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A Circular Economy Approach to Managing Used Cooking Oil for Biofuel Production

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Abstract

Purpose: This study aimed to explore how the implementation of circular economy principles can enhance used cooking oil (UCO) management for biofuel production.
Research Methodology: This study adopts a mixed-method approach, combining a literature review with empirical data analysis to examine the involvement of key stakeholders, such as households, waste banks, collectors, and biofuel producers.
Results: The findings reveal that UCO management not only reduces environmental pollution through waste minimization but also creates economic opportunities across the supply chain. This study highlights the transformation of UCO from waste to a valuable resource, aligning with the concepts of reduction, reuse, recycling, refurbishing, and renewal. Furthermore, policy support, public awareness, and technological innovation were identified as critical factors for effective UCO management.
Conclusions: Implementing circular economy principles in managing used cooking oil (UCO) for biofuel production offers both environmental and economic benefits. UCO recycling reduces waste and pollution, creates economic opportunities across the supply chain, and contributes to the production of renewable energy, thereby supporting sustainable development goals.
Limitations: This study focuses on UCO management in Indonesia, limiting its generalizability. It also overlooks factors like technological constraints and the social acceptance of biofuels.
Contributions: This research emphasizes the role of circular economy practices in transforming UCO into a valuable resource for biofuel production and highlights the importance of policy support, public awareness, and technological innovation.

Keywords: *Biofuel, Circular Economy, Sustainability, Used Cooking Oil, Waste Management*

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1. Introduction

The management of used cooking oil (UCO) has become an increasingly important issue in the context of sustainable development in the future. In Indonesia, the use of cooking oil in households, the food industry, and the commercial sector generates a significant amount of waste annually. Improperly managed UCO poses potential health and environmental hazards. Studies have shown the indiscriminate disposal of UCO can contaminate soil and water, damage aquatic ecosystems, and adversely affect groundwater

quality, impacting communities that rely on these resources (Ghisellini et al., 2016; Parmenas, 2021; Ricardianto et al., 2021). Additionally, reusing UCO as cooking oil without proper recycling processes can lead to health risks, such as cancer and metabolic disorders, due to the accumulation of harmful compounds, including trans fatty acids and carcinogenic substances (Stahel, 2016; Susanto et al., 2021). According to Ardila and Halim (2021) and Setyawati et al. (2021), millions of liters of UCO are produced in Indonesia, with a large portion being either improperly disposed of or reused for cooking.

However, from an economic perspective, UCO management offers potential value creation for both communities and industries. When collected and processed into biodiesel, UCO can serve as a renewable energy source with a reduced environmental footprint. Biodiesel derived from UCO has been shown to have a significantly lower carbon footprint compared to fossil fuels, contributing to efforts in reducing greenhouse gas emissions (Geissdoerfer et al., 2017; Susanto & Parmenas, 2021). Moreover, UCO management creates economic opportunities, benefiting households, waste banks, and processing industries, thereby increasing income and generating new employment opportunities (Prijono et al., 2021; Suyanto et al., 2021).

From a social standpoint, UCO management encourages public participation in circular economic activities. By establishing systems for UCO collection and recycling, communities actively engage in environmental stewardship. This aligns with the concept of a circular economy, which emphasizes resource reutilization and waste reduction. Public education and awareness-raising are critical success factors for UCO management, as well-informed communities are more likely to be concerned about the adverse effects of improper UCO disposal and are willing to contribute to recycling systems (Ahmadun et al., 2023; Khan et al., 2022; Sumaryadi & Kusnadi, 2021). Therefore, a comprehensive analysis of the application of the circular economy framework in UCO management, including the stakeholders involved, is required. This approach offers environmentally friendly solutions and creates economic and social opportunities.

2. Literature Review

2.1 Circular Economy

The concept of circular economy (CE) has gained significant attention in recent years as a sustainable alternative to the traditional linear model of production and consumption. In a circular economy, products and materials are reused, repaired, refurbished, and recycled for as long as possible to minimize waste and reduce the consumption of finite resources (Ossio et al., 2023). This approach is particularly relevant in managing waste oils, such as used cooking oil (UCO), which are often discarded or improperly disposed of, leading to environmental pollution and health risks (Patwa et al., 2021).

