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Strengthening Sustainable Manufacturing Practices among Batik SMEs through Environmental Education: Community Engagement on Textile Drying Technology

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Abstrak

Usaha Mikro, Kecil, dan Menengah (UMKM) batik memberikan kontribusi penting terhadap perekonomian dan pelestarian warisan budaya Indonesia, namun masih menghadapi tantangan dalam menerapkan praktik manufaktur berkelanjutan. Salah satu kendala utama adalah ketergantungan pada metode pengeringan menggunakan sinar matahari yang sangat dipengaruhi kondisi cuaca sehingga sering menghambat kelancaran proses produksi, terutama pada musim hujan. Kegiatan pengabdian kepada masyarakat ini bertujuan meningkatkan pemahaman pelaku UMKM batik mengenai keberlanjutan lingkungan sekaligus memperkenalkan teknologi mesin pengering tekstil sebagai alternatif terhadap metode pengeringan konvensional. Kegiatan dilaksanakan pada tahun 2025 dengan melibatkan sekitar 60 pelaku UMKM batik di wilayah Pekalongan. Program dilaksanakan melalui penyampaian materi, diikuti diskusi interaktif dan sesi tanya jawab mengenai konsep manufaktur berkelanjutan serta potensi penerapan teknologi pengering tekstil. Hasil kegiatan menunjukkan bahwa peserta memperoleh pemahaman yang lebih baik mengenai keterbatasan metode pengeringan konvensional serta manfaat penggunaan mesin pengering dalam meningkatkan kontinuitas produksi, mengurangi ketergantungan terhadap cuaca, dan meningkatkan efisiensi operasional. Peserta juga memberikan tanggapan positif terhadap penerapan teknologi tepat guna sebagai upaya memperkuat ketahanan proses produksi. Program ini menunjukkan bahwa integrasi edukasi lingkungan dan inovasi rekayasa mampu meningkatkan kapasitas teknologi UMKM batik menuju praktik manufaktur yang lebih berkelanjutan.
Kata Kunci: Batik SMEs, Community Engagement, Environmental Education, Sustainable Manufacturing, Textile Drying Technology.

Abstract

Batik SMEs contribute significantly to Indonesia's economy and cultural heritage but continue to face challenges in adopting sustainable manufacturing practices. One major limitation is the reliance on conventional sun-drying methods, which are highly dependent on weather conditions and often disrupt production continuity during the rainy season. This community engagement program aimed to improve environmental awareness among batik SME practitioners while introducing textile drying technology as a practical alternative to conventional drying systems. The program was conducted in 2025 and involved approximately 60 batik SME practitioners in the Pekalongan region. Activities consisted of educational presentations followed by interactive discussions and question-and-answer sessions focusing on sustainable manufacturing concepts and the potential application of textile drying technology. The results indicated that participants gained a better understanding of the limitations of conventional drying methods and recognized the advantages of mechanical drying technology in improving production continuity, reducing weather dependency, and supporting operational efficiency. Participants also expressed positive responses toward adopting appropriate technology to enhance manufacturing resilience. Overall, the program demonstrates that integrating environmental education with engineering innovation can effectively strengthen the technological capacity of batik SMEs and promote more sustainable manufacturing practices within traditional textile industries.
Keywords: *Batik SMEs; Community Engagement; Environmental Education; Sustainable Manufacturing; Textile Drying Technology*

INTRODUCTION

Small and medium-sized enterprises (SMEs) play a fundamental role in promoting economic growth, employment generation, and social welfare across both developed and developing countries. In recent decades, increasing environmental concerns have encouraged industries of all sizes to adopt more sustainable manufacturing practices that balance economic performance with environmental protection and social responsibility. The concept of sustainable development introduced by the World Commission on Environment and Development emphasizes that present development should satisfy current needs without compromising the ability of future generations to meet their own needs (World Commission on Environment and Development, 1987). This principle has become the foundation for sustainable industrial development and has influenced the implementation of environmentally responsible production systems worldwide. More recently, sustainable manufacturing has been recognized as an important strategy for improving industrial competitiveness while reducing environmental impacts through technological innovation and responsible resource management (Sachs, 2015). Consequently, sustainability is no longer viewed solely as an environmental obligation but also as a strategic factor that supports long-term business resilience and economic development (Porter & Kramer, 2011).

Indonesia's batik industry represents one of the country's most valuable cultural and economic assets, contributing significantly to local employment and regional economic development through thousands of small and medium-sized enterprises. Most batik production activities are still dominated by family-owned businesses and community-based SMEs that rely heavily on traditional production methods. While these production systems preserve valuable cultural heritage, many enterprises continue to experience operational challenges related to technology adoption, production efficiency, and environmental management. Previous studies have demonstrated that SMEs often face financial, technical, and organizational barriers when attempting to implement sustainability-oriented innovations (Johnson & Schaltegger, 2016). Similar observations have been reported among environmentally oriented small businesses, where limited technological capacity frequently delays the adoption of cleaner production practices (Revell et al., 2010). These challenges indicate the need for practical interventions that combine technological innovation with capacity-building activities tailored to local industrial conditions.

