Research Paper

THE POTENTIAL OF CIRCULARITY IN THE DEVELOPMENT OF THE UPSTREAM-DOWNSTREAM COFFEE AGROINDUSTRY TO FOSTER A GREEN ECONOMY AND ENHANCE CLIMATE RESILIENCE

Yuli Wibowo[1)]*, Siswoyo Soekarno[2)], and Faireza Mawaddah[3)]

[1)]Department of Agricultural Industrial Technology, Faculty of Agricultural Technology, University of Jember
[2)]Department of Agricultural Engineering, Faculty of Agricultural Technology, University of Jember
[3)]Master's Program in Agroindustrial Technology, Faculty of Agricultural Technology, University of Jember
Jl. Kalimantan No. 37, Sumbersari, Jember Regency 68121, East Java, Indonesia
*Corresponding author: yuliwibowo.ftp@unej.ac.id

Article Info

Received: October 17, 2025
Revised: December 23, 2026
Accepted: January 16, 2026
Published: April 2026

Keywords:

circular economy, coffee agroindustry, green economy, Ketakasi Cooperative, resilience

ABSTRACT. As a cornerstone of sustainable development, the circular economy offers a robust mechanism for addressing climate change by maximizing resource utility and minimizing the environmental footprint of agro-industrial processes. This study evaluates the prevalence of linear production pattern within small coffee agro-industries and explores the transition toward a competitive, sustainable system through circular economy principles. Focused on the Ketakasi Cooperative in the Silo District of Jember Regency, the research utilizes a multi-methodological approach – incorporating the Material Circularity Indicator (MCI), the 9R framework, and impact analysis to assess circularity potential. Findings reveal that the cooperative currently operates on predominantly linear model, evidenced by MCI of 0.223. However, substantial potential for circularity exists through the conversion of coffee waste into compost, liquid fertilizer, briquettes, animal feed, and value-added products from defective beans. The 9R analysis demonstrates that implementation of reducing, reusing, and recycling strategies is economically viable, yielding a Net Benefit/Cost ratio greater than1and a payback period less than six months. These results suggest that adopting circular principles can significantly foster a green economy while enhancing climate change resilience within the coffee agro-industrial sector. This research fills a critical gap by offering a site-specific circular economy model for the coffee industry that balances environmental sustainability with immediate economic profitability through innovative waste repurposing.

INTRODUCTION

Climate change is a significant challenge for the global community. Climate change has a significant impact on production systems. Accordingly, Earth's average temperature has increased by 1.1 °C since the pre-industrial period. In addition, unless mitigation action is taken, Earth's temperature is projected to exceed the limit of 1.5°C over the next two decades (IPCC, 2023). Food and water scarcity, along with extreme events driven by climate change, are significant outcomes of a changing climate. Consequently, significant socio-economic losses are encountered. In Indonesia, losses due to climate change are estimated to reach a value of IDR 544 trillion, which has never occurred before (BPS-Statistics, 2024). It calls for resource-intensive production systems to be developed into more efficient ones. As a result, the government has set the target of Net Zero Emissions by 2060 and has launched the National Circular Economy Strategy.

In this regard, the circular economy has emerged as a significant strategy for mitigating the impacts of climate change by enhancing resource efficiency, reducing waste, and minimizing greenhouse gas emissions. This strategy, developed based on the make-use-return strategy and fueled by the 9R strategy, has been shown to enhance technological innovation and the development of a green economy (Geissdoerfer *et al.*, 2017; Kirchherr *et al.*, 2017). In this regard, the

DOI: https://doi.org/10.24961/j.tek.ind.pert.2026.36.1.67

agriculture and agro-industry sectors are essential sectors for the development of a green economy since they produce around 12% of greenhouse gas emissions and produce a large quantity of organic waste (FAO, 2024). In this respect, the coffee agro-industry sector has significant implications for mitigating the impacts of climate change and waste minimization, since only 1% of the coffee cherry constitutes the final product, with the rest constituting a form of waste and posing a threat to the environment (Rochmah *et al.*, 2021).

Indonesia ranks fourth among the world's top coffee-producing countries, with annual production reaching 794,800 tons (Alfatahi, 2025). Most coffee production in the country occurs through small-scale systems. In the Jember Regency, the most crucial role of the small-scale coffee production system has been observed, particularly in the Silo District. In the country, coffee production totaled 1,959 hectares, resulting in 11,795 tons in 2023 (BPS Kabupaten Jember, 2024). It has been observed that from every 100 kg of coffee cherries, the production of 60-65 kg of solid waste and 40-50 liters of liquid waste takes place for the processing of even 100 kg of coffee cherries. The potential of the waste produced through the coffee production system has been proven through various types of research work carried out in the country, proving the strong potential of the waste produced through the coffee production system in the country (Adziem and Nurhasanah, 2021; Hariyanto *et al.*, 2022; Ichsan and Sitepu, 2021; Mustakim *et al.*, 2019; Muzaifa *et al.*, 2022; Wardhana *et al.*, 2016).

However, this potential is not fully harnessed in small-holder coffee-based agro-industries due to limited circular literacy, a lack of appropriate indicators, technology, and weak institutional capacity (Selvan *et al.*, 2023). Efficiencies gained through supply chain improvements have been reported to help minimize carbon emissions and increase agro-industries' sustainability (Jaya, 2023). In terms of national-scale benefits, studies from Bappenas have estimated that implementing circular economy principles in food systems will lead to savings of up to 40 million tons of biomass and 126 million tons of emissions, specifically CO2e, by 2045 (Ichsan and Sitepu, 2021).

In addition, it has been identified that previous research on the coffee agro-industry in Jember Regency has focused more on sustainability, the supply chain, and the production process individually. However, there are no research studies that deal with all these factors in an integrated manner. To date, no comprehensive study has addressed various aspects, including the characteristics of coffee production, waste, and potential applications of coffee agro-industries in Jember Regency. This has been a contributing factor towards an inability to formulate policies relating to waste management, smallholder empowerment, and community-based green economies (Purnomo *et al.*, 2024; Wibowo *et al.*, 2019). In this regard, this study aims to help fill this information gap by developing an integrated approach that includes the Material Circularity Indicator (MCI) and 9R to evaluate impacts at the economic, social, and environmental levels holistically for the successful implementation of the circular economic concept in smallholder coffee agro-industries.

