

Assessing environmental impacts in batik production through life cycle assessment

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Abstract. This study investigates a small and medium enterprise (SME) in the batik industry located in Pekalongan, Indonesia. The enterprise faces significant challenges due to pollution generated by its production waste, raising serious environmental concerns about air and water quality in the surrounding areas. The research aims to evaluate the environmental impacts of batik production using the Life Cycle Assessment (LCA) method. Findings reveal that the most substantial environmental impact occurs in the Marine Ecotoxicity category. This impact is primarily attributed to the use of chemicals such as sulfuric acid, sodium hydroxide, and sodium carbonate, which dissolve in large quantities of water, leading to marine ecosystem pollution. The study highlights the need for continuous process improvements to achieve more sustainable and environmentally responsible production practices. These improvements align with Sustainable Development Goal (SDG) 12, which focuses on responsible consumption and production.

1 Introduction

Batik, a traditional Indonesian textile art, holds a significant cultural and economic role in the country. Recognized by UNESCO as a Masterpiece of the Oral and Intangible Heritage of Humanity in 2009, batik is deeply embedded in Indonesian heritage and identity. Batik has been an integral part of Indonesian culture for centuries, with various regions in Indonesia showcasing unique styles and motifs, such as Tegal, Pekalongan, Cirebon, and Yogyakarta, among others [1]. This art form has been seamlessly integrated into various aspects of Indonesian life, from traditional attire to modern fashion. This highlights its versatility and adaptability to contemporary trends [2].

The increasing interest in batik is shown by the high sales trend not only domestically but also internationally. Innovations in design and the incorporation of contemporary fashion trends have helped Batik maintain its relevance among younger generations. Internationally, batik continues to gain popularity, with efforts to increase its global market presence. Research indicates that enhancing the export value of batik through improved product quality and strategic marketing is essential for competing in the global market [3].

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The production process of batik printing cloth involves a series of stages, including the weighing of raw materials, the mixing of printing raw materials, the printing process, the temporary drying of the fabric, the dyeing of the fabric, and the washing and drying of the fabric. Each stage of the process requires inputs in the form of energy, materials, and resources, and also generates outputs in the form of semi-finished materials, waste, and emissions. Figure 1 illustrates the process stages along with the inputs and outputs of each production process.

The utilization of fossil-fuelled electrical energy has the potential to increase global warming, as it releases greenhouse gas (GHG) emissions in the form of carbon dioxide (CO₂), sulfur oxides (SO₂) and nitrogen oxides (NO) [4]. The utilization of sodium hydroxide (NaOH), also known as alkali and caustic soda, in the batik cloth washing process, has the potential to have a detrimental impact on human health and the environment due to its toxicity and corrosive properties. Furthermore, the utilization of NaOH results in the deterioration of water quality, including the eutrophication of water bodies, acidification, and the toxicity of aquatic ecosystems [5].

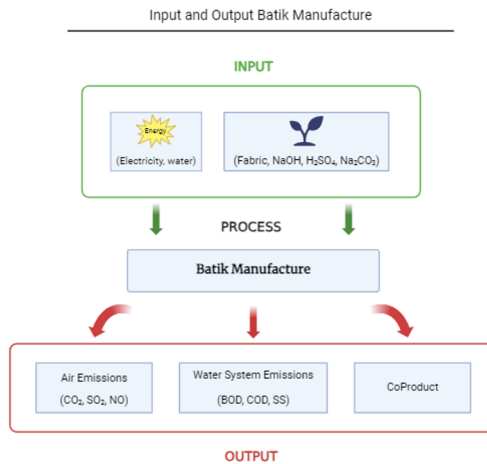


Fig. 1. Input and Output Batik Manufacture

Life Cycle Assessment (LCA) is a methodology for identifying and interpreting the environmental impacts associated with each production process. LCA is a method of evaluating the potential environmental impacts that occur due to the use of resources throughout the life cycle of a product [6]–[10]. This approach can also serve to identify potential strategies for enhancing the environmental performance of a product or system in the near term. Furthermore, studies employing LCA have a long-term orientation by developing a technology known as prospective LCA [11]. The integration of LCA into the batik industry is pivotal for aligning production practices with the Sustainable Development Goals (SDGs), particularly SDG 12 (Responsible Consumption and Production). By reducing greenhouse gas emissions and other pollutants through eco-efficiency strategies, batik producers can significantly lower their environmental impact.