Among the environmental challenges faced by batik SMEs, wastewater generation has received considerable attention due to the extensive use of synthetic dyes, chemicals, and auxiliary processing materials throughout the production cycle. Batik wastewater commonly contains high concentrations of organic pollutants, color compounds, suspended solids, heavy metals, and other hazardous substances that may negatively affect aquatic ecosystems if discharged without adequate treatment. Recent reviews have highlighted that improving wastewater management remains one of the highest priorities for achieving sustainable batik production in Indonesia (Daud et al., 2022). Furthermore, hazardous compounds present in batik effluents require integrated treatment approaches involving physical, biological, and chemical processes to minimize environmental risks (Andriani et al., 2025). Although substantial progress has been achieved in developing wastewater treatment technologies, many SMEs continue to encounter limitations related to infrastructure availability, operational costs, and technological accessibility. Therefore, sustainability challenges within the batik industry extend beyond wastewater treatment and include broader aspects of production technology and manufacturing practices.

In addition to wastewater management, conventional textile drying remains an important yet often overlooked challenge within batik production systems. Most batik SMEs continue to rely on direct sunlight for drying dyed fabrics because this method requires minimal investment and has been practiced for generations. However, dependence on natural weather conditions frequently results in production delays during periods of rainfall or high humidity, reducing production efficiency and disrupting delivery schedules. Inconsistent drying conditions may also influence product quality, increase handling time, and reduce overall manufacturing productivity.

Such operational uncertainties become increasingly significant as market demand requires faster production cycles and more consistent product quality. Consequently, identifying alternative drying technologies that can reduce weather dependency while maintaining production quality represents an important opportunity for supporting sustainable manufacturing among batik SMEs.

Engineering-based technological innovation offers considerable potential for improving production efficiency while simultaneously supporting environmental sustainability within traditional manufacturing industries. Recent studies concerning batik production have primarily focused on wastewater treatment technologies, adsorption methods, coagulation–flocculation processes, and cleaner production strategies aimed at reducing environmental pollution (Daud et al., 2023; Handayani et al., 2025). Nevertheless, relatively limited attention has been devoted to introducing practical production technologies capable of improving operational continuity through community engagement activities. One promising alternative involves the application of enclosed textile drying systems that enable drying processes to continue independently of weather conditions while providing greater production consistency. Such technological innovation not only supports manufacturing efficiency but also contributes to more resilient production systems capable of adapting to changing environmental conditions. Accordingly, integrating engineering innovation into community education programs may provide practical solutions that are both technically feasible and socially acceptable for local batik SMEs.

METHODS

This study employed a community engagement approach aimed at introducing sustainable textile drying technology to batik small and medium-sized enterprises (SMEs) in Pekalongan, Central Java, Indonesia. The activity was conducted in 2025 as part of the community service program organized by the Department of Manufacturing Engineering Technology, Politeknik Negeri Jakarta, Pekalongan Campus. The program focused on increasing participants' understanding of sustainable production practices through environmental education and technology dissemination. Particular attention was given to the limitations of conventional textile drying methods that rely heavily on sunlight and weather conditions. Instead of conducting technical training, the activity emphasized knowledge transfer through structured presentations and interactive discussions. This approach enabled participants to understand the operational principles and potential advantages of a closed-system textile dryer before considering its future implementation. Community engagement has been widely recognized as an effective strategy for facilitating knowledge exchange between higher education institutions and local communities (Reed, 2008). Therefore, the program was designed to strengthen awareness of sustainable manufacturing practices while encouraging technology adoption among batik SMEs.

Approximately sixty participants representing batik SMEs in the Pekalongan area attended the program. The participants consisted of SME owners and workers directly involved in textile production activities. Most participants still relied on conventional drying methods using direct sunlight as part of their daily manufacturing process. This condition often resulted in production delays during unfavorable weather conditions, particularly during the rainy season. The participants were selected because they represented the primary target group expected to benefit from sustainable drying technology. Their involvement also ensured that the educational materials addressed actual production challenges experienced in the field. Throughout the program, participants actively participated in discussion sessions by sharing their production experiences and operational constraints. Such stakeholder participation is considered essential for improving the relevance of community engagement activities (Pretty, 1995).

