Sustainable Batik Waste Management in Giriloyo: Integrating Circular Economy for Environmental and Economic Gains

Indah Fajarini Sri Wahyuningrum[1,*], Trisni Suryarini[1], Mochamad Arief Budihardjo[2], Fitrarena Widhi Rizkyana[1], Annisa Sila Puspita[3,], Agus Wahyudin[1]

[1]Department of Accounting, Faculty of Economics, Universitas Negeri Semarang, Indonesia
[2] Department of Environmental Engineering, Faculty of Engineering, Universitas Diponegoro, Indonesian
[3] Environmental Sustainability Research Group (ENSI-RG), Department of Environmental Engineering, Faculty of Engineering, Universitas Diponegoro, Indonesia
* Corresponding Author: i.fajarini@mail.unnes.ac.id

Abstract.
The traditional batik industry, though culturally vital and economically empowering, generates significant environmental pollution through the discharge of untreated wastewater containing synthetic dyes, heavy metals, and organic pollutants. This study aims to develop a sustainable waste management model for Giriloyo Batik Village by integrating cleaner production and circular economy principles to reduce environmental impacts and improve local livelihoods. Using a participatory approach, the research involved community mapping, the design and implementation of low-cost wastewater treatment systems (including phytoremediation and natural coagulants), and the establishment of creative recycling businesses utilizing batik waste. Results show a reduction of key pollutants COD by 83.7%, BOD by 88.2%, TSS by 88.0%, and Pb by 90.6% while generating new income streams and jobs, particularly for women-led enterprises. The model also demonstrated strong social adoption, with 85% of artisans embracing cleaner practices. These outcomes confirm that low-cost, community-based environmental innovation is both feasible and replicable in similar batik centers such as Laweyan, Lasem, Trusmi, and Pekalongan. This study contributes a novel, scalable framework for sustainable heritage industry practices, offering not just pollution control but also climate-aligned economic transformation. As a UNESCO-recognized craft, batik must evolve sustainably and Giriloyo shows that grassroots innovation can lead that evolution.
Keywords: *Batik Industry; Cleaner Production; Circular Economy; Wastewater Management.*

I. INTRODUCTION

Batik, officially recognized since 2009 by UNESCO as an Intangible Cultural Heritage of Humanity, symbolizes Indonesian national identity and it contributes to the local economy (Akagawa, 2018). Giriloyo Batik Village in Bantul, Yogyakarta, prominently crafts batik also has produced hand-drawn batik for centuries (Arleti et al., 2021). Within this town, there are around 150 working craftspeople who reside because it greatly helps with local jobs and protects customary wisdom. The batik industry faces issues in Giriloyo but it has cultural with economic importance. Factory runoff that is untreated leads to ecological destruction (Jan et al., 2022; Weldeslassie, Naz, Singh, & Oves, 2018). Developing a waste management sustainable model that aligns with small-scale batik producers' needs is crucially necessary under these conditions (Kusumawardani, Kurnani, Astari, & Sunardi, 2024).

Batik production in Giriloyo creates 7,500 to 15,000 liters of wastewater daily according to Yogyakarta Environmental Agency (2023) data, and that wastewater has dangerous substances like naphtol, remazol, also heavy metals like lead (Pb), cadmium (Cd), and chromium (Cr). This wastewater often does go straight into the rivers or onto the land with no proper treatment, then it badly endangers water sources as well as soil health (Ahmad, Aziz, Zia-ur-Rehman, Sabir, & Khalid, 2016). Gadjah Mada University (2022) has studied the groundwater samples deeply (Hendrayana et al., 2024). That study revealed the lead in them concentrated to 0.15 mg/L which is 15 times the amount defined as safe nationally by Ministry of Health Regulation No. 32/2017. The major obstacles to waste mitigation include the lack of decentralized wastewater treatment facilities, the relatively high cost of environmental compliance, limited awareness of sustainable practices, and the absence of community-based institutional frameworks. Without immediate intervention, these environmental burdens may escalate into broader socio-economic and public health concerns.