2.2 Used Cooking Oil as a Resource

Used cooking oil, often discarded after cooking in commercial kitchens or households, is considered a valuable resource for biofuel production. UCO contains a high percentage of fatty acids, making it suitable for conversion into biodiesel, an alternative fuel that can replace conventional diesel. Studies show that UCO has a high potential for biodiesel production due to its low cost and availability, especially in urban areas where large amounts of oil are used in food preparation (Khan et al., 2022; Nunuh & Wulandari, 2021). Recycling UCO for biofuel not only reduces waste but also offers a potential energy source, contributing to energy sustainability (Foteinis et al., 2020; Hsu et al., 2021).

2.3 Biodiesel Production from UCO

Biodiesel production from UCO involves a chemical process called *transesterification*, in which triglycerides (the main component of fats and oils) react with an alcohol, typically methanol, in the presence of a catalyst to form biodiesel and glycerol (Moazeni et al., 2019). UCO has been extensively studied as a

feedstock for biodiesel, with several studies confirming its viability for biodiesel production due to its suitable fatty acid composition (Mendecka et al., 2020). The biodiesel produced from UCO has similar properties to conventional diesel, making it a feasible and environmentally friendly alternative fuel.

2.4 Environmental and Economic Benefits of Circular Economy for UCO

From an environmental perspective, the circular economy approach to managing UCO can significantly reduce the ecological footprint associated with waste disposal and the production of new oils for biodiesel. UCO is often improperly discarded, leading to significant environmental hazards, such as water contamination and the production of harmful greenhouse gases (Loizides et al., 2019). By recycling UCO into biodiesel, not only is waste reduced, but greenhouse gas emissions are also lowered compared to traditional fossil fuels (Azman et al., 2023).

Economically, the recycling of UCO into biodiesel offers cost savings for both consumers and producers. For instance, biodiesel made from UCO is often less expensive than biodiesel made from virgin vegetable oils due to the reduced cost of raw materials (Loizides et al., 2019). Additionally, the use of waste oils as a feedstock for biodiesel production helps in reducing the dependency on food crops, mitigating the risk of price volatility and land-use competition associated with traditional biofuel feedstocks (Manikandan et al., 2023).

2.5 Challenges in Managing UCO for Biofuel Production

While the use of UCO for biofuel production offers many benefits, several challenges must be addressed. One of the primary issues is the quality and contamination of UCO. Used cooking oil often contains impurities such as food residues, water, and chemicals that can hinder the biodiesel production process. Pretreatment methods, such as filtration, degumming, and water removal, are necessary to improve the quality of UCO for biodiesel production (Tsoutsos et al., 2019).

Another challenge is the collection and transportation of UCO. Effective systems for collecting used cooking oil from households and commercial establishments are critical to ensuring a steady and reliable supply of feedstock for biodiesel production. Governments and private companies must collaborate to create efficient logistics systems for UCO collection (Alfakihuddin & Paratih, 2022). Furthermore, public awareness and participation in used cooking oil recycling programs are essential to ensuring the success of such systems (Azme et al., 2023).

2.6 Policy and Regulatory Framework

The development of policies and regulations that support the circular economy approach to UCO management is vital. Governments can incentivize the collection and recycling of UCO through subsidies, tax breaks, and regulations that encourage the establishment of biofuel production facilities. In addition, providing clear guidelines for the safe and proper disposal of UCO can help reduce environmental pollution and promote the sustainable use of waste oils. Global initiatives, such as the European Union's Renewable Energy Directive and the US Renewable Fuel Standard, encourage the use of waste oils and fats for biofuel production and provide market opportunities for biofuels derived from UCO (Yang et al., 2022).