Despite the rich cultural heritage and economic significance of batik in Indonesia, there are still very few comprehensive studies that assess the environmental impact of its production process using LCA. Although the cultural and economic dimensions of batik have been extensively explored, the environmental aspects, especially the implications of current production practices on sustainability, remain under-researched, particularly in batik small, and medium-sized enterprises (SMEs). The existing literature has highlighted the adverse impacts of certain chemicals and fossil fuel-based energy on the environment. However, there

is a lack of empirical data and adequate analysis focusing on specific stages of the batik production process. This gap indicates a critical need for research that not only assesses the environmental impacts but also proposes practical solutions to make batik production more sustainable. Therefore, the objective of this research is to assess the environmental impact of the batik production process.

This research contributes to the field of environmental sustainability in traditional textile production, specifically within the context of Indonesian batik. Firstly, it provides a detailed LCA of the batik production process, identifying the environmental impacts at each stage, from raw material procurement to the final product. This comprehensive evaluation helps to quantify the specific contributions of various inputs and outputs to environmental degradation, particularly in terms of greenhouse gas emissions and water quality deterioration, which is a critical component of green management [12].

2 Material and Methods

This research is based on a case study of a small and medium enterprise (SME) in the batik industry in Pekalongan, Indonesia. The company's challenges are compounded by the pollution caused by its production waste. It led to environmental concerns regarding air and water pollution in the area surrounding Pekalongan. Therefore, this research is proposed to assess the environmental impacts of Batik production by employing the LCA method. This method typically follows four main phases as defined by ISO 14040 and ISO 14044 standards:

1. **Goal and Scope Definition**
This initial phase involves defining the objective of the LCA, the system boundaries, and the functional unit. It sets the stage for data collection and analysis, ensuring that all subsequent steps are aligned with the study's goals [13].
2. **Life Cycle Inventory Analysis (LCI)**
The LCI phase focuses on data collection regarding all inputs and outputs associated with the product or process. This includes materials, energy, emissions, and waste. The quality and comprehensiveness of the data collected significantly impact the reliability of the LCA results [14].
3. **Life Cycle Impact Assessment (LCIA)**
In this phase, the data from the LCI is analyzed to evaluate the potential environmental impacts. Various impact categories such as global warming, acidification, and resource depletion are considered. Methods such as ReCiPe are commonly used to quantify these impacts [15].
4. **Interpretation**
The final phase involves interpreting the results to make informed decisions. It includes identifying significant issues, conducting sensitivity and uncertainty analyses, and drawing conclusions that are coherent with the goal and scope defined initially [16].

3 Results and Discussion

The batik production process encompasses several subsequent stages, including printing, dyeing, washing, and drying. The objective of this study is to assess the environmental impact of the batik production process using the Life Cycle Assessment (LCA) method. In this study, the inputs analyzed include the raw materials used in the production of batik cloth. The analysis concentrated on the materials utilized at each stage of the batik manufacturing

process. The environmental impact of the batik production process was calculated using the Gabi software.

The results of the calculations performed using the Gabi software indicate that the batik-making process has a negative impact on the environment. This is illustrated in Figure 2. The data required to evaluate the environmental impacts were collected by predetermined limits. The batik-making process is conducted for one day until the drying stage is completed; the production yield per process is 200 cloths.

The scope of this analysis encompasses the entirety of the production process, which is called gate-to-gate. It encompasses all stages of processing and utilization of raw materials until the production process is complete. This analysis does not extend to the sewing stage. The data processing diagram for the SMEs utilizing Gabi software is referred in Figure 3. The diagram includes the material inputs of the SMEs' batik process, the stages of the batik process, and the outputs is the results in the form of products and waste from the batik process.