RESEARCH AND METHODS

The research location for this study will be Koperasi Ketakasi (Ketakasi Cooperative), which is in Krajan Hamlet, RT 03/RW 02, Sidomulyo Village, Silo District, Jember Regency, East Java Province, Indonesia. The reason for choosing this location is that Koperasi Ketakasi has been established as a major hub for producing Arabica coffee by smallholders. Accordingly, it can be said that the factors encountered in this location reflect most of the smallholder issues related to resources and waste. Moreover, the areas considered for this purpose included upstream activities such as coffee bean production and the cultivation of coffee bean raw materials. On the other hand, the downstream activity for this purpose was processing coffee beans into coffee powder.

The research design employed for the study integrated primary and secondary information. Primary information for the research was obtained from observational studies, intensive interviews with key players in the agro-industry, and questionnaire surveys. The results of the study helped the researcher identify trends, materials used, waste, and the current practices adopted in the agro-industry. The secondary information used in the study is drawn from government, institutional, and scholarly publications on the application of circular economy principles in the agro-industry, particularly in coffee processing. The approach followed for the research given is quantitative and descriptive.

The first stage entailed recognizing the prevailing conditions of the coffee agro-industry, including the production process, products, processing capacities, and the use of material and energy resources. This stage laid the foundation for later research on the circular economy and material flows.

The positive application of circular economy concepts was determined by using the 9R model: Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, and Recycle; this model is commonly applied to measure waste reduction and reuse possibilities of agro-industrial systems (Kirchherr *et al.*, 2017; Potting *et al.*, 2017; Yulistika *et al.*, 2023). In applying this model, the primary aim is to determine feasible waste-use approaches that account for the technical, economic, and social realities at the cooperative level.

To measure the level of circularity of the production system, the Material Circularity Indicator (MCI) was employed in this study. This approach was based on the underlying structure developed by the Ellen MacArthur Foundation (EMA, 2019), which was further refined by Yunaningsih *et al.* (2024) to suit the needs of agro-industrial production systems. This evaluation was initiated by determining the Virgin Material Input (V), which was a variable used to determining the quantity of non-circular materials used in the process, as follows:

$$V = M(1 - FR - FU - FS)$$

In this equation, M represents the product's total mass. The material inputs are categorized into three fractions: FR for recycled content, FU for reused components, and FS for materials derived from sustainable sources, such as composted biomass.

The following equation defines non-recoverable waste (W_0), which accounts for all residual matter that lacks potential for reuse, recycling, composting, or energy recovery:

$$W_0 = M(1 - CR - CU - CE - CC)$$

where CR denotes circular recycling, CU denotes circular reuse, CE denotes circular composting, and CC denotes circular energy recovery. The total non-recoverable waste (W) was computed as:

$$W = W_0 + \frac{Wf + Wc}{2}$$

where Wf is waste produced from recycled feedstock production, and *Wc* is waste produced from recycling processes.

Linear Flow Index (*LFI*), indicating the degree of dependency of the system on virgin materials and linear material flows, was determined as:

$$LFI = \frac{V + W}{2M + \frac{Wf - Wc}{2}}$$

The higher the LFI value, the more linear the production system.

The Utility Factor ($F(x)$) calculation, which considers the functionality and lifespan of the product compared to an average benchmark, is done using the following equations:

$$x = \left(\frac{\mathrm{L}}{\mathrm{L_{avg}}}\right)\left(\frac{\mathrm{U}}{\mathrm{U_{avg}}}\right)$$

$$F = \frac{0{,}9}{x}$$

where *L* is the actual lifespan of the product, *Lavg* is the average lifespan of similar products, *U* is the actual functional unit of the product, and *Uavg* is the average functional unit of similar products.
The final Material Circularity Indicator (*MCI*) result is calculated as:

$$MCI = 1 - LFIxF(X)$$

A value of *MCI* close to 1 implies a higher level of circularity and efficiency in the materials used, while lower values imply a more linear production system.

Alongside the MCI analysis, this study investigated the economic, social, and environmental dimensions of circular economic implementation. Economic feasibility was gauged via the Benefit–Cost Ratio and Payback Period (Kasmir and Jakfar, 2003), following agro-industrial investment frameworks (Yulistika *et al.*, 2023). Social impacts were qualitatively examined through indicators such as community empowerment and job creation, while environmental benefits were measured by waste reduction, improved resource efficiency, and lower greenhouse gas emissions.

Ultimately, strategic recommendations were formulated by synthesizing the MCI results with the broader economic, social, and environmental assessments. These practical, context-aware proposals account for local technological capabilities, institutional frameworks, and cooperative-based management to foster a transition toward a sustainable, community-driven circular economy

RESULTS AND DISCUSSIONS

Identification of the Coffee Agro-industrial System

To characterize the coffee agro-industrial production system, fieldwork comprising observations and interviews with cooperative managers was conducted at Koperasi Ketakasi in Sidomulyo Village, Silo District, Jember Regency. The cooperative has 87 active members and is assisted by 298 Fairtrade-certified farmers in the production of coffee on around 118 hectares. The primary products processed in Koperasi Ketakasi are robusta and arabica coffee, with

 DOI: https://doi.org/10.24961/j.tek.ind.pert.2026.36.1.67

an annual production capacity of 1,300 tons of green coffee beans, which are exported to both domestic and international markets. The production capacity and market orientation of the cooperative are in line with previous studies on smallholder-based coffee agro-industries in Indonesia (Novita *et al.,* 2012; Pawiengla *et al.,* 2020).