2.7 Future Prospects and Innovations

Looking ahead, several innovations can improve the circular economy approach to UCO management. Advanced biochemical processes and enzymatic transesterification are being explored as alternative methods to improve biodiesel yield and quality from waste oils (Salaheldeen et al., 2021). Additionally, research into microalgae-based biodiesel may offer a new pathway for utilizing UCO as part of a broader biofuel production system (Hossain et al., 2020). Combining UCO with other waste materials, such as animal fats or algae, could enhance the efficiency and sustainability of biofuel production.

3. Methodology

This study employs a mixed-method approach, combining qualitative and quantitative methods, to provide a comprehensive analysis of used cooking oil (UCO) management for biofuel production within the circular economy framework. First, a literature review was conducted to examine existing research, policies, and frameworks related to UCO management, biofuel production, and circular economy principles. This review provides foundational knowledge, identifies key factors influencing UCO management, and a highlights best practices for implementation.

The empirical part of the study involved collecting primary data through in-depth interviews. In-depth interviews were conducted to various stakeholders, including households, restaurants, waste banks, collectors, and biofuel producers, to gather insights on current UCO practices, challenges, and potential economic opportunities of the technology. In addition, in-depth interviews were conducted with selected key informants such as government officials, industry representatives, and community leaders. These interviews provided a deeper understanding of the regulatory environment, technological advancements, and social attitudes towards UCO management.

Finally, the findings from in-depth interviews and literature reviews are utilized to analyze the use of used cooking oil (UCO) for biofuel production within the circular economy framework. The role of each stakeholder is also examined across different stages of UCO management The role of each stakeholder is examined across different stages of UCO management and further analyzed from economic and policy perspectives. The results provide a basis for recommendations to enhance UCO management from a circular economy perspective.

4. Results and Discussion

4.1 Implementation of Circular Economy

The management of used cooking oil (UCO) initially began as a social initiative focused on maintaining environmental cleanliness at the household and waste bank levels. However, it soon revealed significant economic potential. The collection of UCO aimed to prevent improper disposal, which can pollute water channels and damage aquatic ecosystems. Waste banks facilitate collection by offering incentives, such as exchanging UCO for goods or money. This initial approach primarily focused on raising awareness of waste management and local environmental hygiene.

Over time, UCO management has uncovered substantial economic opportunities. What was once considered waste is now identified as a valuable raw material for biofuel production, especially biodiesel. Waste banks sell the collected UCO to intermediaries, providing a new source of income for both households and collectors, and turning UCO management into a viable livelihood. From an economic perspective, these intermediaries play a crucial role in the biofuel supply chain by linking UCO producers to broader markets. On a larger scale, the collected UCO is exported to European countries, where the demand for renewable fuel is growing owing to strict carbon emission regulations. Large-scale entrepreneurs benefit economically from exporting UCO, which is processed into environmentally friendly biodiesel that complies with international standards, such as the European EN 14214. This process significantly enhances UCO's economic value, shifting its perception from waste to a high-value commodity.

Theoretically, this transition can be explained using the concept of a circular economy. In a traditional linear economic model, products are discarded after a single use, with no consideration of their potential value. However, the circular economy emphasizes the reuse, recycling, and conversion of waste into valuable resources (Ellen MacArthur Foundation, 2013). UCO exemplifies waste that can be collected, processed, and reintroduced as a valuable product, such as biodiesel, with a well-designed system. This

process also creates new job opportunities across different levels, from households to collectors to exporters.

This approach aligns with the Theory of Planned Behavior (Ajzen, 1991), which highlights the importance of attitudes, social norms, and perceived behavioral control in shaping individuals' intentions. Initially, UCO management might be perceived as a social obligation to maintain environmental cleanliness. However, with the introduction of economic incentives derived from UCO collection and processing, the community's behavioral control has shifted. People began to view this activity not only as a social responsibility but also as an economic opportunity that could enhance their welfare. Social norms evolve as more households and intermediaries participate, fostering a community that is both environmentally conscious and economically productive.