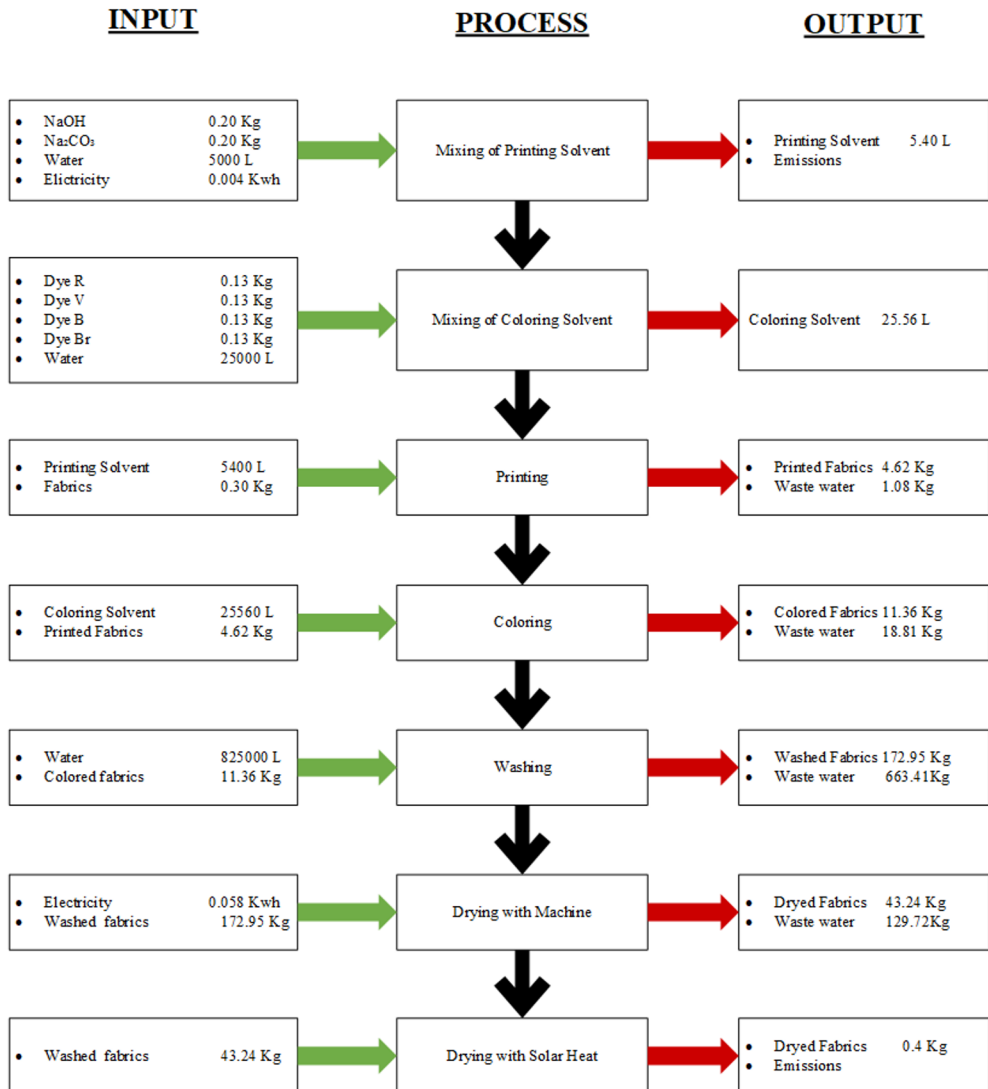


Fig. 2. Input, process, and output inventory in Batik printing production

The Life Cycle Impact Assessment (LCIA) represents the third stage in the life cycle analysis process. Its objective is to classify and assess environmental impacts based on input data obtained in the second stage, namely the Life Cycle Inventory (LCI). In this study, an environmental impact analysis was conducted utilizing the Gabi software. The input data, which has been compiled under the life cycle inventory, is entered into Gabi software, which then produces a diagram that describes the environmental impact of the overall batik production process.