From the observation, arabica coffee processing at Koperasi Ketakasi involves a full-wash method comprising several steps, including sorting, pulping, fermentation, washing, drying, hulling, roasting, grinding, and packaging. The processing method involves high water usage and handling. The application of the full wash processing method in the study corresponds to the processing method in the specialty coffee production system (Suhada *et al.,* 2025). The energy sources that facilitate the processing method include household electricity, liquefied petroleum gas (LPG), and solar energy. The operation utilizes a local workforce sourced from the surrounding community. The primary processing infrastructure consists of a pulper, a huller, a 25 kg-capacity roasting unit, and basic warehousing facilities.

The production of Arabica coffee powder at Koperasi Ketakasi follows a 12-stage sequence, beginning with the reception of fresh cherries and concluding with final packaging. This process encompasses key phases, including sorting, pulping, fermentation, washing, drying, hulling, roasting, grinding, and packaging. To visualize material transformation and mass reduction throughout these stages, an input-output flow diagram was developed based on on-site observations (Figure 1).

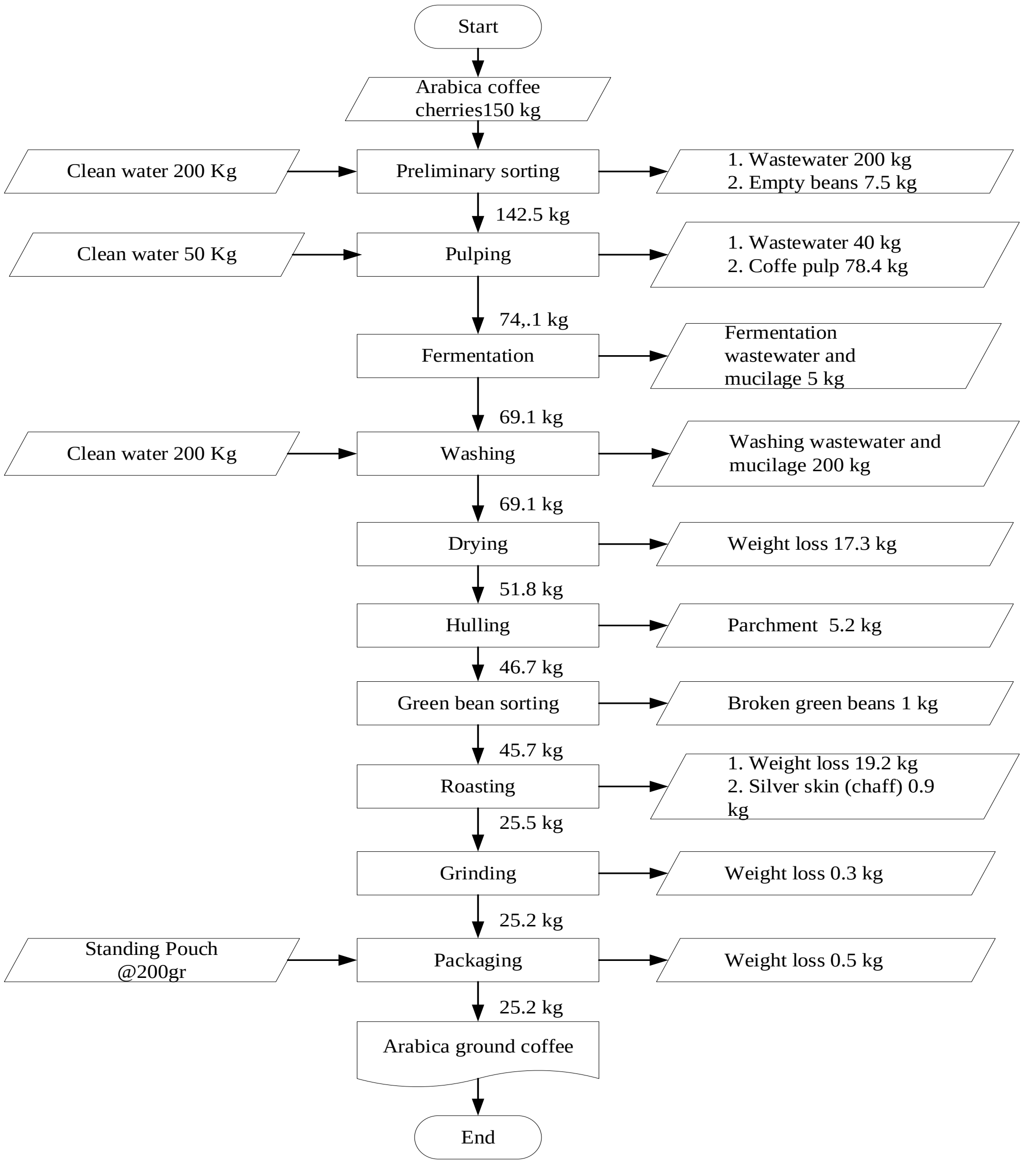

Figure 1. Input-output diagram of Arabica coffee processing at Ketakasi

The comprehensive input–output diagram for Arabica ground coffee production at Koperasi Ketakasi is presented in Figure 1, covering the entire workflow from cherry reception to final packaging. This visualization maps the distribution of material flow across all processing stages, highlighting critical points of material loss. Consequently, the diagram serves as a foundational tool for evaluating production efficiency, identifying waste generation pathways, and conducting subsequent assessments of resource utilization and material circularity within the agro-industrial system.

From an initial input of 150 kg of Arabica coffee cherries, the process yielded 45.7 kg of green beans (30.4%) and 24.7 kg of ground coffee (16.4%). These figures indicate that over half of the raw material's original mass is discarded as solid or liquid waste. The primary solid waste component was coffee pulp (78.4 kg), followed by parchment husks (5.2 kg), silver skin (0.9 kg), and various sorting and packaging residues. Conversely, the liquid waste produced was around 440 kg from sorting, pulping, and washing activities. The biochemical oxygen demand (BOD) and chemical oxygen demand (COD) of liquid waste were high, indicating a high potential for organic pollution if released untreated into the environment. The findings of this study support the findings of the previous studies that showed similar results, which highlighted that coffee processing chains are significant contributors to the production of organic waste and water pollution (Irawan *et al.,* 2024; Rahmah *et al.,* 2023).