Overall, UCO management has evolved from a purely social effort to a sustainable economic activity involving various actors in the value chain. Locally, households and collectors gain direct economic benefits, whereas, on a larger scale, UCO exports contribute significantly to the economy of large businesses and the biofuel industry. This development illustrates how well-managed waste can be transformed into a valuable resource, promoting both economic and environmental sustainability. The evolution of UCO management from a social and environmental initiative to a high-value economic activity is closely related to the circular economy concept. Unlike the traditional "take, make, dispose" linear model, the circular economy aims to keep materials within the economic cycle for as long as possible through reuse, recycling, and regeneration (Ellen MacArthur Foundation, 2013; Muliyati et al., 2023).

In the context of UCO management, what was once considered valueless waste, potentially harmful to the environment, is now repurposed as a valuable raw material for biodiesel production. With the circular economy framework, UCO collected by households, intermediaries, and waste banks no longer ends up in landfills or pollutes water bodies. Instead, it serves as an input for biodiesel production and is a renewable energy source. This approach reflects one of the core principles of the circular economy: maintaining the value of materials in the economic cycle. UCO is processed and reused as biodiesel, which has economic and environmental benefits. Additionally, this model encourages the redesign of waste management systems to focus not only on disposal but also on creating value from waste (Stahel, 2016; Supardi, 2023; Tahir, 2023).

The circular economy model has positive implications for job creation and income generation. UCO collection creates economic opportunities for households, waste banks, and intermediaries. On an industrial level, large-scale businesses managing UCO exports to international markets gain even greater economic benefits as UCO is processed into biodiesel that meets global standards. This aligns with the concept of resource regeneration in the circular economy, where reuse reduces the need for new resources while creating a sustainable economic value (Nabilla & Soehaditama, 2023).

Furthermore, UCO management within the circular economy framework supports environmental sustainability, particularly by reducing carbon emissions, as biodiesel derived from UCO has a lower carbon footprint than fossil fuels. Thus, UCO management in a circular economy model offers not only economic benefits but also contributes to environmental sustainability goals by promoting renewable energy use and reducing greenhouse gas emissions (Geissdoerfer et al., 2017).

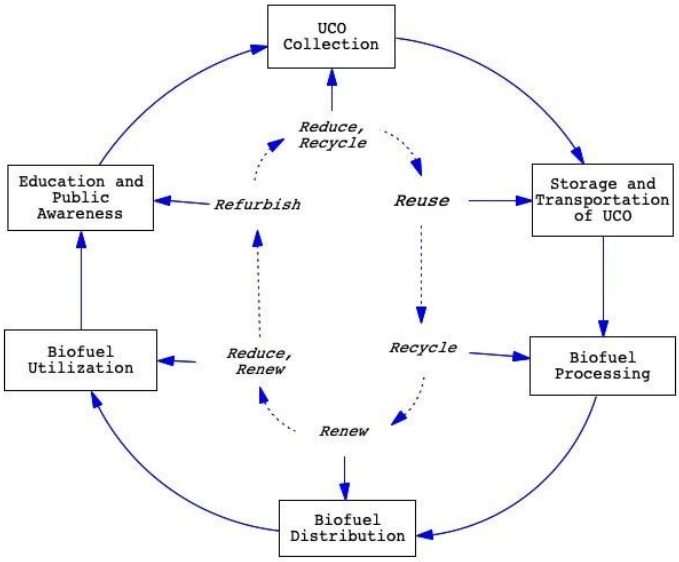

Figure 1. Circular Economy Approach in UCO Management
Source: Data Processed, 2024

Based on Figure 1, implementing a circular economy in UCO management for biofuel involves several stages, from collection to biofuel usage. Each stage applies principles such as reduction, reuse, recycling, refurbishment, and renewal, all of which contribute to creating a more sustainable and efficient system. In the initial stage of UCO collection, the concepts of Reduce and Recycle are implemented to minimize the disposal of used cooking oil into the environment. Oil generated from households and businesses are collected for recycling instead of being discarded improperly. This reduction in waste mitigates the risk of water and soil pollution, a common issue resulting from the improper disposal of used cooking oil. Through recycling, UCO which is regarded as waste, is transformed into a valuable resource that can be reused in biofuel production (Ellen MacArthur Foundation, 2013).