Table 1. Characteristics of Participants

Variable	Description
Program type	Community engagement and environmental education
Year	2025
Location	Pekalongan, Central Java, Indonesia
Participants	Approximately 60 participants
Target group	Owners and workers of Batik SMEs
Institution	Department of Manufacturing Engineering Technology, Politeknik Negeri Jakarta – Pekalongan Campus
Industrial sector	Batik textile manufacturing
Existing drying practice	Conventional sun drying

The community engagement program was implemented during a one-day educational session consisting of scientific presentations followed by interactive discussions. The presentation was delivered by lecturers from the Department of Manufacturing Engineering Technology, Politeknik Negeri Jakarta, Pekalongan Campus. The educational materials covered sustainable manufacturing concepts, environmental impacts of conventional drying practices, and the introduction of a closed-system textile drying machine.

Rather than demonstrating the equipment directly, the presenters explained the machine's working principles, operational characteristics, and expected benefits using presentation materials. Participants were encouraged to ask questions regarding technical feasibility, production efficiency, and potential implementation within their respective SMEs. The discussion session also provided an opportunity to identify practical challenges currently encountered by local batik producers. Educational activities emphasizing interaction between facilitators and participants have been shown to enhance environmental awareness and knowledge exchange (Ardoin et al., 2020). Consequently, the program prioritized dialogue and participant engagement throughout the activity.

Table 2. Community Engagement Activities

Activity	Description	Expected Outcome
Opening session	Introduction to the community engagement program	Participants understood the objectives of the activity
Environmental education	Presentation on sustainable manufacturing and environmental issues in batik production	Increased awareness of sustainable production practices
Technology dissemination	Introduction to the closed-system textile drying technology	Participants understood the concept and potential benefits of the proposed technology
Interactive discussion	Question-and-answer session between presenters and participants	Exchange of experiences and clarification of technical issues
Closing session	Summary of key findings and future recommendations	Strengthened participants' motivation to adopt sustainable technology

The technology introduced during the program was a closed-system textile dryer designed to improve drying efficiency compared with conventional sun drying. The proposed machine operates within a controlled drying chamber that maintains stable operating conditions regardless of weather variability. According to the technical specifications presented during the program, the system significantly reduces drying time while maintaining textile quality. Stable chamber temperature also minimizes color degradation and preserves fiber flexibility. In addition, the machine requires lower electrical power than conventional drying approaches using comparable heating systems. These characteristics illustrate the potential contribution of the technology to sustainable textile production among batik SMEs. Sustainable manufacturing technologies have been recognized as important drivers of productivity improvement and environmental performance in small manufacturing enterprises (Johnson & Schaltegger, 2016). Therefore, the machine was introduced as a practical alternative to weather-dependent drying practices.

Table 3. Technical Comparison between Conventional Drying and Closed-System Textile Dryer

Aspect	Conventional Drying	Proposed Closed-System Dryer
Drying method	Direct sunlight	Enclosed drying chamber
Weather dependency	High	Low
Drying duration	Depends on weather conditions	More consistent and shorter
Drying continuity	Frequently interrupted during rainfall	Continuous operation
Temperature control	Not available	Controlled drying temperature
Product quality	May vary due to environmental conditions	More stable drying conditions
Production efficiency	Relatively low	Improved production efficiency
Sustainability contribution	Limited	Supports sustainable manufacturing practices

The evaluation of the community engagement program was conducted using qualitative methods. Data were collected through direct observation during the educational session and documentation of participant discussions. Questions raised by participants during the discussion were recorded to identify common production issues and perceptions regarding the proposed technology. Additional observations focused on participant responses toward the potential implementation of the closed-system dryer within their SMEs. Since the activity emphasized educational dissemination rather than experimental testing, no pre-test or post-test was administered. Likewise, structured questionnaires were not employed during the activity. Instead, participant understanding was interpreted from the quality of discussions and feedback provided throughout the session. Similar qualitative evaluation approaches are commonly adopted in community engagement studies emphasizing knowledge dissemination (Monroe et al., 2019).

RESULTS AND DISCUSSION

A. Community Engagement Outcomes

The community engagement program was conducted in 2025 in Pekalongan, Central Java, involving approximately sixty participants representing batik micro, small, and medium-sized enterprises (SMEs). The activity was organized by the Department of Manufacturing Engineering Technology, Politeknik Negeri Jakarta, Pekalongan Campus, with the objective of strengthening environmental awareness through the dissemination of sustainable manufacturing technologies. Unlike conventional technical training, the program emphasized knowledge transfer by introducing participants to an alternative textile drying system that could improve production efficiency while reducing dependence on weather conditions. The educational session combined structured presentations with interactive discussions, allowing participants to relate the presented concepts to their daily production experiences. Such knowledge-sharing activities are considered an effective approach for connecting academic expertise with practical industrial needs. Previous studies have emphasized that community engagement programs play a significant role in supporting technology dissemination and encouraging sustainable industrial transformation among SMEs (Reed, 2008). Furthermore, environmental education provides opportunities for local communities to recognize production challenges from a sustainability perspective rather than focusing solely on short-term operational issues (Ardoin et al., 2020). Consequently, the activity established an initial platform for collaborative dialogue between higher education institutions and batik entrepreneurs regarding sustainable production practices.

