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Circular Economy Breakthrough: Converting Used Cooking Oil Into Sustainable Biodiesel

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Abstract

Used cooking oil is a household waste that has not yet been optimally managed, potentially leading to economic losses and environmental pollution. This study aims to analyze the behavior of housewives in Banyumas District in utilizing used cooking oil, identify the potential for developing biodiesel from used cooking oil, and formulate strategies and roles for relevant stakeholders to optimize used cooking oil management. The methodology employed in this research is mixed-method, utilizing primary data from surveys and secondary data from various related studies and publications. The analysis reveals that most housewives in Banyumas directly dispose of used cooking oil without prior processing. Adopting a circular economy approach in converting used cooking oil into biodiesel can prevent pollution and provide a sustainable alternative energy source. This practice can also raise public awareness about environmental preservation, promote responsible consumption, and create additional income and green jobs. Implementing this policy requires collaboration from various stakeholders, including the government, academics, business actors, the community, and the media.

Keywords: Circular economy, used cooking oil, biodiesel, clean energy

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INTRODUCTION

Palm oil is one of the key plantation commodities contributing a lot to Indonesia's economy. In 2022, Indonesia produced 45,580 million tons of palm oil and continued to increase by 48,230 million tons in the year 2023 (Ministry of Agriculture, 2022). This palm oil industry contributed about 13.50% of the non-oil and gas exports and also 3.50% of Indonesia's total GDP (Ministry of Agriculture, 2022). This industry is also a great promoter of energy sovereignty, driving grassroots economic sectors, and providing employment opportunities (Purba & Sipayung, 2017).

The high value of palm oil can be related to many characteristics it possesses as a favored vegetable oil among consumers. The major product from palm oil is cooking oil, inseparable from the daily life of Indonesians, and fastened with culinary traditions that heavily involve fried dishes. More often, Indonesians consume more fried dishes than boiled dishes (Setiawan et al., 2024). It is hence unsurprising that Indonesia 2022/2023 emerged as the largest consumer of palm oil in the world (Data Indonesia, 2023).

It can also be seen in Banyumas District, Central Java Province, which is famous for its specialty dish of *mendoan*, a lightly fried fermented soybean cake covered in flour. This tradition is very well-rooted in the community of Banyumas up to the household level. *Mendoan* is a common dish in many situations and thereby has turned into a staple food. As a result, the consumption of cooking oil is relatively high in Banyumas. In 2023, the average consumption of palm oil in Banyumas District was 0.262 liters per capita per week, or higher than the national average of 0.224 liters per capita per week (BPS, 2024).

The high consumption of palm oil at the household level has not been accompanied by sufficient awareness regarding the management of used cooking oil (Montororing et al., 2024). Most households do not properly manage the used cooking but dispose of it freely into the environment (Budiyoko et al., 2022; Riswati et al., 2022). This practice also has the potential to eventually result in environmental disturbance, including blockages to drainage systems and deterioration in the quality of urban environments (Pauhesti et al., 2022; Tanjung et al., 2022). The improper practices of used cooking oil waste management contribute to increasing the chances of aquatic ecosystem destruction due to the pouring of used cooking oil into water bodies, disturbing the life of aquatic organisms (Margono, 2023; Tsoutsos et al., 2016).

Used cooking oil proper and efficient management may bring economic benefits to the community (Goh et al., 2020; Lopresto, 2024). The concept of a circular economy offers a potential solution by transforming waste, such as used cooking oil, into valuable economic resources (Khajuria et al., 2022; Romero-Hernández & Romero, 2018). The circular economy will ensure that materials are being reused, remanufactured, or recycled to extend their life cycle and diminish environmental impacts (Bappenas, 2022). The implementation of circular economy principles for used cooking oil can be achieved by converting it into biodiesel (Freitas et al., 2022; Mena-Cervantes et al., 2022), a renewable and sustainable energy source. Transforming used cooking oil into biodiesel extends the life cycle of palm oil, creates economic benefits for the community (Hartini et al., 2020), reduces dependence on fossil fuels (Goh et al., 2020; Suzihaque et al., 2022), decreases pollution (Sahar et al., 2018; Zhao et al., 2021), and generates green jobs (Bappenas, 2022).

