JESE 5 (1) (2025)

Journal of Environmental and Science Education

http://journal.unnes.ac.id/sju/index.php/jese

Analysis of Carbon Footprint and Water Footprint in Laundry MSMEs Business Using Life Cycle Assessment

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DOI: 10.15294/jese.v5i1.2480

Article Info

Received 21 March 2025
Accepted 17 April 2025
Published 25 April 2025

Keywords:
LCA, Impact Assessment, Carbon Footprint, Water Footprint, Laundry

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Abstract

Laundry MSMEs are resource-intensive, consuming significant electricity and water while discharging wastewater with high concentrations of detergent residues. Accordingly, assessing their environmental impacts is essential to support sustainable practices in the laundry sector. This study aims to quantify the carbon footprint and water footprint of a laundry MSME, identify the hotspot, and propose mitigation strategies. A gate-to-gate Life Cycle Assessment (LCA) was conducted using SimaPro software. Impact assessment applied IPCC 2021 GWP100 for carbon footprint and AWARE methodology for water footprint. The result shows that laundering 1 ton of clothes generates 5,072 kg CO_2-eq and 687 m^3 of water use. The washing process is identified as the main hotspot, contributing 3,470 kg CO_2-eq (68% of total emissions) and 654 m^3 (95% of total water use). These findings highlight the need for targeted interventions at the washing stage to reduce environmental impacts and enhance resource efficiency in the laundry sector.

ISSN 2775-2518

INTRODUCTION

Climate change, primarily driven by anthropogenic activities, is now widely recognized as a serious threat not only at a global scale but also at regional and local levels. Recent data shows that January 2025 was recorded as the hottest month globally, with an average temperature 1.75°C above pre-industrial levels, making it the 18th out of the last 19 months in which global temperatures exceeded 1.5°C above pre-industrial levels (World Meteorological Organization, 2025). In the context of a worsening environmental crisis, the small and medium-sized enterprise (SME) sector plays a significant yet often overlooked role in environmental policy discussions. According to a study conducted by the Institute for Essential Services Reform (IESR), the SME sector in Indonesia contributes a substantial amount of energy-related emissions, including from the laundry sector (Institute for Essential Services Reform, 2024).

Conventional laundry processes require high energy consumption, particularly for washing machines and water heaters. In addition, the large volumes of water used often result in detergent-laden wastewater that poses environmental contamination risks (Jabbar et al., 2024; Mezzanotte et al., 2025). The environmental impact of laundry operations extends beyond energy and water consumption. A life cycle analysis conducted on hospital laundry facilities revealed that the average greenhouse gas emissions amounted to 0.225 kg CO_2e per item and 0.5080 kg CO_2e per kilogram of laundry. Furthermore, the use of gas for heating accounted for 75.7% of the total greenhouse gas emissions at the laundry site (John et al., 2024).

In addition to its carbon footprint, the water footprint of laundry businesses is also a growing concern. Commercial laundry operations consume large volumes of water, which subsequently become wastewater. This wastewater often contains detergents and other chemical substances that can contribute to eutrophication. The elevated nutrient concentrations in receiving water bodies promote excessive algal growth, which in turn poses serious threats to aquatic ecosystems and biodiversity. (Aqilah et al., 2023; Zairinayati & Shatriadi, 2019).

The contribution of carbon and water footprints from laundry operations to environmental degradation can be analyzed using a Life Cycle Assessment (LCA) approach. LCA enables the evaluation of environmental impacts throughout the entire value chain of laundry services—from resource acquisition to end-of-life waste management—and provides critical insights for impact mitigation strategies (Romagnoli et al., 2023). This comprehensive assessment helps identify key environmental hotspots and informs more sustainable operational decisions. Previous studies have applied LCA to highlight eutrophication potential as a major environmental impact associated with laundry activities (Aqilah et al., 2023; John et al., 2024; Mezzanotte et al., 2025). However, specific LCA analyses focusing on the SME laundry sector in Indonesia remain scarce. Nevertheless, employing LCA as an environmental assessment tool holds significant potential for supporting decision-making processes, particularly in initiatives related to water recycling and waste management (Abagnato et al., 2024; Jørgensen et al., 2004).

Although several studies have examined the environmental impacts of laundry activities—such as analyses on eutrophication potential and comparative studies of washing quality versus environmental burden (Aqilah et al., 2023; Tomšič et al., 2024), there remains a significant gap in the scientific literature regarding the application of Life Cycle Assessment (LCA) specifically within the context of Indonesian SME laundry businesses. This gap is problematic, given the unique characteristics of these enterprises, which typically operate using basic technologies, have limited water management practices, and display varying levels of environmental awareness. Most LCA studies related to laundry have focused on large-scale facilities or settings in developed countries, whose operational profiles differ greatly from those of Indonesian SMEs. Therefore, a comprehensive analysis that incorporates the socio-economic and technological context of local SMEs is crucial to developing relevant and actionable environmental mitigation strategies.