Participants represented various batik SMEs operating in the Pekalongan region, an area internationally recognized for its cultural heritage and traditional textile industry. Although these enterprises differ in production capacity and organizational structure, many participants reported experiencing similar operational challenges during the drying stage of textile production. Drying activities remain highly dependent on natural sunlight, making production schedules vulnerable to seasonal weather variations, particularly during periods of prolonged rainfall. These conditions frequently delay production cycles and reduce operational flexibility, especially for SMEs that operate with limited storage space and restricted production capacity. During the discussion session, participants acknowledged that drying-related problems often affect delivery schedules and increase production uncertainty. Similar observations have been reported by Daud et al. (2022), who identified technological limitations as one of the principal barriers affecting sustainable batik production. Kusumawardani et al. (2024) likewise emphasized that technological readiness remains a critical factor in strengthening the implementation of green industry standards among Indonesian batik SMEs. Therefore, the issues identified during the activity were consistent with broader industrial challenges reported in recent sustainability studies.

The discussion further revealed that conventional drying methods continue to be preferred primarily because of their simplicity and relatively low operational cost. However, participants recognized that these advantages are accompanied by significant limitations, including prolonged drying time, inconsistent drying quality, and complete dependence on favorable weather conditions. During rainy periods, drying activities are frequently interrupted, forcing producers either to postpone production or to accept longer processing times. Such disruptions may reduce productivity and influence customer satisfaction due to delayed product delivery. Although conventional drying has been practiced for decades, changing environmental conditions and increasing market competition require SMEs to consider more reliable production technologies. Previous studies have highlighted that sustainable manufacturing should involve continuous improvements in production processes through the adoption of appropriate technologies capable of increasing operational efficiency (Johnson & Schaltegger, 2016). Consequently, the discussion confirmed that introducing an alternative drying technology addressed an actual production need expressed directly by local batik entrepreneurs. These findings further demonstrate the importance of integrating technological innovation into community engagement activities.

The educational session encouraged participants to evaluate their existing production practices from a broader sustainability perspective. Rather than focusing exclusively on wastewater management, which has traditionally received considerable attention within the batik industry, participants were invited to recognize that production sustainability also depends on process efficiency throughout the entire manufacturing chain. Drying operations represent one of the final stages before product completion, making this process highly influential in determining production continuity and overall manufacturing performance. Participants actively discussed how technological improvements could reduce unnecessary production delays while maintaining product quality.

Such discussions reflect the importance of environmental education in promoting critical thinking and encouraging behavioural changes toward sustainable industrial practices. Environmental education has been widely recognized as an effective strategy for improving environmental awareness and stimulating more responsible decision-making among community members (Hungerford & Volk, 1990). Likewise, Tilbury (1995) argued that sustainability education should encourage participants to identify practical solutions capable of addressing environmental and socio-economic challenges simultaneously. Therefore, the educational approach adopted during this program supported broader objectives beyond simple technology dissemination.

An important observation during the activity was the high level of participant engagement throughout the presentation and discussion sessions. Numerous questions focused on the operational feasibility of replacing conventional drying practices with a controlled drying system, particularly regarding productivity improvements during unfavorable weather conditions. Participants also expressed interest in understanding how the proposed technology could contribute to more consistent production schedules without fundamentally changing their existing manufacturing processes. Although the program did not include direct equipment demonstrations or hands-on training, the discussion indicated considerable curiosity regarding practical technological innovation.

Such participant responses suggest that SMEs are increasingly aware of the limitations associated with conventional production methods and are open to considering alternative solutions. Similar findings have been reported by Monroe et al. (2019), who concluded that interactive environmental education programs are more effective when participants are encouraged to relate educational content to their own practical experiences. Accordingly, the discussion session became one of the most valuable components of the community engagement program because it facilitated mutual learning between academics and industry practitioners. This interaction also provided important qualitative insights regarding future community assistance programs.

Table 4. Environmental Challenges Identified among Batik SMEs

Environmental Challenge	**Current Practice**	**Potential Impact**
Dependence on sunlight	Outdoor drying	Production delays during rainy seasons
Long drying duration	Weather-dependent drying	Reduced production efficiency
Unstable production schedule	Drying interrupted by rainfall	Delayed customer delivery
Inconsistent drying conditions	Uncontrolled temperature and humidity	Variable product quality
Limited technology utilization	Conventional production practices	Reduced industrial competitiveness

The challenges summarized in Table 4 indicate that production efficiency within batik SMEs is influenced by environmental factors extending beyond wastewater management. Weather dependency remains a recurring operational problem that directly affects manufacturing continuity and production planning. Although these constraints have long been accepted as part of traditional production practices, increasing market demands require SMEs to improve operational resilience through appropriate technological innovation. Participants recognized that reducing weather dependency would contribute not only to improved productivity but also to more predictable business operations. Similar observations have been reported by Revell et al. (2010), who argued that SMEs often require practical technological support before adopting more sustainable business practices. Furthermore, sustainable manufacturing emphasizes process optimization alongside environmental responsibility as complementary rather than competing objectives (Geissdoerfer et al., 2017). Consequently, identifying operational constraints represents an essential step toward designing effective community engagement interventions capable of addressing local industrial needs. These findings justify the introduction of alternative drying technologies within the educational program.