This study aims to analyze the behavior of housewives in Banyumas District in managing used cooking oil, assess the potential for utilizing used cooking oil as biodiesel within the

framework of the circular economy, and map the roles of stakeholders in promoting biodiesel development from used cooking oil. Effective management of used cooking oil can provide significant economic benefits for the community and mitigate negative environmental impacts (César et al., 2017). Additionally, properly used cooking oil management can create new business opportunities and increase household incomes (Loizides et al., 2019). This initiative is also aligned with the sustainable development goals (SDGs), particularly goal 12, which emphasizes the importance of responsible consumption and production, and goal 7, which focuses on the development of sustainable clean energy.

RESEARCH METHODS

This study employs a mixed-method approach, combining qualitative and quantitative data to gain a comprehensive understanding of a phenomenon (Amadi, 2023), specifically household behavior and the potential for biodiesel production from used cooking oil. Primary data related to the behavior of households in handling used cooking oil were collected through a structured online survey among 65 housewives in Banyumas District. The frequency of using cooking oil, practices about its disposal, awareness regarding the environmental consequences of improper disposal of waste oil, and interest in re-cycling used cooking oil were some of the questions included in the survey.

Secondary data, particularly in analyzing the potential of used cooking oil as biodiesel within the framework of the circular economy and mapping stakeholder roles in promoting biodiesel development, were gathered from relevant literature, reports, and studies on biodiesel production from used cooking oil This is achieved through the review of the relevant literature reports and studies on biodiesel production from used cooking oil, which gave indications on the items related to the production techniques, cost-benefit analysis, and environmental impact assessment of biodiesel.

Quantitative data obtained through the survey had cross-tabulation to analyze household behavior concerning used cooking oil management. On the other hand, qualitative data obtained from secondary sources were thematically analyzed to give an overview of the biodiesel production potential and key stakeholders' roles for optimization in managing used cooking oil. The mapping of the stakeholder role was done using the pentahelix framework that integrates five complementary actors: academia, industry, community, government, and media. This model emphasizes the importance of cross-sector collaboration in promoting sustainable development and fostering competitive innovation (Hazin et al., 2024; Tadung, 2023). The Pentahelix model will help in bringing appropriate ecosystem support for the implementation of a circular economy through the conversion of used cooking oil to biodiesel by encouraging active interaction among these five actors. The implications of this analysis were then synthesized into a general overview of the potential for a circular economy in Banyumas District.

RESULTS AND DISCUSSION

Housewives significantly contribute to the administration and use of utilized cooking oil (Kaban et al., 2024). According to survey findings, a substantial proportion of respondents (82.9%) indicated that they acquire cooking oil on multiple occasions within a month. This suggests that the predominant shopping behavior among respondents involves

a monthly cycle, where they generally procure essential household items in bulk to satisfy their monthly requirements. Regarding the volume of cooking oil usage, 48.6% of participants indicated that they utilize between 3 to 4 liters monthly, whereas 28.6% disclosed a consumption of 1 to 2 liters. The remaining 22.9% noted that their monthly cooking oil usage surpasses 5 liters. Importantly, the average consumption of cooking oil noted in this study exceeds the average consumption statistics for Banyumas District (BPS, 2024). An overview of practices concerning used cooking oil management at the household level can be found in Table 1.

Table 1. Survey Results on Household Behavior in Managing Used Cooking Oil in Banyumas District

Variable	Percentage
Frequency of cooking oil purchases per month:	
a. Once	80,0%
b. More than once	20,0%
Amount of cooking oil used per month:	
a. 1-2 liters	30,8%
b. 3-4 liters	47,7%
c. More than 4 liters	21,5%
Methods of managing used cooking oil:	
a. Disposed directly (through sink drains, gutters, rivers, etc.)	60,0%
b. Disposed in trash (after being placed in bottles or other containers)	27,7%
c. Collected at waste banks	4,6%
d. Other methods	7,7%

Source: Primary data (processed)

At the same time, housewives' practices in terms of the reutilization of cooking oil reveal that 82.9% of respondents claimed to reuse cooking oil up to three times. On the other hand, the rest, which is 17.1% revealed that they reuse cooking oil more than three times. Constant heating of cooking oil transforms the fats into saturated fat and releases carcinogenic free radicals (Haryanto, 2020) that could induce various health illnesses (Encephala, 2018; Khuzaimah, 2017). This suggests that the participants have an appropriate understanding of the health hazards associated with the reuse of cooking oil.

