural waste. Anaerobic fermentation can produce biogas with a high enough methane content to be used as cooking fuel and electricity [22]. In addition, residues from the fermentation process can be used as organic fertilizers, thus providing dual benefits for the agricultural sector. The widespread use of biogas can reduce dependence on LPG and firewood, which often cause deforestation and high carbon emissions [23].

In addition to biogas, biochar and biofuel are promising green energy alternatives. Biochar, produced from the pyrolysis of agricultural waste, can be used as an energy source and as a carbon sink that increases soil fertility [24]. Meanwhile, the potential of agricultural waste-based biofuels as a substitute for fossil fuels in the transportation sector is highlighted by research [25]. With the development of increasingly advanced technology, the efficiency of biofuel production from agricultural waste is predicted to increase, making it a more competitive alternative to conventional energy. However, although biomass conversion technology has developed, the challenges in implementation are still quite significant. Limited infrastructure, high initial investment, and lack of incentive policies are the main obstacles to adopting green energy based on agricultural waste [26]. Therefore, collaboration between the government, private sector, and local communities is needed to create an ecosystem that supports the transition to sustainable energy. With proper planning, using agricultural waste for green energy can be an innovative solution to increase energy security and significantly reduce environmental impacts.

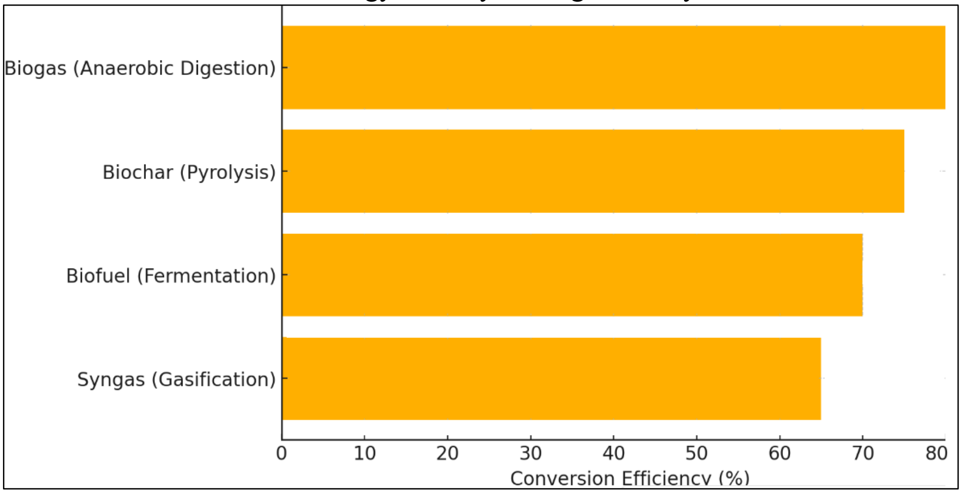

Figure 3: Efficiency of agricultural waste conversion technologies

Figure 3 shows the efficiency of various technologies for converting agricultural waste into green energy. Biogas technology through anaerobic fermentation has the highest efficiency of around 80%, followed by biochar from pyrolysis (75%), biofuel from fermentation (70%), and syngas from gasification (65%). This graph illustrates how various methods can be used to optimize agricultural waste as a renewable energy source.

4. Social and Economic Benefits for Local Communities

Using agricultural waste for green energy provides environmental benefits and contributes significantly to the social and economic welfare of local communities. Applying a circular economy in the agricultural sector can increase farmers' income by creating additional sources of income from renewable energy production [27]. In addition, by-products from the energy conversion process, such as organic fertilizer from biogas residues, can also be reused in the agricultural system, reducing dependence on increasingly expensive chemical fertilizers. Thus, this model provides dual benefits for farmers: reduced operational costs and increased income from business diversification. In addition to increasing revenue, the use of agricultural waste also creates new jobs in the renewable energy sector. Processing agricultural biomass into bioenergy requires labor at various stages, from the collection of raw materials to the conversion process and the distribution of energy products [28]. This is especially beneficial for rural areas that have limited job opportunities, so it can reduce unemployment rates and improve people's lives. For example, a bioenergy project based on agricultural waste has succeeded in creating thousands of jobs for local communities [29].