Although waste is currently underutilized at the cooperative level, the identified waste streams present several opportunities for circular economic implementation. Coffee pulp and parchment husk can be processed into organic fertilizers or cascara products, while liquid waste can be treated through anaerobic processes to produce liquid fertilizer and reduce environmental impacts. Similar waste valorization pathways have been demonstrated in other coffee agro-industrial systems, indicating the technical feasibility of these options (Subroto *et al.,* 2023; Tsigkou *et al.,* 2025).

Evaluation of Circular Economy Potential in Ground Arabica Coffee Production

Based on the results of waste identification, it can be concluded that most by-products from arabica coffee production at Koperasi Ketakasi are currently underutilized and disposed of. Based on field observations, it is found that the solid and liquid waste streams have a great potential for reprocessing based on circular economy concepts, using the 9R approach (Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, and Recover) when considered from a technical, environmental, and social point of view.

Coffee pulp that is wet and makes up the highest proportion of solid waste can be processed into compost, bioenzymes, or fermented livestock feed. However, based on observations at the cooperative level, it has been noted that the processing of coffee pulp is not widely practiced due to a lack of equipment and training. It has been shown in previous studies that compost made from coffee pulp can increase soil fertility and reduce the use of chemical fertilizers by as much as 30%, which shows that it has great potential (Hariyanto *et al.,* 2022). Likewise, the fermentation wastewater produced in the pulping stage is currently released untreated. This wastewater can be reused by simple biofiltration processes to decrease organic pollutant concentrations. Previous research has shown that these processes can reduce BOD concentrations by up to 70%, making it safer for reuse, although this is not currently available at the research location (Yunaningsih *et al.,* 2024). Moreover, defective coffee beans, which are usually discarded or sold at a lower price, were also considered another underutilized by-product. These coffee beans can be processed into more valuable products such as instant coffee, cosmetic scrubs, or teaching materials. This practice has been done by other small-scale coffee producers in East Java, indicating that cooperation between cooperatives and local businesses can help make this possible (Pawiengla *et al.,* 2020).

In terms of energy, field tests show that the drying process in Koperasi Ketakasi is still conducted using conventional sun drying for 7-14 days, resulting in time wastage and the potential for fungal growth. The use of greenhouse solar dryers may reduce drying time by as much as 40% (Sunarto *et al.*, 2024). In general, the application of circular economic approaches in the production of arabica ground coffee can help to minimize waste, maximize resource use, and add value to the product. In addition to promoting sustainability, the approach also provides opportunities for product development and the empowerment of local economies. In the first phase, the most practical approach would be to implement Reduce, Reuse, and Repurpose approaches. The performance of circularity is further assessed using quantitative criteria, including the Material Circularity Indicator (MCI), which will be discussed in the next section.

Material Circularity Indicator (MCI) Calculation and Interpretation

The Material Circularity Indicator (MCI) analysis was conducted to evaluate the material circularity of the arabica coffee production system at Koperasi Ketakasi. According to the material flow data presented in Table 1, the total input for the production process amounted to 575.3 kg. Virgin materials, defined as natural, non-recycled raw inputs, accounted for 86.37% of this total, while circular inputs, in the form of composted coffee pulp, accounted for 13.63%. These findings underscore the predominantly linear nature of the current production system, where most materials are ultimately discarded as waste.

Virgin material input is dominant, indicating low material recycling in the system. Based on the total input, 496.9 kg (86.37%) remains unrecovered, indicating that reuse, recycling, and energy recovery have not yet been practiced at the cooperative level. The field observations have confirmed that coffee pulp and defective coffee beans are mainly disposed of or used to a very limited extent, despite their potential economic value. Such conditions have been associated with high pressure on natural resources and low circular efficiency in agro-industrial systems (EMA, 2019; Rocchi *et al.,* 2021). This condition clearly shows that there is an opportunity to improve material efficiency through the implementation of effective waste management practices (Tandiono and Endah, 2023).

The calculated Linear Flow Index (LFI) of 0.863 also verifies the linear nature of the production system. A high LFI index indicates a one-way flow of material from input to waste, with little to no recycling or feedback loops. This result is consistent with the absence of recycling, reuse, and energy recovery opportunities in the production process, as well as with past studies showing that high LFI indexes are associated with greater environmental impacts and lower circularity (Kirchherr *et al.*, 2017). The Utility Factor (F(X)) index of 0.9 indicates that the final product is highly functional and has a long lifespan for its intended purpose. However, this indicator does not consider the potential utility in value of unused by-products and waste streams. In the case of Koperasi Ketakasi, this means that while product quality is high, system value could be significantly enhanced by incorporating waste utilization methods, as found in past studies on the circular economy (Fu and Zhang, 2025).

An MCI score of 0.223 on a scale of 0 to 1 indicates that material circularity is low and that the linear production system remains dominant (Table 1). For coffee agro-industrial systems that have integrated waste management and by-product processing, the MCI score has been found to exceed 0.5 (Rocchi *et al.,* 2021). This is an important indication that the potential for improving material circularity at Koperasi Ketakasi is enormous. In conclusion, the MCI analysis clearly indicates that, although the current arabica coffee production system at Koperasi Ketakasi is linear, it has immense potential to transform into a circular economy. The MCI analysis is an important tool for monitoring and improvement, which will enable Koperasi Ketakasi to further minimize its negative impact on the environment while generating even more economic value *(*Gayda, *2023;* Møller *et al*., 2024).

Economic, Social, and Environmental Impacts and Strategic Recommendations for Circular Economy Implementation

Based on the economic, social, and environmental impact analysis conducted in this study, various types of waste produced from coffee processing, such as liquid waste, coffee pulp, husk, parchment, mucilage, and defective coffee beans, have a great potential for use in a circular economy system.