The diagram provides an overview of the general system being studied and illustrates the extent to which each stage of the process affects the system as a whole. The environmental impact categories evaluated by the Gabi software encompass various critical aspects, as illustrated in Figure 4. The results of this analysis assess how each stage in the batik production process contributes to the various environmental impacts identified. For example, the category of health damage indicates the extent to which the production process results in the generation of hazardous substances with the potential to pose a risk to human health. In addition, the ecosystem pollution category enables an understanding of the potential impact on aquatic life and the overall quality of the ecosystem.

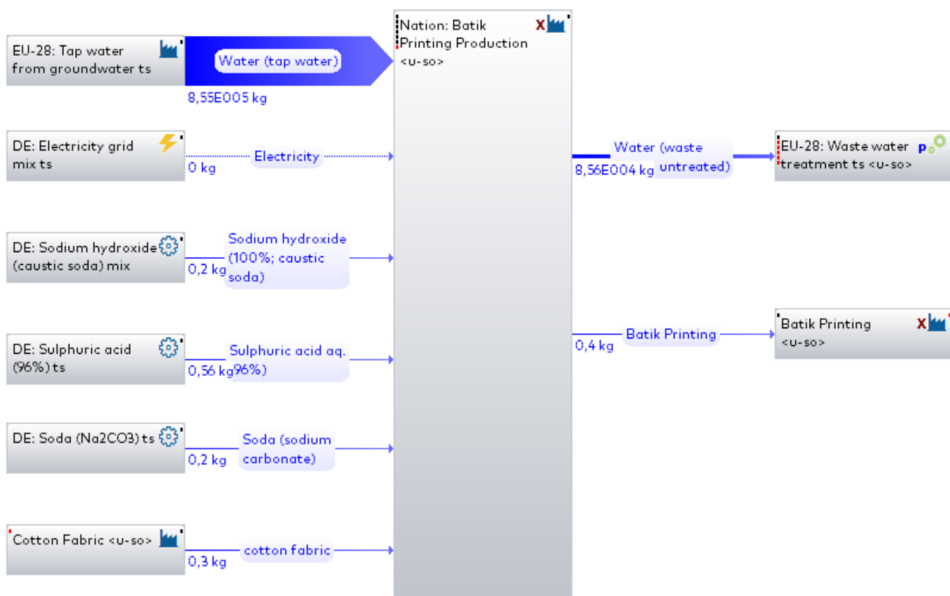


Fig. 3. Batik printing production diagram

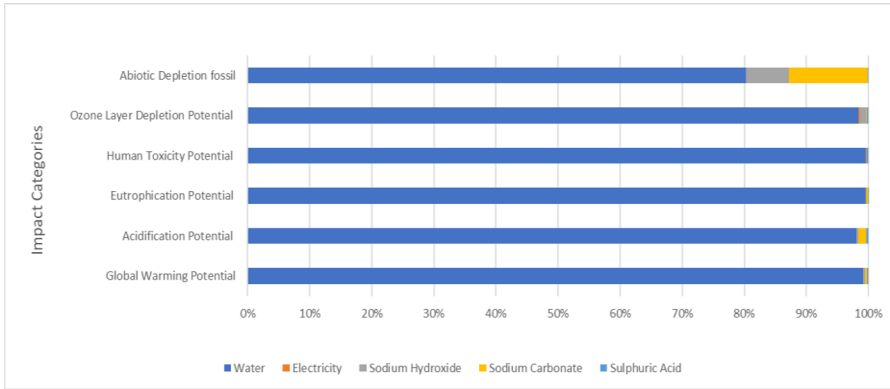


Fig. 4. LCIA impact categories

Figure 5 illustrates the environmental impact of the Batik process in small and medium-sized enterprises (SMEs). The analysis indicates that the greatest environmental impact is observed in the Marine Ecotoxicity category. This is due to the utilization of chemicals such as sulphuric acid, sodium hydroxide, and sodium carbonate, which dissolve in large quantities of water, thereby contributing to the pollution of marine ecosystems.