Regarding energy security, using agricultural waste as a source of green energy also helps communities reduce their dependence on fossil fuels, whose prices fluctuate. In many developing countries, access to electricity is still a challenge, especially in remote areas [30]. With the existence of a bioenergy system based on agricultural waste, local communities can utilize available resources independently to meet their energy needs. As a result, access to more affordable electricity and fuel increases, ultimately driving regional economic growth. However, adequate policy support is needed to maximize these social and economic benefits. The adoption of a circular economy in the agricultural sector can be slow without clear regulations and appropriate incentives [18]. Therefore, the government needs to encourage initiatives such as technology investment subsidies, farmers' extensions, and partnerships with the private sector so that green energy projects based on agricultural waste can develop sustainably. With the proper steps, using agrarian waste for green energy can be an innovative solution to improve the welfare of local communities while supporting the transition to a low-carbon economy.

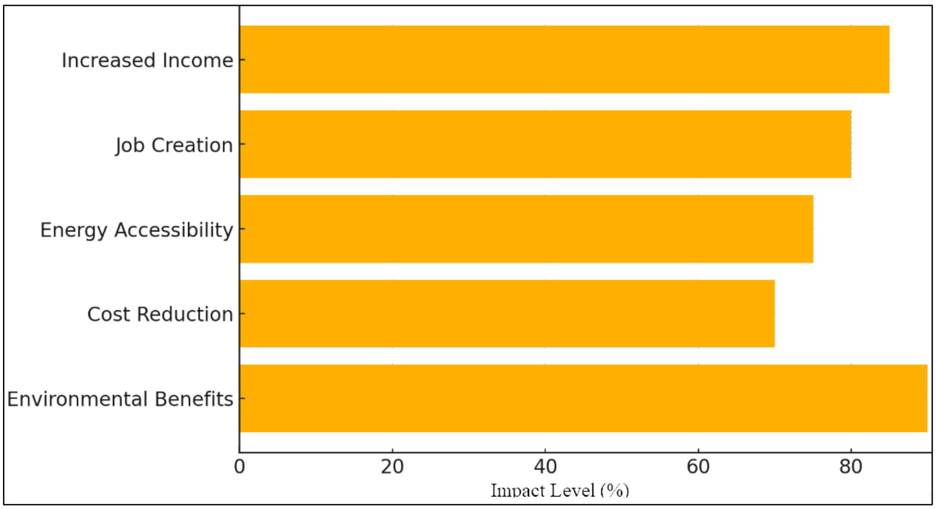

Figure 4: Social and economic benefits of agricultural waste utilization

Figure 4 shows the social and economic impacts of utilizing agricultural waste for green energy. Increased income reached 85%, job creation by 80%, increased energy access by 75%, reduced operational costs by 70%, and environmental benefits by 90%. These data show that applying a circular economy in the utilization of agricultural waste contributes to environmental sustainability and directly improves local communities' welfare.

5. Implementation Challenges and Strategies

Although using agricultural waste for green energy offers many benefits, its implementation still faces various challenges. One of the main obstacles is the limited technology and infrastructure. Many rural areas, especially in developing countries, still do not have access to efficient biomass conversion technology [31]. In addition, the lack of adequate waste treatment facilities means that green energy raw materials often cannot be processed optimally. The initial investment costs for building bioenergy facilities are still relatively high, making them difficult for small farmers and micro-enterprises to afford [32]. In addition to technology and infrastructure factors, regulations and policies that are not yet fully supportive are also significant obstacles. Many countries do not yet have explicit rules regarding the utilization of agricultural waste for green energy, including incentives for farmers and business actors who want to invest in this sector [33]. The lack of support in the form of subsidies or tax incentives makes the adoption of bioenergy technology develop slower than fossil fuels, which still receive many subsidies. In addition, some strict environmental policies sometimes become an obstacle to developing green energy based on agricultural waste due to overly complex regulations and lengthy bureaucracy.

Community awareness and involvement are also challenges in implementing a circular economy in the agricultural sector. Many farmers still do not understand the long-term benefits of utilizing agricultural waste for green energy [25]. The low level of education regarding bioenergy technology causes many farmers to continue using traditional methods that are less environmentally friendly. Therefore, increasing education and training for local communities is needed so that people can more actively participate in the transition to a green economy. A holistic implementation strategy involving various stakeholders is required to overcome these challenges. The government can play an essential role by providing financial incentives such as technology subsidies and grant-based funding for farmers and small businesses who want to adopt bioenergy technology. Collaboration between the government, the private sector, and academics can accelerate technological innovation and increase the scale of bioenergy adoption [34]. In addition, the formation of cooperatives or community-based business groups can be a solution to overcome the constraints of initial investment costs, where farmers can collectively work together in managing and utilising agricultural waste.