Regarding the management of used cooking oil, the majority of housewives in the Banyumas District have not yet adopted proper practices. 60% of the total respondents answered that they disposed used cooking oil directly via sink drains, gutters, or rivers. On the other hand, 28.6% revealed that they threw it in the trash after putting it in containers or packaging. Only 2.8% of the respondents had deposited used cooking oil in the waste bank appropriately, while 8.5% disposed of used cooking oil by selling or using other methods. The direct disposal of used cooking oil through drainage and landfills poses a significant risk to water and soil pollution (Damayanti et al., 2020; Erviana, 2019). According to Vanessa & Bouta (2017), quoting from The Guardian, the financial cost of reparation for environmental pollution due to 10 tons of waste from fried cooking oil reaches around $600.000, or approximately IDR 7.2 billion. Meanwhile, the direct discharge of used frying oil into the natural environment simply means the loss of any value-added uses or economic opportunities from recycling the oil (Goh et al., 2020; Khan et al., 2019).

On the other hand, several activists and community groups in Banyumas District have initiated collection facilities for used cooking oil. According to one of the collectors in Purwokerto, the average price of used cooking oil ranges between IDR 4,000 and 5,000 per liter. The collected oil is then processed into biodiesel or exported. By 2019, Indonesia was

estimated to export about 148,000 tons of used cooking oil (TNP2K et al., 2020). However, large-scale utilization of used cooking oil, such as biodiesel production, is predominantly carried out outside the Banyumas District area.

Biodiesel can be produced through the transesterification process, which involves reacting vegetable oils or animal fats with short-chain alcohols, such as methanol. The primary product of this reaction is fatty acid methyl ester (FAME), with glycerol as a byproduct. During transesterification, triglycerides from oils or fats are first converted into diglycerides, then monoglycerides, and finally into glycerol (Furqon et al., 2018; Wirawan et al., 2024). Acids, bases, or enzymes can catalyze biodiesel production, and it is also possible to perform the reaction without a catalyst (Tambunan et al., 2011). However, base-catalyzed transesterification is the most commonly used method due to its ability to produce large quantities of biodiesel, minimize corrosion in equipment, and maintain a high reaction rate (Furqon et al., 2019; Wirawan et al., 2024). Despite these advantages, base catalysts have a limitation, as they can react with free fatty acids (FFAs) in the feedstock, forming soap, which hampers separation and reduces biodiesel yield.

Various feedstocks can be used for biodiesel production, including vegetable oils, microalgae, animal fats, and waste cooking oil. As the world's largest producer of palm oil, with a production exceeding 45 million tons in 2022 (BPS, 2023; Furqon et al., 2024), Indonesia has significant potential to produce biodiesel from palm oil derivatives (CPO, RBDPO). However, these derivatives are still in competition with other sectors, particularly the food industry. Used cooking oil presents an interesting alternative as it is a byproduct that is no longer suitable for consumption, thereby eliminating competition with the food sector. If improperly disposed of, used cooking oil can become an environmental pollutant. Approximately 31% of micro-enterprises and 40% of households generate used cooking oil from used cooking oil. With an average household consumption of 0.7 liters per week and 11.34 liters per week for micro-enterprises, the potential for used cooking oil utilization is substantial (Sudaryadi et al., 2022).

Indonesia's vast palm oil production and its large population and growing culinary industry ensure a stable supply of used cooking oil. Restaurants, street food vendors, and households contribute to used cooking oil production (Goembira & Ihsan, 2018; Kharina et al., 2018). In 2019, Indonesia's consumption of cooking oil reached 16.2 million kiloliters, which, if converted to biodiesel, represents a potential of 3.24 million kiloliters (TNP2K et al., 2020). In Banyumas District. per capita palm oil consumption in 2023 averaged 0.262 liters per week (BPS, 2024), amounting to a total of 479,086.1 liters. From this, the estimated used cooking oil produced is 88,630.93 liters. Given that 1 liter of used cooking oil can yield 0.2 liters of biodiesel (TNP2K et al., 2020), the potential biodiesel output from Banyumas' used cooking oil could reach 17,726.19 liters per week. The scale of used cooking oil production, both nationally and regionally in Banyumas, is sufficient to support large-scale biodiesel production. Additionally, the increasing interest of the government in renewable energy provides opportunities to enhance used cooking oil collection networks and processing facilities.

The production of biodiesel from used cooking oil is fundamentally similar to other feedstocks ready for immediate use. However, high free fatty acid content, impurities, density, and viscosity can pose challenges during application. These issues can be addressed through various pretreatment processes, such as

steam injection, neutralization, vacuum evaporation, and filtration, as well as other chemical or thermochemical technologies. Some researchers highlight the associated costs of these pretreatments, but studies have shown that production costs can be reduced by up to 45%, making the process economically viable (Wong & Devi, 2014). Used cooking oil is priced at half to one-third the cost of new vegetable oils, and in some cases, used cooking oil is discarded as waste, even though raw material costs account for 75-90% of total production costs (Suzihaque et al., 2022).