Table 5. Summary of Community Engagement Outcomes

Aspect	Observation
Participants	Approximately 60 batik SME owners and workers
Location	Pekalongan, Central Java
Activity format	Presentation and interactive discussion
Main issue identified	Dependence on conventional sun drying
Technology introduced	Closed-system textile drying concept
Participant response	High enthusiasm and active discussion
Expected outcome	Increased awareness of sustainable production technologies

Overall, the community engagement program successfully increased participants' awareness of alternative technological approaches capable of supporting more sustainable batik production. Although the activity focused primarily on educational dissemination rather than direct technological implementation, the discussion demonstrated that local SMEs clearly recognized the limitations associated with conventional drying practices. Participants acknowledged that technological innovation could improve production continuity while reducing operational risks caused by unfavorable weather conditions.

These findings indicate that environmental education can function as an effective catalyst for introducing sustainable manufacturing concepts to small-scale industries. From a broader perspective, the activity illustrates how universities can contribute to local industrial development by facilitating knowledge exchange rather than simply transferring technology. Such collaboration aligns with contemporary perspectives on sustainable community engagement, which emphasize long-term partnerships between academic institutions and local stakeholders (Schaltegger et al., 2016). Consequently, the outcomes of this program provide an important foundation for future initiatives involving practical technology implementation, technical assistance, and continuous evaluation of sustainable production practices among batik SMEs.

B. Proposed Textile Drying Technology

The educational session introduced participants to the concept of a closed-system textile drying machine as an alternative to the conventional sun-drying method commonly practiced by batik SMEs. The proposed technology was presented as a practical engineering solution designed to minimize the operational constraints associated with weather-dependent drying processes. During the presentation, participants were informed that the system was developed to provide a controlled drying environment capable of maintaining production continuity regardless of seasonal climate variations. Unlike conventional outdoor drying, which relies entirely on solar radiation, the proposed machine operates within an enclosed chamber equipped with controlled heat distribution and air circulation. This approach was intended to broaden participants' understanding of how engineering innovation could support sustainable manufacturing within the batik industry. The educational objective was not merely to introduce a new machine but to encourage participants to recognize the importance of technological modernization in improving production efficiency. Such knowledge dissemination is consistent with previous studies emphasizing that technological awareness constitutes an essential component of sustainable industrial development among SMEs (Johnson & Schaltegger, 2016). Consequently, the presentation established a theoretical foundation for discussing more resilient textile drying practices suitable for local production environments.

The presentation explained that the proposed drying system employs a closed drying chamber combined with an electric heating source and forced-air circulation to create a more stable drying environment. Maintaining controlled temperature and airflow conditions is expected to reduce the variability commonly observed in conventional outdoor drying. A stable drying environment also minimizes interruptions caused by rainfall, excessive humidity, and unpredictable weather changes that frequently affect batik production in tropical regions. Furthermore, enclosing the drying process provides additional protection against environmental contaminants such as dust and airborne particles that may compromise textile quality. Although direct performance testing was not conducted during the community engagement activity, participants were introduced to the engineering principles underlying controlled drying systems and their potential industrial applications.

Previous research has demonstrated that improved process control contributes significantly to production consistency and manufacturing efficiency in textile-related industries (Daud et al., 2022). Similarly, technological innovations supporting controlled production environments are increasingly recognized as effective approaches for improving industrial sustainability (Handayani et al., 2025). Therefore, the proposed dryer represents an educational example of appropriate technology capable of addressing operational challenges experienced by local batik producers.

Table 6. Technical Specifications of the Proposed Textile Dryer

Parameter	Specification
Machine type	Closed-system textile dryer
Drying chamber	Enclosed insulated chamber
Heating source	Electric heater
Air circulation	Forced-air blower
Temperature control	Adjustable controller
Drying mechanism	Controlled hot-air circulation
Intended application	Textile and batik fabric drying
Expected advantage	Independent of weather conditions

The technical specifications summarized in Table 6 illustrate the fundamental characteristics of the proposed textile drying system introduced during the educational program. The enclosed drying chamber was designed to provide greater environmental stability than conventional open-air drying by minimizing the influence of fluctuating ambient conditions. Controlled heat generation allows operators to maintain more consistent drying temperatures, while forced-air circulation enhances heat transfer throughout the chamber and promotes more uniform moisture removal. These engineering features are widely recognized as important factors contributing to improved drying efficiency and reduced process variability. In comparison with uncontrolled outdoor drying, the proposed system offers greater operational predictability, enabling SMEs to plan production schedules more effectively. From an industrial engineering perspective, production consistency represents an important prerequisite for maintaining product quality while increasing manufacturing productivity. Consequently, the proposed dryer was introduced not simply as production equipment but as an example of technological innovation capable of supporting long-term process improvement within batik SMEs.