Previous studies have examined strategies such as cleaner production practices and centralized wastewater treatment to mitigate environmental damage caused by the batik industry. For instance, Ayele, Getachew, Kamaraj, and Suresh (2021) emphasized the potential of using natural dyes and modifying production technologies to reduce pollution levels. Meanwhile, Sulthonuddin and Herdiansyah (2021) applied the Analytical Hierarchy Process (AHP) to prioritize batik wastewater management strategies based on environmental, social, and economic factors. However, existing literature tends to focus on technical or policy-oriented solutions in urban or industrial contexts. There is a lack of research that integrates local participation, circular economy practices, and social entrepreneurship in small-scale, rural batik production communities.

The primary objective of this study is to develop a sustainable batik waste management model that reduces environmental pollution while enhancing the economic value of waste through creative reuse and recycling. This initiative aims to empower artisans with low-cost, appropriate treatment technologies and to establish local institutions capable of managing waste independently. Additionally, the study promotes stakeholder collaboration linking artisans, government institutions, academic bodies, and private enterprises in the creation of a green business ecosystem. The expected outcomes align with several Sustainable Development Goals (SDGs), including SDG 8 (Decent Work and Economic Growth), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), and SDG 15 (Life on Land). Through this effort, Giriloyo is envisioned to become a leading example of sustainable artisanal industry development in Indonesia.

II. METHODS

II-1. Cleaner Production and Circular Economy Framework

The methodology in this study was based on a hybrid framework combining Cleaner Production (CP) and Circular Economy (CE) principles to promote sustainable batik waste management. Cleaner Production, as defined by UNEP (2001), is a continuous application of an integrated preventive environmental strategy to processes, products, and services to improve overall efficiency and reduce risks to humans and the environment. CP implementation in the Giriloyo Batik Village focused on reducing the use of toxic materials, improving process efficiency, minimizing waste generation, and incorporating safe reuse and recycling practices. In parallel, the Circular Economy framework applied the principles of reduce, reuse, and recycle (3R) to transform waste into valuable resources, including wax, cloth scraps, and wastewater. This approach facilitated environmental improvement while unlocking new economic opportunities through green product innovation, waste valorization, and community-based entrepreneurship.

II-2. Stages of Implementation

The implementation stages were structured into four main phases, adapted from UNEP's CP methodology and participatory rural development models:

1. **Phase 1:** *Problem Exploration and Community Engagement (Months 1–2)* Initial activities included social mapping using Participatory Rural Appraisal (PRA), SWOT analysis, and needs assessment regarding environmental practices, artisan knowledge, and technological gaps.
2. **Phase 2:** *Participatory Planning and Technology Co-Design (Months 3–4)* This phase involved co-designing waste treatment systems and business plans with artisans through workshops. The proposed technologies included phytoremediation for wastewater, low-temperature wax distillation, and upcycling of fabric scraps. Institutional structures such as village-owned enterprises and women's waste groups were also initiated.
3. **Phase 3:** *Collaborative Implementation and Capacity Building (Months 5–10)* Training modules totaling 120 hours were delivered covering technical, design, and marketing aspects. Pilot-scale installations for wastewater treatment and product innovation were launched, alongside ongoing mentoring and digital promotion.
4. **Phase 4:** *Monitoring, Evaluation, and Replication (Months 11–12)* Environmental indicators (BOD, COD, Pb levels), economic indicators (income growth, ROI), and social indicators (participation rate, gender empowerment) were assessed. Evaluation informed iterative improvements and provided the basis for replication in other batik centers.

Economic feasibility was assessed using Net Present Value (NPV) and Return on Investment (ROI) calculations, which considered initial investment, operational costs, and projected revenue from recycled product sales and resource savings. These financial indicators helped determine the payback period and long-term sustainability of the interventions. Technical feasibility was evaluated based on the functionality and reliability of the installed treatment systems under real-world operating conditions. Environmental feasibility involved pre- and post-intervention analysis of key pollution parameters, including reductions in COD, BOD, TSS, and heavy metals, as measured through laboratory testing and field sampling. The integration of these assessments ensured a holistic validation of the model across economic, technical, and environmental dimensions (Hamilton, ElSawah, Guillaume, Jakeman, & Pierce, 2015).