Performance tests on used cooking oil-based biodiesel show little difference compared to biodiesel produced from other vegetable oils. Tests on diesel engines demonstrate impressive performance, combustion efficiency, and emissions that are competitive with biodiesel derived from fresh vegetable oils (Enweremadu & Rutto, 2010). Used cooking oil biodiesel reduces emissions by up to 85%, including reductions in hydrocarbon, SO_2, CO, and particulate matter emissions, which effectively contributes to environmental protection (Yaqoob et al., 2021).

The utilization of waste cooking oil as raw material for biodiesel synthesis could be stated as an epistemologically quite reasonable move in the circular economic paradigm frame of Banyumas District. The fundamental philosophy of the circular economy is to reduce all kinds of waste by reusing and recycling existing resources (Barreiro-Gen & Lozano, 2020; Tambovceva et al., 2021), it also includes used cooking oil. In this regard, the utilization of the pentahelix methodology, in which there is collaboration between five key elements: the government, academia, industry/business, community, and media, will be very important for the optimum utilization of used cooking oil to produce biodiesel. The pentahelix model for developing used cooking oil into biodiesel is illustrated in Figure 1.

a. Government

The local government plays a vital role in managing used cooking oil (Haryanto, 2020). They function as both a regulatory body and a facilitator in the establishment of a supportive ecosystem for the management of used cooking oil. The local government must formulate regulations that oversee the distribution of utilized cooking oil within their designated areas and promote management initiatives, commencing from the most fundamental administrative divisions such as neighborhoods (RT/RW), utilizing mechanisms such as waste banks or comprehensive utilized used cooking oil management facilities.

Figure 1. Pentahelix Model

On the regulatory and policy front, government regulations could be set in place where used cooking oil is collected both from households and food industries, and progress can be enhanced through policy incentives such as providing subsidies for biodiesel producers or reduction of household taxes in exchange for effectively dealing with the waste produced. In terms of infrastructure, the government can also develop facilities for used cooking oil management to support collection and processing activities, such as setting up collection centers in each district or village,

along with biodiesel processing facilities. Given its authority, the government can act as a hub, facilitating collaboration among various stakeholders, including academia, business, and the community, through discussion forums, training, and outreach programs (Maryani & Muhi, 2021; Rizky et al., 2024).

b. Academia

Scholars from universities and research institutions provide the necessary scientific and technological basis to support the utilization of used cooking oil for biodiesel production. They are involved in the development of appropriate technologies and suitable methods of conversion of used cooking oil to biodiesel. This is aimed at ensuring that products obtained from the conversion are clean, ecologically friendly, and safe to use.

Academics can also be involved, especially those coming from universities, in undertaking community outreach programs as a way to raise public awareness of the importance of managing used cooking oil and its potential linked to the circular economy. They can also train SMEs and households on appropriate used oil management and its related economic and environmental benefits. In the meantime, research institutions can also partner with the business sector in developing innovative solutions for biodiesel utilization both locally and nationally.

c. Business

The commercial industries, and more so SMEs, play a very key role in the value chain surrounding the conversion process of used cooking oil to biodiesel. Commercial players have the mandate to ensure not only the conversion of used cooking oil into high-quality biodiesel but also that the product is sufficiently economical to compete with other sources of energy. Used cooking oil-based biodiesel processing technologies need enhancement through increased investment to realize better levels of efficiency in production (Avagyan & Singh, 2019; Goh et al., 2020).

Restaurants, hotel, and catering establishments can likewise be valuable contributors to the collection of used cooking oil (Loizides et al., 2019; Rincón et al., 2019). They can collaborate with civic groups or even government agencies in the logistics of collecting the used oil and its transport to processors. Moreover, business actors can develop attractive marketing models for consumers, both in the industrial and household sectors, to ensure that biodiesel from used cooking oil is widely accepted as an environmentally friendly alternative energy source.

d. Community

The role of the community is essential in the collection and management of used cooking oil at the household level (Putri et al., 2023; Santoso et al., 2022). In addition, communities act as catalysts for the collective consciousness of the benefits of the circular economy (Asgar et al., 2024). There is a need to raise awareness about the dangers of improper disposal of used cooking oil and its economic potential if managed properly. Through environmental and social campaigns, communities can educate households on the importance of collecting used cooking oil and delivering it to processing centers.