During the storage and transportation phase, the collected UCO is temporarily stored before being transferred to the processing facilities. The principle of reuse is applied here, as the collected oil will be repurposed as a raw material for biodiesel. This process prevents the wastage of new resources and, by treating UCO as a reusable asset, reflects a circular economy that emphasizes the sustainable use of materials (Stahel, 2016).

The biofuel processing stage, where UCO is converted into biodiesel through processes like transesterification, embodies the recycling principle. This recycling process transforms oil, which is no longer suitable for cooking, into biodiesel, a renewable fuel that can serve as an alternative to fossil fuels. Additionally, by-products such as glycerol generated during this process can be utilized in other industrial applications, maximizing the use of all components of raw materials (Geissdoerfer et al., 2017).

The Renew principle is predominant in the biofuel distribution phase. Biofuels produced from UCO are renewable energy sources that can replace non-renable fossil fuels and reduce carbon emissions. The distribution of biofuels from renewable sources supports the transition towards a low-carbon economy, contributing to climate change mitigation efforts. During the biofuel utilization stage, both the Reduce and Renew concepts are applied. Biofuel derived from UCO not only decreases carbon emissions from vehicles or machinery but also substitutes the consumption of fossil energy. This aligns with the sustainability goals of the circular economy, where the use of renewable energy is prioritized to reduce

the global carbon footprint and prolong the life of resources.

The education and public awareness phase applies the concept of Refurbish, not in the context of physical materials, but rather in altering societal perceptions and attitudes towards UCO waste. Through educational programs and awareness campaigns, the public's understanding of how UCO can be used as a valuable resource is refreshed. This mental transformation encourages broader participation in sustainable waste management.

The collection of UCO has proven to open new business opportunities, particularly in the context of a circular economy. Previously regarded as waste, UCO now possesses economic value as raw materials for biofuel production. This collection process involves various economic actors, from households and restaurants to collectors, all of whom benefit economically from this system.

With the provision of incentives for UCO collection, communities can exchange their used oil for money or goods through waste banks or waste collectors. Intermediaries, such as collectors, earn income by selling UCO to biofuel processing plants. This creates a chain of economic activities that engage multiple stakeholders, including collectors, distributors, and exporters. As the demand for biofuels in international markets grows, UCO has become a high-value commodity, offering broader business opportunities for those involved in this supply chain.

4.2 Economic Aspect Analysis

In the business process of UCO management for biofuel production, the price of UCO increases at each stage of the supply chain owing to value addition through consolidation, quality improvement, and processing. The first stage involves households, restaurants, and small- and medium-sized enterprises (SMEs). At this point, UCO is viewed as waste and usually sold at a low price, ranging from IDR 1,000 to 3,000 per liter. Restaurants and SMEs that produce larger volumes can sell UCO at higher prices, approximately IDR 4,000–IDR 5,000 per liter.

Subsequently, UCO is typically collected by waste banks, which act as intermediaries between the community and collectors. Waste banks buy oil from the community and sell it to collectors at a higher price, around IDR 5,000 to IDR 6,000 per liter. Waste banks enhance UCO's value by ensuring that the oil collected is clean and free from contamination, making it more valuable in the next market phase.

Local collectors then purchase oil from waste banks, restaurants, or large households. They consolidate oil in large quantities for sale to aggregators or exporters. At this stage, UCO prices range from IDR 5,500 to IDR 7,500 per liter, and collectors often filter and clean the oil to enhance its quality and value. Aggregators or large-scale collectors are the next actors in the supply chain. They buy UCO in bulk from local collectors and prepare it for export or sale to biofuel producers. Here, the price of UCO can reach IDR 7,500–8,500 per liter, depending on the quality and volume available.

Exporters form the subsequent phase, purchasing oil from aggregators and preparing it for export to international markets. UCO is often exported to countries with stringent renewable energy regulations, such as those in Europe, where it is used as a biofuel. The price at the export stage can rise to IDR 8,000–10,000 per liter, influenced by global market demand and transportation costs. The final stage involves biofuel production, in which UCO is processed into biodiesel through transesterification. Biofuel producers usually buy UCO at a price of around IDR 8,000 to IDR 12,000 per liter, depending on the quality and the purchasing location. The selling price of the produced biodiesel is determined by market conditions and government policies, such as the B30 biodiesel blending mandate.