III. RESULT AND DISCUSSION

III-1. Effectiveness of Communal Wastewater Treatment Technology

The implementation of the communal wastewater treatment plant in Giriloyo Batik Village demonstrates a significant reduction in key pollutant parameters. The treatment system, which integrates physical screening, natural coagulants, phytoremediation, and anaerobic–aerobic biological filtration, was evaluated through laboratory testing. As shown in Table 1, the Chemical Oxygen Demand (COD) was reduced from 920 mg/L to 150 mg/L, achieving a removal efficiency of 83.7%. Biological Oxygen Demand (BOD) decreased from 380 mg/L to 45 mg/L, corresponding to an 88.2% reduction. Total Suspended Solids (TSS) were lowered by 88.0%, while the concentration of lead (Pb) was reduced by 90.6%. These findings indicate that the applied treatment system can bring effluent concentrations below the national environmental thresholds established by the Ministry of Environment and Forestry. Compared to similar batik wastewater studies, the treatment performance at Giriloyo is notably higher. For instance, Sirait (2018) reported COD removal efficiencies between 72–79% using conventional sedimentation and filtration systems in Malang, while Sulthonuddin and Herdiansyah (2021) documented only a 65% lead removal rate in Pekalongan due to the absence of integrated phytoremediation stages. Furthermore, when juxtaposed with data from the Celaket Batik Industry (Table 2), which reported untreated wastewater with BOD levels of 5,226 mg/L, COD of 29,000 mg/L, and TSS of 2,036 mg/L substantially exceeding national thresholds the treatment outcomes in Giriloyo illustrate substantial environmental improvement. The inclusion of nature-based solutions, such as the use of *Eichhornia crassipes* for metal absorption and *Moringa oleifera* seeds for coagulation, has proven effective in reducing toxic constituents in wastewater with minimal operational costs.

Table 1. Pollutant Removal Efficiency of Communal Wastewater Treatment System

Parameter	Inlet	Outlet	% Removal

COD	920 mg/L	150 mg/L	83.7%
BOD	380 mg/L	45 mg/L	88.2%
TSS	250 mg/L	30 mg/L	88.0%
Pb	0.85 mg/L	0.08 mg/L	90.6%

From a sustainability perspective, the Giriloyo model demonstrates strong alignment with the principles of Cleaner Production and Circular Economy. In addition to pollutant reduction, the treated water is reused for irrigation of natural dye plants, and biogas generated from sludge digestion is used to fuel wax heating processes (Kalengyo, Ibrahim, Fujii, & Nasr, 2024). These integrated practices exemplify a closed-loop approach that not only mitigates environmental harm but also contributes to local economic resilience and community empowerment (Kara, Hauschild, Sutherland, & McAloone, 2022).

III-2. Creative Recycling Business Model

The integration of recycling innovations into the batik production chain has effectively created new economic opportunities for the Giriloyo community. The community used waste materials like cloth scraps, residual wax (malam), together with sludge, so it developed creative products of high added value. These initiatives sustain the environment by minimizing waste also employing people inclusively promoting local entrepreneurship. Re-Batik fashion items as well as Malam crafts along with Batik Art pieces happened to be the three main product categories around which recycling activities were structured. Each one was supported by digital marketing strategies, design standardization, and skills training. In Table 2, the Re-Batik fashion line included bags, apparel, and accessories made from batik fabric offcuts toward a monthly income of IDR 25–35 million; it created jobs for 15 workers, most of whom were women. IDR 10–15 million was the monthly revenue recorded by the Malam Craft initiative, with 6 full-time workers absorbed by the low-temperature distillation and repurposing of residual batik wax into candles and decorative items. The Batik Art Pieces, that were created through collaborations with local artists, involved a transformation of waste-based batik fragments to framed artworks, giving IDR 7–10 million for each month while employing 4 artists.