Communities can initiate the establishment of waste banks or used cooking oil banks in every neighborhood (RT/RW) or community group to facilitate collective used cooking oil collection. The accumulated oil can subsequently be marketed to biodiesel manufacturers or appropriate business entities. Furthermore, communities may partner with

governmental and academic organizations to implement training and empowerment initiatives concerning the management of used cooking oil at the household level, allowing communities to reap economic advantages from this activity.

e. Media

Such a phenomenon decides that the most vital role of the media is to share information and run campaigns on the merits of using used cooking oil for biodiesel and the circular economy. The media itself must actively educate the public through effective awareness of the importance of managing used cooking oil and its process for transformation into biodiesel. Public campaigns through print, electronic, and digital media can enhance public understanding.

Furthermore, the media plays a crucial role in promoting public engagement by implementing initiatives that inspire individuals or communities to participate in the management of used cooking oil. About advocacy, the media can additionally function as an intermediary between the public and governmental bodies by fostering dialogues and advocating for policies that endorse the management of used cooking oil.

Table 2. Success Indicators of Pentahelix Model Elements

Actor	Success Indicators
Government	• There are regulations and policies governing the management of used cooking oil. • There is budgetary support for used cooking oil management, either through the national (APBN) or regional (APBD) budgets. • There are organizations or institutions responsible for handling used cooking oil management. • There is good coordination and cooperation between government institutions, both at the central and regional levels, regarding efforts to manage used cooking oil. • There is enforcement of the laws and policies that have been established.
Academia	• Conducting research related to the implementation of circular economy principles, particularly in the management of used cooking oil and biodiesel. • Integrating the themes of the circular economy and used cooking oil management into biodiesel production within the academic curriculum. • Incorporating the themes of the circular economy and used cooking oil management into biodiesel production in community service and student fieldwork programs. • Active participation of universities in the formulation of regulations and policies on used cooking oil management for biodiesel production.
Business and Private sector	• Strong commitment from business actors, particularly in the food and restaurant sectors, in managing used cooking oil, demonstrated through policies and practices for used cooking oil management. • Integration and financial support for used cooking oil management within the company's internal policies. • Implementation of corporate social responsibility programs prioritized in the social and environmental fields.

Actor	Success Indicators
	• Adoption of the latest technologies in the effective and reliable processing of used cooking oil into biodiesel. • Development of business models for biodiesel from used cooking oil, covering both the raw material collection process and the marketing of the resulting product.
Community	• Increased community participation in the collection and management of used cooking oil, demonstrated by the establishment of collection and management centers at the neighborhood (RT/RW), village, or district level. • The creation of a strong collaboration between community groups and other institutions, both governmental and private, in the agenda for used cooking oil management. • Enhanced community capacity to manage used cooking oil into other valuable products. • Involvement of community groups in the drafting or formulation of regulations and policies on used cooking oil management. • Community group involvement in monitoring and evaluating the implementation of government regulations and policies related to used cooking oil management.
Media	• The active role of the media and press, supported by communication and information technology, in disseminating information on the dangers of improperly managed used cooking oil and efforts to convert it into biodiesel. • The active role of the media and press in providing access to information and education to enhance public understanding of the importance of used cooking oil management and methods to convert it into biodiesel. • The active role of the media and press in advocating policies that support the management of used cooking oil, while providing accurate and real-time information to the public.

Source: Processed from various sources

Success indicators for each of the actors according to the pentahelix framework can be viewed in Table 2. The implementation of a circular economy in used cooking oil management also increases public awareness of responsible consumption. It helps to attain manifold SDGs, especially Goals 12 on responsible consumption and production, 7 on affordable and clean energy, and 11 on sustainable cities and communities. Moreover, the practice of these principles can create green employment and would surely lead to a sustainable and ecologically viable future.

CONCLUSION

The great potentiality of used cooking oil as feedstock for biodiesel production within a circular economy perspective may be revealed by this study. Current behavior in the household of Banyumas District is that most of the waste oil is disposed of in a very inappropriate manner; therefore, education and infrastructure development should be carried out to support sustainable waste management. This will indeed equate to waste reduction, production of renewable energy, and green jobs of which come with great

environmental and economic benefits. But such a transition to biodiesel production using used cooking oil calls for broad-based involvement and participation from the government, businesses, academia, and the community. Through the transition to the circular economy, Banyumas transforms its waste into a valuable resource that contributes to local economic development and global sustainability goals.

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