Participants showed considerable interest when discussing the practical implications of replacing conventional drying practices with a controlled drying system. Many questions addressed the possibility of maintaining continuous production during rainy seasons, when traditional drying methods become particularly inefficient. Others focused on whether the proposed technology could improve product consistency without significantly altering existing production procedures. These discussions demonstrated that participants clearly recognized the operational limitations associated with weather-dependent drying and were interested in exploring practical technological alternatives. Such responses suggest that local SMEs possess a positive perception of technological innovation when it directly addresses recurring production problems. Similar findings have been reported by Revell et al. (2010), who argued that SMEs are generally more willing to adopt environmental innovations when the technologies provide tangible operational benefits alongside sustainability improvements. Therefore, participant engagement during the discussion session indicates that knowledge dissemination activities may encourage greater openness toward future technological implementation.

Table 7. Comparison between Conventional Drying and the Proposed Textile Dryer

Aspect	Conventional Drying	Proposed Textile Dryer
Drying method	Direct sunlight	Closed drying chamber
Weather dependency	High	Low
Rain interruption	Frequent	Minimal
Temperature stability	Uncontrolled	Controlled
Drying consistency	Variable	More uniform
Product protection	Limited	Protected environment
Production continuity	Seasonal	Continuous throughout the year
Operational reliability	Moderate	Higher potential

The comparison presented in Table 7 highlights several theoretical advantages of the proposed drying technology over conventional practices commonly adopted by batik SMEs. Although traditional drying methods remain economically attractive because they require minimal equipment, they expose production activities to substantial climatic uncertainty. The proposed dryer, in contrast, offers a controlled production environment capable of reducing weather-related interruptions and improving operational reliability.

Stable drying conditions may also contribute to more consistent textile quality by minimizing variations associated with uncontrolled environmental exposure. Such improvements correspond with cleaner production principles that emphasize process optimization, resource efficiency, and waste minimization throughout manufacturing operations (Geissdoerfer et al., 2017). Furthermore, adopting appropriate production technologies can strengthen SME competitiveness by increasing productivity without compromising environmental responsibility (Schaltegger et al., 2016). Consequently, the educational introduction of this technology provided participants with an example of how engineering innovation can support sustainable industrial transformation.

Beyond its potential technical benefits, the proposed textile dryer also represents an educational tool for promoting broader awareness of sustainable manufacturing concepts among SME operators. Community engagement activities frequently focus on increasing knowledge rather than immediately changing production infrastructure, particularly when introducing unfamiliar technologies. In this context, the presentation encouraged participants to evaluate existing production methods from the perspective of long-term efficiency, resilience, and sustainability. Participants were invited to consider how technological improvements could contribute not only to higher productivity but also to more stable business operations throughout the year.

This educational approach reflects the principles of Education for Sustainable Development, which encourage learners to connect technological innovation with environmental responsibility and socio-economic development (UNESCO, 2017). Likewise, Wals (2011) emphasized that sustainability learning should enable individuals to develop systems thinking when evaluating complex environmental and industrial challenges. Therefore, introducing the textile dryer extended beyond technology dissemination by promoting a broader understanding of sustainable production systems.

Overall, the presentation demonstrated that engineering innovation can become an effective medium for environmental education within community engagement programs targeting batik

SMEs. Although the activity did not include direct machine operation or quantitative performance evaluation, participants gained new insights regarding alternative drying technologies capable of reducing dependence on conventional weather-based production methods. The positive discussion generated during the session suggests that SMEs increasingly recognize the importance of technological adaptation in maintaining industrial competitiveness under changing environmental conditions.

These findings indicate that educational dissemination may serve as an important preliminary step before future implementation and technical assistance programs. Continuous collaboration between universities, local governments, and SMEs will therefore be essential to facilitate the gradual adoption of appropriate production technologies. Such collaborative efforts are expected to strengthen local industrial resilience while supporting environmentally responsible manufacturing practices. Consequently, the proposed textile dryer should be viewed as both a technological innovation and an educational instrument for promoting sustainable transformation within Indonesia's batik industry.