Table 2. Economic Impact of Creative Recycling Products

Product Type	Monthly Revenue (Rp)	Job Creation	Export Potential
Re-Batik Fashion	25–35 million	15 workers	Medium
Malam Craft (Wax)	10–15 million	6 workers	High (Japan/EU)
Batik Art Pieces	7–10 million	4 artists	High

These outcomes highlight how circular economy practices are viable commercially. Industries that are artisanal can especially benefit from these practices. Waste-based production models are profitable because financial analyses indicated a Return on Investment (ROI) would take 14 months, NPV reached Rp 185 million over three years, and Internal Rate of Return (IRR) grew 28%. Compared to similar programs in Trusmi and Lasem, the Giriloyo model shows higher return potential due to product diversification and the integration of digital sales platforms (Sulthonuddin & Herdiansyah, 2021). In line with SDG 8 (Decent Work and Economic Growth) and SDG 12 (Responsible Consumption and Production), the creative recycling business model not only strengthens environmental responsibility but also empowers communities through job creation, export readiness, and sustainable income generation (Franco & Newey, 2019).

III-3. Social and Environmental Impacts

The implementation of the sustainable batik waste management model at Giriloyo has measurably improved both social wellbeing and environmental quality. The project has brought improvement to community awareness about waste hazards for people. The project fostered behavioral shifts toward cleaner production practices. Environmentally speaking, the project succeeded because it reduced pollution from batik waste, particularly since it reduced wastewater pollutant loads so it improved ambient water quality (Daud, Abdullah, Hasan, Ismail, & Dhokhikah, 2022). Table 3 summarizes the most meaningful environmental improvements, with reductions in key pollutant parameters. These reductions include COD values (–83.7%), and BOD values (–88.2%), and TSS values (–88.0%), plus Pb values (–90.6%). Also, native fish species came back to the local river like biological indicators and soil quality improved for agriculture in six months after intervention. Water samples that people took from wells inside a 500-meter radius of production units complied with national drinking water standards because the intervention helped prevent further contamination of groundwater sources. From a social perspective, 85% of batik artisans reported that they adopted cleaner production techniques with reduced use of hazardous dyes, better separation of solid and liquid waste. Also, environmental education and waste training modules were finished by 90% of participants. That increased participants' ability to identify, treat, also reuse production by-products. Also prominent was the empowerment of women, for female artisans and entrepreneurs led 70% of the new recycling businesses. These outcomes align with those studies based in the community such as Handayani, Widianarko, and Pratiwi (2021) reported that positive health and environmental results followed after low-cost treatment interventions. However, the Giriloyo case stands out for its integrated model combining waste engineering, economic incentives, and gender-based empowerment under one program. This comprehensive approach illustrates the broader co-benefits of environmental interventions when paired with community engagement and inclusive development strategies (Newell, Dale, & Roseland, 2018).

Table 3. Summary of Social and Environmental Impacts

Impact Category	Indicator	Result	Target Achievement
Environmental Quality	COD Reduction	83.7%	Achieved
	BOD Reduction	88.2%	Achieved

	TSS Reduction	88.0%	Achieved
	Pb Reduction	90.6%	Achieved
	Fish species richness in river	Increased from 8 to 13 species	Exceeded
	Soil fertility index	Increased by 22%	Achieved
	Groundwater contamination (Pb)	< 0.01 mg/L	Below threshold
Social Outcomes	Adoption of clean production	85% of artisans	Achieved
	Training completion rate	90% of targeted participants	Achieved
	Women's leadership in waste enterprises	70%	Exceeded
	Community health complaints (e.g., dermatitis, respiratory)	Decreased by 60%	Achieved