Overall, the price increase at each stage of the UCO supply chain reflects value addition through consolidation, purification, and biofuel processing. In addition to its environmental benefits, UCO management opens economic opportunities within the community, from households and SMEs to large-

scale industries. Government incentives and international market demand for biofuel feedstocks further influence the price and sustainability of UCO management processes.

4.3 Policy Aspect Analysis

To enhance the implementation of the circular economy in UCO management and ensure its sustainability, several policies and initiatives must be carried out in an integrated and continuous manner. A primary strategy involves strengthening the regulations governing UCO management, from collection and processing to utilization as a biofuel feedstock. The government can implement policies requiring restaurants, hotels, and households to manage their UCO separately and collaborate with waste banks and other collection institutions. Additionally, regulations on the quality standards for UCO that can be used as biofuel feedstocks must be tightened to ensure that the recycled oil is safe and of high quality.

From a regulatory perspective, the government plays a vital role in facilitating and supporting UCO management. Appropriate regulations can promote investment in UCO collection and processing infrastructure while offering economic incentives to businesses and community members. On the other hand, strict enforcement of penalties for illegal UCO disposal can bolster compliance and encouraging more responsible practices (Wang et al., 2019).

Increased awareness and community participation are critical in a circular economy. Massive educational campaigns should be launched to inform the public about the hazards of reusing UCO as cooking oil and its benefits when processed into a biofuel. Community involvement in UCO collection can be bolstered through incentive programs, such as compensation or reward points for households and SMEs that actively donate or sell their UCO. This step aligns with the circular economy's emphasis on waste reduction, reprocessing, and resource reuse (Geissdoerfer et al., 2017).

Moreover, collaboration between the government, private sector, and civil society is essential for developing UCO management infrastructure. The government can partner with businesses like collectors and biofuel producers to build effective UCO collection and processing facilities. Investing in efficient and environmentally friendly UCO processing technologies is crucial for ensuring long-term sustainability. According to Ellen MacArthur Foundation (2013), one of the main pillars of the circular economy is innovation in technology and processes that enable optimal and sustainable resource utilization.

By implementing circular economy principles at each stage of UCO management, this system focuses not only on waste reduction but also on creating new value from previously useless materials. This approach supports global goals for achieving better environmental and economic sustainability in aquaculture. Overall, UCO management is a concrete example of a circular economy application, where waste is transformed into a valuable resource, supporting community economic welfare and environmental sustainability.

5. Conclusions

The management of used cooking oil (UCO) within the circular economy framework offers various benefits, both environmental and social. This process transforms waste into valuable resources, aligning with the principles of reduction, reuse, recycling, refurbishing, and renewal. By implementing an efficient system for the collection, storage, processing, and conversion of UCO into biofuel, it is possible to minimize waste, reduce environmental pollution, and create economic opportunities throughout the supply chain of the biofuel.

The involvement of multiple actors, including households, waste banks, collectors, exporters, and biofuel producers, illustrates the potential for collaboration in waste management. When managed effectively, this approach not only promotes environmental sustainability fosters active community awareness and

participation, ultimately contributing to a healthier environment and economic growth.

In conclusion, adopting a circular economy model for UCO management can facilitate the transition to renewable energy sources, lower carbon emissions, and unlock new economic opportunities. This process directly supports local economies while advancing broader sustainability goals. To maximize these benefits, it is crucial to integrate educational initiatives, supportive policies, and technological innovations into the management system.

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Author Contributions

ASS conceptualized the study, designed the methodology, and conducted data analysis. TTT contributed to wrote the manuscript, the study's design, and data collection. BS provided critical revisions to the manuscript, and JTH approved the final version for publication.

Conflicts of Interest

The authors declare no conflict of interest in the publication of this research. This study was conducted independently, and there are no financial or personal influences on the results.

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