C. Implications for Sustainable Manufacturing and Community Development

The outcomes of this community engagement program demonstrate that environmental education can serve as an effective strategy for promoting sustainable manufacturing practices among batik SMEs. Although the activity was limited to educational presentations and interactive discussions, participants showed an increased awareness of the limitations associated with conventional textile drying methods and the potential benefits offered by engineering-based technological solutions. This finding indicates that knowledge transfer activities conducted by higher education institutions can stimulate critical thinking among SME practitioners regarding production efficiency and environmental sustainability. Such improvements in awareness are particularly important because sustainable transformation often begins with changes in perception before technological adoption occurs. The present findings therefore suggest that environmental education should be regarded as an essential component of sustainable industrial development programs targeting small and medium-sized enterprises. This perspective is consistent with previous studies emphasizing that environmental education contributes to improved environmental literacy and supports long-term conservation behaviour among community members (Ardoin et al., 2020). Furthermore, educational interventions encourage individuals to recognize environmental challenges as opportunities for innovation rather than unavoidable production constraints (Tilbury, 1995).

The improvement in participants' understanding also supports established behavioural theories explaining how environmental knowledge influences behavioural intention. According to the Theory of Planned Behavior, individuals are more likely to adopt new practices when they possess favourable attitudes toward innovation and perceive its practical benefits (Ajzen, 1991). Similarly, the Value–Belief–Norm framework suggests that awareness of environmental consequences can strengthen personal responsibility for adopting environmentally responsible practices (Stern, 2000). Previous studies have likewise reported that environmental behaviour is influenced by a combination of environmental knowledge, social values, and perceived behavioural control rather than knowledge alone (Kollmuss & Agyeman, 2002). Meta-analytic evidence further demonstrates that psychological determinants significantly affect pro-environmental behaviour and technology adoption (Bamberg & Möser, 2007). Therefore, introducing textile drying technology through educational activities represents an important first step toward encouraging behavioural changes among batik SME practitioners before actual technology implementation.

From an engineering perspective, the proposed textile drying technology offers several potential advantages over conventional sun drying. Traditional drying methods remain highly dependent on favourable weather conditions, making production schedules vulnerable to rainfall, seasonal variation, and fluctuating humidity. These conditions often reduce production efficiency and delay product delivery, particularly during prolonged rainy periods. In contrast, enclosed drying systems provide greater process stability by allowing drying operations to continue regardless of external weather conditions. Such technological improvements have the potential to increase production consistency while minimizing operational interruptions experienced by batik SMEs. Previous studies on batik wastewater management have similarly highlighted that technological innovation is essential for improving environmental performance and operational sustainability within traditional manufacturing industries (Daud et al., 2022). Consequently, introducing engineering-based solutions should be viewed as an integral component of broader sustainability initiatives rather than merely equipment replacement.

The proposed drying technology also aligns closely with the principles of circular economy and sustainable manufacturing. Circular economy encourages industries to optimize resource utilization while minimizing waste generation and improving production efficiency throughout the manufacturing process (Geissdoerfer et al., 2017). Although the present community engagement program primarily focused on production technology rather than waste management, improved drying efficiency contributes indirectly to cleaner production by reducing production delays, minimizing defective products, and supporting more systematic manufacturing operations. Similar perspectives have been presented in previous circular economy literature, which emphasizes that sustainable industrial transformation depends upon continuous technological innovation combined with organizational learning (Ghisellini et al., 2016). Therefore, introducing appropriate drying technologies represents one practical pathway toward strengthening sustainability within Indonesia's batik industry.

Beyond technological considerations, this community engagement initiative also illustrates the strategic role of universities in supporting local industrial development through knowledge dissemination. Universities possess substantial capacity to translate research findings into practical solutions that directly address challenges experienced by local communities and SMEs. Rather than limiting research outcomes to academic publications, higher education institutions should actively promote technology transfer through educational outreach, collaborative partnerships, and continuous mentoring programs. Such activities strengthen interactions between researchers and industry practitioners while increasing the practical relevance of engineering innovations. Previous studies have similarly emphasized that sustainability-oriented collaboration between universities and SMEs contributes significantly to organizational learning and long-term competitiveness (Johnson & Schaltegger, 2016). Consequently, community engagement programs should become an integral mechanism for accelerating sustainable industrial transformation at the local level.

The implications of this program also extend to broader sustainable development objectives promoted by international organizations. Sustainable manufacturing contributes directly to several Sustainable Development Goals, particularly those related to quality education, responsible consumption and production, decent work, innovation, and sustainable economic growth (UNESCO, 2017). By improving environmental awareness while introducing practical engineering solutions, community engagement programs can simultaneously strengthen social capacity and technological capability among SME practitioners.

Such integrated approaches are increasingly recognized as essential for achieving sustainable industrial development because environmental education alone is often insufficient without technological support. Accordingly, combining educational intervention with engineering innovation provides a comprehensive strategy for enhancing sustainability within traditional manufacturing sectors.