Table 1. Material Circularity Indicator (MCI) output parameters

No.	Parameter	Symbol	Value	Notes
1	Total material input	M	575.3	Kg
2	Fraction sold	FR	0	No product fraction sold
3	Reused fraction	FU	0	No material reused
4	Composted fraction	FS (CE)	0.1363	Proportion of composted coffee pulp
5	Virgin material input	V	496.9	kg
6	Recycled/used fraction	CR, CU	0	No recycling
7	Energy recovery fraction	CC	0	No energy recovered
8	Unrecovered waste	W	496.9	kg
9	Linear flow index	LFI	0.863	High value indicates linearity
10	Utility factor	F(X)	0.9	Based on product function and lifespan ratio=1
11	Circularity Indicator (MCI)	MCI	0.223	scale 0–1; higher=more circular

This potential can be tapped by the implementation of different 9R strategies, especially 'reduce, reuse, recycle, repurpose, and recovery,' which are technically feasible and economically viable for small and medium-scale coffee processing units. From the feasibility analysis, it has been identified that different waste utilization options are economically viable and create environmental and social value, as presented in Table 2.

Table 2 presents waste utilization alternatives that not only have economic feasibility, as evidenced by net benefit-cost ratios greater than 1 and relatively short payback periods, but also provide substantial environmental and societal benefits. The production of organic liquid fertilizer from liquid waste, coffee pulp production into compost, briquettes, or animal feed, and the use of fermented mucilage and defective coffee beans to produce value-added products help to mitigate pollution loads and add economic value to the local economy (Yulistika *et al.*, 2023).

The adoption of these strategies can help to improve the income of coffee business actors, generate new job opportunities at the MSME scale, and improve the synergies between the agricultural and livestock sectors, while also improving community access to affordable and quality coffee products (Herawati *et al.*, 2024).

These strategic recommendations offer a feasible approach to improve material circularity and reduce linear system inputs, thereby facilitating the transition off small-scale coffee agro-industries towards sustainable, competitive circular economy model.

Table 2. Circular economic alternatives in the coffee industry

No.	Problem	Solution	Circularity Level	Benefits
1	Liquid waste	Organic liquid fertilizer (POC) (Bojórquez-Quintal *et al.*, 2024; Rahmah *et al.*, 2023)	R8 / Repurpose	Economic: 1.000 L waste → ± 500 L POC - Investment: IDR 2.000.000 - Fixed cost: IDR 3.000.000/year - Variable cost: IDR 7.000.000/year - Production: 12.000 L/year - Selling price: IDR 2.000/L - Revenue: IDR 24.000.000/year - Profit: IDR 14.000.000/year - Net B/C: 2.4 > 1 - Payback: 0.14 years Environmental: reduces water pollution Social: provides affordable organic fertilizer for farmers
2	Fresh coffee pulp	Organic compost (Dadi *et al.*, 2019; Ruiz *et al.*, 2021)	R8 / Repurpose	Ekonomi: 1-ton Fresh coffee pulp → ± 500 kg compost - Investment: IDR 2.000.000 - Fixed cost: IDR 3.000.000/year - Variable cost: IDR 5.000.000/year - Production: 8.000 kg/year - Selling price: IDR 2.000/kg - Revenue: IDR 16.000.000/year - Profit: IDR 8.000.000/year - Net B/C: 2.00 > 1 - Payback: 0.25 years Environmental: reduces the accumulation of rapidly decomposing and odorous pulp Sosial: provides affordable organic fertilizer for farmers and supports sustainable agriculture
3	Dry coffee husk	Briquettes (Anggono *et al.*, 2023; Tesfaye *et al.*, 2022)	R9 / Recover	Economic: 100 kg dry husk → ± 80 kg briquettes - Investment: IDR 1.500.000 - Fixed cost: IDR 2.000.000/year - Variable cost: IDR 5.000.000/year - Production: 4.000 kg/year - Selling price: IDR 3.000/kg - Revenue: IDR 12.000.000/year - Profit: IDR 5.000.000/year - Net B/C: 1.71 > 1 - Payback: 0.30 years

No.	Problem	Solution	Circularity Level	Benefits
				Environmental: reduces dry husk accumulation and greenhouse gas emissions from natural decomposition Social: provides affordable alternative fuel for households and local MSMEs
4	Coffee parchment	Mixed animal feed (Benitez *et al.*, 2019; Carneiro *et al.*, 2025)	R7 / Repurpose	Economic: 200 kg parchment + 100 kg bran/cornmeal → ± 250 kg fermented feed - Investment: IDR 2.000.000 - Fixed cost: IDR 2.000.000/year - Variable cost: IDR 6.000.000/year - Production: 9.000 kg/year - Selling price: IDR 2.000/kg - Revenue: IDR 18.000.000/year - Profit: IDR 10.000.000/year - Net B/C: 2.25 > 1 - Payback: 0.20 years Environmental: reduces the accumulation of hard-to-decompose parchment and pollution potential Social: provides affordable animal feed for local farmers and strengthens connections between coffee MSMEs and the livestock sector
5	Mucilage	Compost mix (Dadi *et al.*, 2019)	R8 / Repurpose	Economic: 1 ton coffee pulp + 200 L fermented mucilage → ± 600 kg compost - Investment: IDR 2.000.000 - Fixed cost: IDR 3.000.000/year - Variable cost: IDR 5.000.000/year - Production: 8.000 kg/year - Selling price: IDR 2.000/kg - Revenue: IDR 16.000.000/year - Profit: IDR 8.000.000/year - Net B/C: 2.00 > 1 - Payback: 0.25 years Environmental: reduces solid waste buildup and odor from fermented mucilage Social: provides affordable organic fertilizer for local farmers, improves coffee farm soil quality
		Fermented fish feed (Roslan *et al.*, 2024)	R7 / Repurpose	Economic: 500 L fermented mucilage + 100 kg bran → ± 600 kg fish feed - Investment: IDR 1.500.000 - Fixed cost: IDR 2.000.000/year - Variable cost: IDR 5.000.000/year - Production: 5.000 kg/year - Selling price: IDR 2.500/kg - Revenue: IDR 12.500.000/year - Profit: IDR 5.500.000/year - Net B/C: 1.79 > 1 - Payback: 0.27 years Environmental: reduces odor and organic waste Social: provides affordable fish feed for local farmers
6	Defective coffee beans (broken/small)	Traditional local ground coffee (Febrianto and Zhu, 2023; Lee *et al.*, 2023)	R7 / Repurpose	Economic: 100 kg defective beans→ ± 80 kg ground coffee - Investment: IDR 2.500.000 - Fixed cost: IDR 4.000.000/year - Variable cost: IDR 8.000.000/year - Production: 7.000 pcs (50 g)/year - Selling price: IDR 3.000/pcs