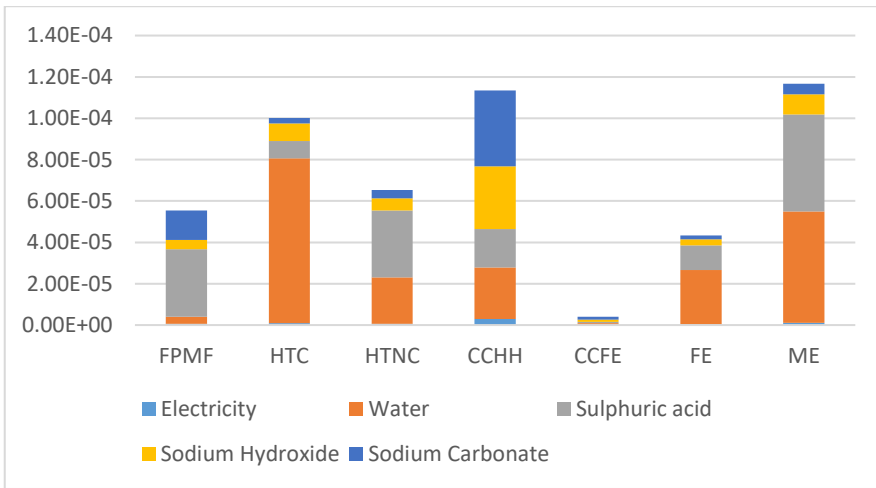


Fig. 5. The environmental impacts of Batik production process

Among the various stages of the batik production process, the batik washing stage is the one that consumes the greatest quantity of water. This high-water consumption has a direct impact on the volume of wastewater generated, which contains several harmful chemicals that have the potential to pollute the aquatic environment. It is in line with the research of Fidiastuti [17] which highlights the persistence of synthetic dyes like naphthol and indigosol in batik wastewater, which are difficult to degrade and pose a significant risk to aquatic ecosystems. Moreover, the presence of heavy metals such as iron, copper, chromium, cadmium, and lead has been reported in batik wastewater. Astuti [18] found that the concentrations of these metals in some samples exceeded safe limits, posing a risk to both aquatic life and human health. The high biological oxygen demand (BOD) and chemical oxygen demand (COD) values further indicate the potential of batik wastewater to deplete oxygen levels in water bodies, leading to hypoxic conditions detrimental to aquatic organisms [19].

Consequently, it is imperative to implement corrective measures to mitigate this adverse impact. One potential solution is the implementation of more effective wastewater treatment systems, which would serve to minimize pollution. Furthermore, the replacement of chemicals with more environmentally friendly alternatives should be considered to reduce the ecotoxicity of the process.

By identifying the main sources of environmental impact in the batik production process, it is possible to design more effective mitigation strategies. For instance, the utilization of more water-efficient washing technologies can markedly decrease water consumption and wastewater volume. Effective waste management strategies can significantly reduce the environmental impacts, as conducted some previous researches in other application [20]–[22]. Furthermore, training and educating batik industry players on environmentally friendly production practices can assist in reducing the negative environmental impacts. Training and education can enhance users' knowledge and skills, as demonstrated by various studies across multiple application fields [23]–[32].

4 Conclusion

This research is based on a case study of a small and medium enterprise (SME) in the batik industry in Pekalongan, Indonesia. The company's challenges are compounded by the pollution caused by its production waste. It led to environmental concerns regarding air and water pollution in the area surrounding Pekalongan. Therefore, this research is proposed to assess the environmental impacts of Batik production by using the LCA method. The analysis indicates that the greatest environmental impact is observed in the Marine Ecotoxicity category. This is due to the utilization of chemicals such as sulphuric acid, sodium hydroxide, and sodium carbonate, which dissolve in large quantities of water, especially in the batik washing stage. The findings of this analysis underscore the significance of ongoing monitoring and evaluation of the batik production process. This allows for the continuous improvement of the process to achieve more sustainable and environmentally responsible production. Furthermore, further research is recommended to explore new methods and technologies that can be applied in the batik industry to reduce the overall environmental impact.

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Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors disclose no conflict.

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