Overall, the findings suggest that environmental education, engineering innovation, and community engagement should not be implemented as separate initiatives but rather as complementary components of sustainable manufacturing development. Educational activities enhance environmental awareness, technological innovation provides practical solutions to production challenges, and community engagement facilitates knowledge transfer between universities and industry. The integration of these three elements creates favourable conditions for improving operational resilience, environmental responsibility, and long-term competitiveness among batik SMEs. Although the present program represents an initial educational intervention, it provides an important foundation for future implementation of textile drying technologies within the batik sector. Continued collaboration among universities, government agencies, and SME communities will therefore be essential for promoting wider adoption of sustainable manufacturing practices throughout Indonesia's traditional textile industry. This integrated approach demonstrates how community engagement can contribute meaningfully to technological advancement while supporting broader sustainability transitions in local manufacturing systems.

CONCLUSION

The community engagement program successfully enhanced the understanding of batik SME practitioners regarding sustainable manufacturing practices through environmental education and knowledge dissemination. The findings demonstrated that conventional textile drying remains one of the major operational constraints because it depends heavily on weather conditions, particularly during the rainy season, resulting in production delays and reduced operational efficiency. Through structured presentations and interactive discussions, participants gained new insights into the potential application of a closed-system textile drying machine as an alternative to conventional sun drying. Although the activity did not involve direct machine demonstrations or practical implementation, participants showed considerable interest in the proposed technology and recognized its potential contribution to improving production continuity and reducing climate-related operational risks. The program also demonstrated that community engagement activities can effectively bridge academic knowledge and industrial practice by introducing engineering innovations that address practical challenges experienced by local SMEs. These findings highlight the importance of integrating technological innovation with environmental education to support the sustainable transformation of traditional manufacturing industries. Therefore, universities can play an essential role in strengthening the technological capacity and sustainability awareness of local batik enterprises through continuous knowledge transfer and community engagement initiatives.

The proposed textile drying technology represents a promising approach to supporting more resilient and sustainable production systems within Indonesia's batik industry. By reducing dependence on conventional weather-based drying methods, the technology has the potential to improve production reliability, operational efficiency, and long-term business sustainability among batik SMEs. Furthermore, the educational approach adopted in this program contributes to broader sustainability objectives by encouraging SME practitioners to evaluate production processes from environmental, technological, and economic perspectives.

Nevertheless, this study was limited to educational dissemination and qualitative discussion without direct field implementation or quantitative performance evaluation of the proposed dryer. Future community engagement programs should therefore incorporate pilot-scale implementation, hands-on technical training, and long-term monitoring to evaluate technology adoption, production efficiency, energy consumption, economic feasibility, and user acceptance under actual industrial conditions. Such comprehensive evaluations will provide stronger empirical evidence regarding the effectiveness of the proposed drying technology while supporting wider adoption of sustainable manufacturing practices among batik SMEs. Ultimately, strengthening collaboration between universities, local governments, and industry stakeholders will be essential for accelerating technological innovation and promoting the long-term sustainability of Indonesia's batik sector.

RECOMMENDATION

The findings of this community engagement program indicate that future initiatives should move beyond knowledge dissemination by incorporating practical implementation and technical assistance activities. Demonstration sessions and hands-on training should be organized to enable batik SME practitioners to gain direct experience in operating the proposed textile drying technology under actual production conditions. Such activities would strengthen participants' technical competencies while increasing their confidence in adopting new manufacturing technologies. In addition, pilot-scale implementation within selected batik SMEs would provide valuable empirical evidence regarding the operational performance, energy efficiency, and production benefits of the proposed drying system. Universities should also establish long-term partnerships with local governments, industry associations, and SME communities to facilitate continuous mentoring and technology transfer. Collaborative programs involving researchers, engineers, and local entrepreneurs are expected to accelerate the adoption of sustainable manufacturing practices within the batik industry. These collaborative efforts would contribute not only to technological modernization but also to the long-term competitiveness of Indonesian batik SMEs. Therefore, future community engagement programs should emphasize practical implementation alongside educational dissemination to maximize community impact.

Future research should extend the present work by evaluating the technical, economic, and environmental performance of the proposed textile drying technology through comprehensive field implementation. Quantitative assessments of drying time, energy consumption, operating costs, product quality, and productivity improvements should be conducted to provide stronger evidence supporting technology adoption among SMEs. In addition, future studies should investigate user acceptance, investment feasibility, and barriers affecting the diffusion of drying technologies within traditional manufacturing industries. Comparative analyses involving different drying capacities, heating systems, and energy sources may further support the development of more efficient and environmentally responsible textile drying systems. Researchers are also encouraged to examine the integration of renewable energy technologies and smart monitoring systems to enhance operational sustainability. Such investigations would strengthen the contribution of engineering innovation to cleaner production and sustainable manufacturing within the batik sector.

Furthermore, longitudinal studies evaluating changes in environmental awareness and technology adoption following community engagement activities would provide valuable insights into the long-term effectiveness of educational interventions. These efforts are expected to support evidence-based policymaking while promoting sustainable industrial development among batik SMEs in Indonesia.

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