DOI: https://doi.org/10.24961/j.tek.ind.pert.2026.36.1.67

No.	Problem	Solution	Circularity Level	Benefits
				- Revenue: IDR 21.000.000/year - Profit: IDR 9.000.000/year - Net B/C: 1.75 > 1 - Payback: 0.28 years Environmental: reduces food loss Social: provides affordable ground coffee for the community
		Ready-to-drink coffee (RTD) (Herawati *et al.*, 2024; Lin *et al.*, 2022)	R7 / Repurpose	Economic: 100 kg defective beans→ ± 9.000 bottles of 250 ml coffee - Investment: IDR 5.000.000 - Fixed cost: IDR 5.000.000/year - Variable cost: IDR 10.000.000/year - Production: 9.000 bottles/year - Selling price: IDR 3.000/botol - Revenue: IDR 27.000.000/bottles - Profit: IDR 12.000.000/year - Net B/C: 1.80 > 1 - Payback: 0.42 years Environmental: reduces defective coffee bean waste Social: provides affordable and convenient coffee drinks for consumers

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The research evaluated the production system, waste generation, and the possibility of implementing circular economy principles in the smallholder arabica coffee agro-industry of Koperasi Ketakasi in Jember Regency. The results indicate that the production system remains linear, as evidenced by a Material Circularity Indicator (MCI) of 0.223, with most input materials not being reused or recycled. The greatest material loss occurs in the wet processing step, particularly pulping and washing, which account for most of the processing time and generate most of the solid and liquid waste, followed by losses in the sorting process and the underutilization of by-products such as defective coffee beans and fermentation wastewater. The evaluation of the implementation of circular economy principles using the 9R method indicates that the implementation of principles emphasizing reduce, reuse, and repurpose is technically and economically viable, as evidenced by the Net B/C ratios of values greater than 1 and payback periods of less than 0.5 years for different waste utilization options like compost, organic liquid fertilizer, briquettes, animal feed, and products made from defective coffee beans. This implies that implementing circular economic principles can improve the efficiency of production, mitigate environmental impacts, enhance the welfare of coffee-producing communities, and strengthen climate resilience and the production system, thereby contributing to the transition of small coffee agro-industries toward a sustainable development pathway.

Recommendations

Future research should focus on the long-term implications of implementing circular economics in the coffee agro-industry, particularly in terms of material circularity, emissions reduction, and income stability. The stakeholders, cooperatives, local government, and institutions that support them are encouraged to apply circular economic strategies, particularly the reduce, reuse, and repurpose strategy, to improve efficiency and reduce waste. On the other hand, the development of the coffee agro-industry through the application of circular economic principles can be seen as a strategy to build resilience, as it allows the use of production waste as valuable resources in the next production cycle, thereby improving the competitiveness of the smallholder-based agro-industrial system.

REFERENCES

Adziem AHW and Nurhasanah Y. 2021. Inisiasi lokal model ekonomi sirkular melalui pertanian terpadu sebagai adaptasi petani di Kalimantan Timur selama pandemi Covid-19. *Learning*

Society: Jurnal CSR, Pendidikan, dan Pemberdayaan Masyarakat, *2*(1): 88–100.

Alfatahi BR. 2025. Indonesia Jadi Produsen Kopi Terbesar ke-4 di Dunia - GoodStats Data. GoodStats Data. https://data.goodstats.id/statistic/indonesia-jadi-produsen-kopi-terbesar-ke-4-di-dunia-QA412.

Anggono W, Gotama GJ, Pronk C, Hernando IC, Sutrisno T. 2023. Characteristics of biomass briquettes from coffee husk as sustainable fuel. *BIO Web of Conferences*. 62: 1–6. https://doi.org/10.1051/bioconf/20236203002

Benitez V, Rebollo-Hernanz M, Hernanz S, Chantres S, Aguilera Y, Martin-Cabrejas MA. 2019. Coffee parchment as a new dietary fiber ingredient: Functional and physiological characterization. *Food Research International*, 122: 105–113. https://doi.org/10.1016/j.foodres.2019.04.002.

Bojórquez-Quintal E, Xotlanihua-Flores D, Bacchetta L, Diretto G, Maccioni O, Frusciante S, Rojas-Abarca LM, Sánchez-Rodríguez E. 2024. Bioactive compounds and valorization of coffee by-products from the origin: a circular economy model from local practices in Zongolica, Mexico. *Plants*. 13(19): 1 – 23. https://doi.org/10.3390/plants13192741.

BPS Kabupaten Jember. 2024. Kecamatan Silo Dalam Angka (Silo District in Figures): Volume xxxviii.

BPS-Statistics. 2024. Produk Domestik Bruto Indonesia Triwulan 2020-2024. In 07100.24011 (Vol. 7, Numbers 1907–4557, pp. 1–120).

Carneiro ACO, Zanuncio AJV, Carvalho AG, Jorge JACG, dos Santos RJC, Demuner IF, Peres LC, Winter SG, de Castro VR, Branco-Vieira M, Araújo SdeO. 2025. Sustainable production of coffee husk pellets: applying circular economy in waste management and renewable energy production. *Resources*. 14(2). https://doi.org/10.3390/resources14020026.