III-4. Behavioral Transformation and Model Replication

The implementation of the sustainable batik waste management model in Giriloyo transformed the behaviors of local artisans in a prominent way (Pribudi, 2020). Before the intervention, waste disposal practices were largely informal and environmentally detrimental. Most solid waste was either burned or buried, also 65% of wastewater was sent into rivers. After the capacity-building programs, almost 85% of artisans adopted cleaner production principles. Also, these engagement processes did help. These include separation of waste at its source, reuse of wax, use of natural dyes, as well as active participation within communal wastewater treatment operations. This behavioral shift indicates that people grow more environmentally aware and willingly integrate sustainability into cultural production practices. Empowering of women artisans drove at this key behavioral transformation that they constituted 70% of a workforce for processing waste and producing batik. Women played a central role in educating the community about sustainable practices and managing cooperative enterprises, along with implementing the recycling innovations. Household income grew substantially due to their leadership role in economic activities. Upcycled fashion, crafts, also eco-friendly art are examples of activities that increased community resilience. Environmental literacy and economic agency that combined among women increased at the intervention's overall impact. Because of the way the model builds upon success within Giriloyo, it shows great potential for replication across batik centers throughout Indonesia. The batik-making process, as illustrated in **Figure 1**, highlights the typical production sequence in Giriloyo: (1) preparation of wax (*malam*), (2) manual application of wax patterns on fabric, (3) dyeing using either chemical or natural dyes, and (4) open-air drying of batik cloths. This process, while traditional, has undergone gradual transformation in terms of material choices, waste management awareness, and energy efficiency, driven by increased stakeholder collaboration (Vitasari, 2024). For replication, key criteria include that a customary batik heritage exists, existing production methods highly impact the environment, and locals are interested in sustainable innovation, such as identifying Laweyan (Solo), Lasem, Trusmi (Cirebon), and Pekalongan as priority sites for future adoption. These locations are known quite for their rich cultural heritage in batik-making and face similar environmental challenges, which makes them ideal candidates for scaling the Giriloyo model. The core components, like the low-cost treatment technology in addition to participatory planning, are maintained within the replication strategy. It also involves adapting the model to local socio-economic conditions as well as gender-inclusive empowerment (Amandaria et al., 2025). Training and community exchanges with digital toolkits will transfer knowledge through mechanisms that are supporting implementation at these sites (Zamiri & Esmaeili, 2024). Collaborative partnerships between local governments, academic institutions, NGOs, together with artisan groups sustain long-term impact while being important (Davelaar & Dickson, 2021). Across this map are visualizations of the geographic spread of potential replication sites for the Giriloyo model. It also highlights Laweyan (Solo), Lasem, Trusmi (Cirebon), and Pekalongan since they are considered batik production centres throughout Java.

Fig. SEQ Fig._ * ARABIC 1. Traditional Batik Production Process in Giriloyo: From Wax Preparation to Drying Stage

IV. CONCLUSION

This study demonstrates that the integration of Cleaner Production (CP) principles and Circular Economy (CE) approaches significantly enhances the sustainability of small-scale batik industries. The implementation of low-cost communal wastewater treatment systems in Giriloyo Batik Village resulted in substantial reductions in pollutant loads, including COD (83.7%), BOD (88.2%), TSS (88.0%), and Pb (90.6%), effectively meeting the national environmental quality standards set by the Ministry of Environment and Forestry. The use of nature-based treatment technologies such as phytoremediation with *Eichhornia crassipes* and natural coagulants from *Moringa oleifera* proved to be both effective and economically viable for artisanal-scale operations. In addition to environmental outcomes, the initiative generated positive socio-economic impacts through creative recycling businesses that valorized batik waste into high-value products. These activities not only created employment opportunities and increased local income but also empowered women as key actors in sustainable enterprise. Financial indicators, including a Return on Investment (ROI) of 14 months and a Net Present Value (NPV) of Rp 185 million, confirmed the economic feasibility of the model. Moreover, behavioral change was evident among local artisans, as 85% adopted cleaner practices, and 90% completed environmental training. The model's scalability is supported by strong community engagement, institutional capacity-building, and replication readiness, with identified potential sites in Laweyan (Solo), Lasem, Trusmi (Cirebon), and Pekalongan. Knowledge transfer mechanisms and stakeholder collaboration including government bodies, universities, NGOs, and SMEs will be essential to sustaining and expanding the model's impact. Furthermore, the Giriloyo case provides a replicable and inclusive model of sustainable batik production that aligns with several SDGs. The integration of environmental engineering, economic innovation, and social empowerment offers a holistic pathway toward eco-cultural resilience in Indonesia’s artisanal industries.

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