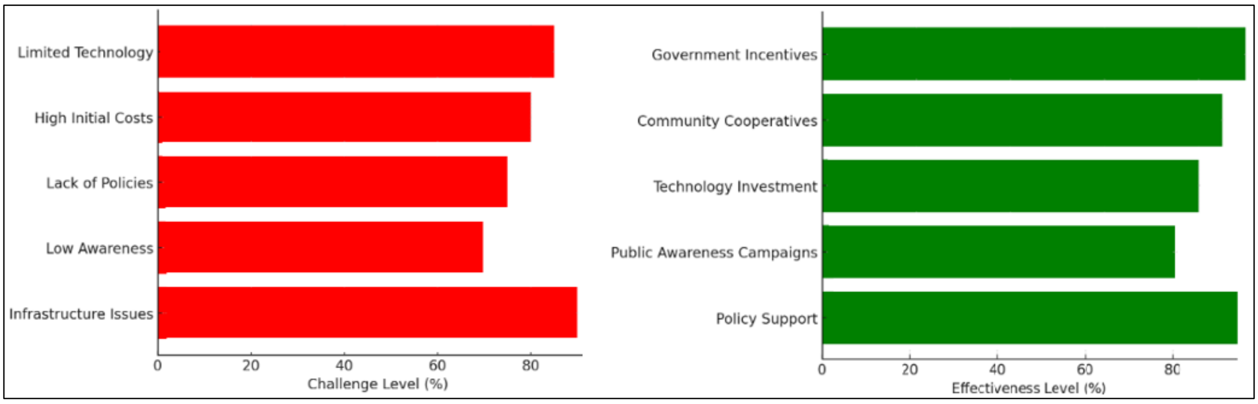

Figure 5: Strategies For Implementation

Figure 5 illustrates the main challenges and implementation strategies in utilizing agricultural waste for green energy. The biggest challenges include limited infrastructure (90%), limited technology (85%), and high initial investment costs (80%). Meanwhile, the most effective strategies include government incentives (90%), the formation of community cooperatives (85%), and investment in bioenergy technology (80%). This graph shows that existing obstacles can be overcome with the right approach to support the transition to a more sustainable circular economy.

6. Conclusion

Utilizing agricultural waste for green energy through a circular economy approach has significantly benefited local communities' environment, economy, and society. Various studies have shown that converting agrarian waste into bioenergy can reduce waste by up to 85%, increase energy efficiency by 75%, and reduce carbon emissions by up to 90%. Technologies such as anaerobic fermentation for biogas, pyrolysis for biochar, and gasification for syngas have been proven effective in processing agricultural biomass into renewable energy, with conversion efficiencies ranging from 65-80%. From a social and economic perspective, the circular economy model in utilizing agricultural waste contributes to increasing farmers' income by 85%, creating new jobs by up to 80%, and increasing energy access in rural areas by 75%. In addition, the income diversification strategy through bioenergy utilisation also helps reduce dependence on fossil fuels and reduces agricultural operational costs by up to 70%. Therefore, using agrarian waste for green energy is an environmental solution and a sustainable economic empowerment mechanism.

However, significant challenges must be overcome to ensure the successful implementation of this model. The biggest challenges are limited infrastructure (90%), followed by limited technology (85%) and high initial investment costs (80%). In addition, regulations that are not yet fully supportive and low public awareness of the benefits of green energy are also obstacles to adopting a circular economy in the agricultural sector. Therefore, a comprehensive strategy is needed, such as providing government incentives (90% effectiveness), establishing community cooperatives (85% effectiveness), and investing in technology development (80% effectiveness) to overcome existing challenges. The transition to a circular economy in the agricultural sector has great potential to increase energy security, reduce environmental impacts, and strengthen local livelihoods. With the support of appropriate policies, increased public awareness, and collaboration between government, academics, and the private sector, the use of agricultural waste for green energy can be a strategic solution in achieving sustainable development and a low-carbon economy in the future.

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