Dadi D, Daba G, Beyene A, Luis P, Van der Bruggen B. 2019. Composting and co-composting of coffee husk and pulp with source-separated municipal solid waste: a breakthrough in valorization of coffee waste. International *Journal of Recycling of Organic Waste in Agriculture*. 8(3): 263–277. https://doi.org/10.1007/s40093-019-0256-8.

Ema EM. 2019. Circularity Indicators: An Approach to Measuring Circularity-Methodology. https://content.ellenmacarthurfoundation.org/m/77e62bc9924c20d0/original/Circularity-Indicators-Methodology.pdf

FAO. 2024. The State of Food Security and Nutrition in the World 2024. FAO; IFAD; UNICEF; WFP; WHO; https://doi.org/10.4060/cd1254en

Febrianto NA, Zhu F. 2023. Coffee bean processing: Emerging methods and their effects on chemical, biological and sensory properties. In Food Chemistry (Vol. 412). Elsevier Ltd. https://doi.org/10.1016/j.foodchem.2023.135489

Fu P and Zhang Y. 2025. Enhancing resource efficiency and value addition in food and agricultural by-product processing: a green recycling approach. *Frontiers in Sustainable Food Systems*. 9. https://doi.org/10.3389/fsufs.2025.1589807.

Gayda SV. 2023. Determination of the circularity indicator in the forest sector according to the principles of the circular economy. Forestry, Forest, Paper and Woodworking Industry, 49, 99–114. https://doi.org/10.36930/42234908.

Geissdoerfer M, Savaget P, Bocken NMP, Hultink EJ. 2017. The Circular Economy – A new sustainability paradigm? *Journal of Cleaner Production*, 143:757–768. https://doi.org/10.1016/j.jclepro.2016.12.048

Hariyanto B, Fanani F, and Nugroho SE. 2022. Rekayasa Fermentasi Kopi An Aerobik dengan Metode Karbonik dan Semi Karbonik Maserasi. *Jurnal Pengembangan Potensi Laboratorium*. 1(2): 79–85. https://doi.org/10.25047/plp.v1i2.3098

Herawati D, Davin C, Dewi YN, Yulianti Y. 2024. Effect of storage duration on phenolics stability in ready-to-drink coffee beverage. *Coffee Science*, 19. 1–8. https://doi.org/10.25186/.v19i.2194.

Ichsan and Sitepu MF. 2021. Roadmap Ekonomi Sirkular di Kabupaten Tangerang Mendukung Tujuan Pembangunan Berkelanjutan (Number March). https://www.researchgate.net/publication/359044325_Laporan_Akhir_Kajian_Ekonomi_Sirkular_FINAL.

IPCC. 2023. Sections. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. In Arias P, Bustamante M, Elgizouli G, Flato, Howden M, Méndez-Vallejo C, Pereira JJ, Pichs-Madruga R, Rose SK, Saheb YR, Sánchez Rodríguez, Ürge-Vorsatz D, Xiao

C, Yassaa N, Romero J, Kim J, Haites EF, Y. Jung, R. Stavins, (Eds.), IPCC. https://doi.org/10.59327/IPCC/AR6-9789291691647.

Irawan A, Rabemanolontsoa H, and McLellan BC. 2024. Comprehensive Environmental Impact Analysis of Dry Processing Methods for Specialty Coffee Beans in Bondowoso, Indonesia Using Life Cycle Assessment. *Biomass (Switzerland*). 4(3) : 843–864. https://doi.org/10.3390/biomass4030047.

Kasmir J. 2003. *Studi Kelayakan Bisnis (Edisi Revisi).* Jakarta*:* Kencana Prenada Media Group.

Kirchherr J, Reike D, and Hekkert M. 2017. Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*. 12: 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005.

Lee YG, Cho EJ, Maskey S, Nguyen DT, Bae HJ. 2023. Value-added products from coffee waste: a review. *Molecules*. 28(8): 3562. https://doi.org/10.3390/molecules28083562.

Lin H, Tello E, Simons CT, Peterson DG. 2022. Identification of non-volatile compounds generated during storage that impact flavor stability of ready-to-drink coffee. *Molecules*. 27(7). https://doi.org/10.3390/molecules27072120

Møller H, Lyng KA, Röös E, Samsonstuen S, Olsen HF. 2024. Circularity indicators and added value to traditional LCA impact categories: example of pig production. *International Journal of Life Cycle Assessment*. 29(8): 1380–1392. https://doi.org/10.1007/s11367-023-02150-4.

Mustakim MN, Sari M, and Kholis MN. 2019. Pemanfaatan minyak biji kopi (fine robusta toyomerto) sebagai bahan baku pembuatan parfum eau de toilette. *Agroindustrial Technology Journal*. 3(1): 20. https://doi.org/10.21111/atj.v3i1.3793.

Muzaifa M, Rohaya S, Nilda C, Harahap KR. 2022. Kombucha fermentation from cascara with addition of red dragon fruit (Hylocereus polyrhizus): *Analysis of Alcohol Content and Total Soluble Solid. Atlantis Press.* https://doi.org/10.2991/absr.k.220102.020.

Novita E, Suryaningrat IB, Andriyani I, Widyotomo S. 2012. Analisis keberlanjutan kawasan usaha perkebunan kopi (KUPK) Rakyat Di Desa Sidomulyo Kabupaten Jember. *AGRITECH.* 32(2): 126-135.

Pawiengla AA, Yunitasari D, Adenan M. 2020. Analisis keberlanjutan usahatani kopi rakyat di kecamatan Silo kabupaten Jember. *Jurnal Ekonomi Pertanian dan Agribisnis.* 701–714. https://doi.org/https://doi.org/10.21776/ub.jepa.2020.004.04.01

Potting J, Hekkert M, Worrell E, Hanemaaijer A. 2017. Circular Economy: Measuring innovation in the product chain - Policy report. PBL Netherlands Environmental Assessment Agency, (January), 1–46.

Purnomo BH, Ni’maturrakhmat VN, Wibowo Y. 2024. System dynamic model of green supply chain management robusta coffee Argopuro in Indonesia: A case study. *Coffee Science*. *19*. https://doi.org/10.25186/.v19i.2211.

Rahmah DM, Mardawati E, Kastaman R, Pujianto T, Pramulya R. 2023. Coffee pulp biomass utilization on coffee production and its impact on energy saving, CO2 emission reduction, and economic value added to promote green lean practice in agriculture production. *Agronomy*. 13(3): 1–26. https://doi.org/10.3390/agronomy13030904.

Rocchi L, Paolotti L, Cortina C, Fagioli FF, Boggia A. 2021. Measuring circularity: an application of modified material circularity indicator to agricultural systems. *Agricultural and Food Economics*. 9(1): 1–13. https://doi.org/10.1186/s40100-021-00182-8

Rochmah HF, Kresnanda AS, and Asyidiq ML. 2021. Pemanfatan limbah ampas kopi sebagai upaya pemberdayaan petani kopi CV Frinsa Agrolestari, Bandung, Jawa Barat. *Jurnal Sains Terapan: Wahana Infomasi dan Alih Teknologi Pertanian*. 11(2): 60–69. https://doi.org/10.29244/jstsv.11.2.60 - 69.

Roslan NA, Sukri SAM, Wei LS, Shahjahan M, Rohani MF, Yea CS, Kabir MA, Guru A, Goh KW, Kallem P, Abdul Kari Z. 2024. Replacement of fishmeal by fermented spent coffee ground: Effects on growth performance, feed stability, blood biochemistry, liver, and intestinal morphology of African catfish (Clarias gariepinus). *Aquaculture Reports*. 36. https://doi.org/10.1016/j.aqrep.2024.102073.

Ruiz MSM, Reiser M, and Kranert M. 2021. Composting and methane emissions of coffee by-products. *Atmosphere*. 12(9). https://doi.org/10.3390/atmos12091153.

Selvan T, Panmei L, Murasing KK, Guleria V, Ramesh KR, Bhardwaj DR, Thakur CL, Kumar

D, Sharma P, Digvijaysinh Umedsinh R, Kayalvizhi D, Deshmukh HK. 2023. Circular Economy in Agriculture: Unleashing the potential of integrated organic farming for food security and sustainable development. *Frontiers in Sustainable Food Systems*. 7. https://doi.org/10.3389/fsufs.2023.1170380.

Subroto G, Avivi S, Suud HM, Kusbianto DE, Zahrosa DB, Soejono D, Prabowo RU. 2023. Pemanfaatan limbah kulit kopi arabika sebagai pupuk kompos di Desa Sukorejo Kecamatan Sumber Wringin Kabupaten Bondowoso. *INTEGRITAS : Jurnal Pengabdian*.7(2): 382–390. https://doi.org/10.36841/integritas.v7i2.3807.

Suhada A, Syah H, and Lubis A. 2025. Identifikasi titik kritis tahapan pasca panen kopi robusta dan uji penilaian cupping skor. *Jurnal Ilmiah Mahasiswa Pertanian*. 10(1): 233-244.

Sunarto BP, Siswantoro A, Izzati EM, Jamroni M. 2024. Pengembangan model pertanian kopi berbasis kawasan di dataran tinggi. *Jurnal Ekonomi Pertanian dan Agribisnis*. 8(3): 1181–1191. https://doi.org/10.21776/ub.jepa.2024.008.03.30

Tandiono JL and Endah SA. 2023. The potential utilization of coffee waste of pt javabica into bio-briquette as environmentally friendly fuel. *Majalah Ilmiah Pengkajian Industri*. 14(3): 203–210. https://doi.org/10.29122/mipi.v14i3.4225.

Tesfaye A, Workie F, and Kumar VS. 2022. Production and characterization of coffee husk fuel briquettes as an alternative energy source. *Advances in Materials Science and Engineering*,. https://doi.org/10.1155/2022/9139766.

Tsigkou K, Demissie BA, Hashim S, Ghofrani-Isfahani P, Thomas R, Mapinga KF, Kassahun SK, Angelidaki I. 2025. Coffee processing waste: Unlocking opportunities for sustainable development. Renewable and Sustainable Energy Reviews, 210(June 2024), 115263. https://doi.org/10.1016/j.rser.2024.115263.

Wardhana DI, Wibowo Y, and Suwasono S. 2016. Strategi pengembangan agroindustri kopi yang berkelanjutan. Prosiding Seminar Nasional APTA, (Jember 26-27 Oktober), 395–400. https://repository.unej.ac.id/bitstream/handle/123456789/79859/Danu Indra W_Pros APTA 2016_1.pdf?sequence=1.

Wibowo Y, Maulida YR, and Purnomo BH. 2019. Rencana produksi olahan kopi di perusahaan daerah perkebunan (PDP) Kahyangan Jember Menggunakan Metode Fuzzy Tsukamoto. *Agrointek*. 13(1): 61–71. https://doi.org/10.21107/agrointek.v13i1.4875

Yusriana, Jaya R , and Sembiring MT. 2023. Ekonomi sirkular pada manajemen rantai pasok agroindustri: konseptual dan rancangan implementasi. *Jurnal Teknologi Industri Pertanian*. 33(2): 196–205. https://doi.org/10.24961/j.tek.ind.pert.2023.33.196.

Yulistika E, Suprihatin, and Purwoko. 2023. Potensi penerapan konsep ekonomi sirkular untuk pengembangan industri tahu yang berkelanjutan. *Jurnal Teknologi Industri Pertanian*. 33(3): 254–266. https://doi.org/10.24961/j.tek.ind.pert.2023.33.3.254

Yunaningsih A, Satriadi Y, and Mauluddin A. 2024. Indikator sirkularitas di dalam tata kelola limbah pabrik kelapa sawit studi kasus: limbah cair (POME) Pabrik Kelapa Sawit. *Jurnal Penelitian Pendidikan Indonesia*. 10(4): 888. https://doi.org/10.29210/020243688.