The implementation of LCA in SME laundry businesses offers dual benefits—both environmental and economic. LCA studies on laundry practices have identified the use phase as having the highest environmental impact, due to frequent machine operation and detergent use (Koerner, 2010). By pinpointing such environmental hotspots, SMEs can adopt resource efficiency strategies that directly contribute to operational cost savings. Furthermore, research on greywater recycling systems demonstrates that wastewater treatment technologies can enhance the resilience and adaptability of local water systems (Oarga-Mulec et al., 2023; Van de Walle et al., 2023). From a circular economy perspective, LCA can also help identify opportunities for resource reuse and waste reduction—transforming environmental stewardship into a new value proposition for SME laundry businesses, thereby improving their competitiveness in a market that increasingly values environmental credentials.

This study aims to conduct a comprehensive analysis of the carbon footprint and water footprint of SME laundry businesses in Indonesia using a Life Cycle Assessment (LCA) approach, identify environmental impact hotspots along the value chain, and formulate mitigation strategies that are both technically and economically feasible. The significance of this research lies not only in addressing the knowledge gap regarding the specific environmental profiles of Indonesian SME laundry businesses but also in providing a methodological LCA framework that can be adapted by micro, small, and medium enterprises with limited resources. The findings of this study are expected to inform policy development and initiatives that promote more sustainable business practices in the SME laundry sector, in line with Indonesia's commitment to reducing greenhouse gas emissions. Furthermore, as highlighted in previous studies on greywater life cycle assessments for water conservation, the LCA approach in this research can serve as an effective decision-support tool for water recycling and waste management initiatives. (Kobayashi et al., 2020; Rodríguez et al., 2021).

METHOD

This study uses a Life Cycle Assessment (LCA) approach according to ISO 14040 and ISO 14044, which includes four main stages: definition of goals and scope, inventory analysis, impact assessment, and interpretation. Below is an explanation for each stage:

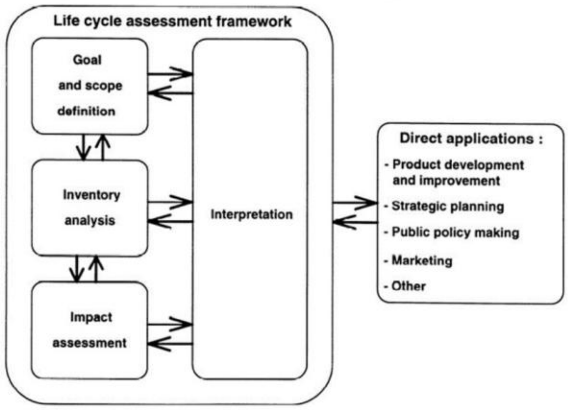

Figure 1 LCA Framework (Kholil et al., 2022)

Goal and Scope

This study used a gate-to-gate scope, meaning the analysis encompassed only the processes occurring within the laundry MSME's operations, excluding any upstream or downstream stages. This gate-to-gate scope was chosen to ensure that the study remains focused on the direct operational processes of the laundry and their contribution to environmental impacts.

Life Cycle Inventory

The life cycle inventory is conducted by collecting both primary and secondary data related to the laundry process. Primary data is obtained directly through surveys and interviews with local laundry MSMEs, gathering information such as electricity consumption, water usage, detergent usage, fuel consumption, and the amount of laundry processed. Primary data collection follows the general guidelines of ISO 14040 and ISO 14044 to ensure data completeness and quality because the life cycle depends on the data collected from the system so this is a very important process (Baldini et al., 2017). Meanwhile, secondary data is gathered from literature in journals, research findings, and other sources to strengthen this study, as well as from the Ecoinvent database to complement any data unavailable from primary data.

Life Cycle Impact Assessment

LCA modeling was carried out using the SimaPro software as a tool to build the life cycle model and quantitatively calculate environmental impacts. The inventory data that had been collected was an input into SimaPro (Mahath et al., 2019), and for processes or supporting materials unavailable through primary data, secondary data from the Ecoinvent database integrated with SimaPro was used (Kim & Park, 2020). SimaPro was selected because it is widely employed in academic and industrial research, supports various impact assessment methods, and has a comprehensive database covering numerous processes.

In the Life Cycle Impact Assessment (LCIA) phase, this study focuses on two impact categories, which is carbon footprint and water footprint. The carbon footprint is among the most widely used environmental metrics for assessing the environmental impacts linked to a specific product or process (De Souza Grilo et al., 2018). The carbon footprint is calculated using the IPCC 2021 GWP 100-year method, which estimates the global warming potential over a 100-year period (Coelho Junior et al., 2019). This method provides characterization factors for CO_2 (and other greenhouse gases) in units of kg CO_2 equivalent. However, in this study, the carbon footprint calculation is limited to CO_2 emissions generated throughout the laundry system (for instance, from electricity use), assuming that other greenhouse gas emissions (CH_4, N_2O, etc.) are relatively small or are otherwise accounted for by the CO_2 estimate alone.

Meanwhile, the water footprint is assessed using the AWARE (Available WAter REmaining) method. AWARE is a water scarcity footprint indicator developed through consensus by Water Use in Life Cycle Assessment (WULCA) to evaluate the impact of water consumption on regional water availability (Boulay et al., 2018). The core principle of this method involves calculating the remaining available water in a certain area (watershed) after fulfilling human and ecosystem needs, the greater the water consumption in that area, the higher the indicated water scarcity impact (Hayek et al., 2021). In this context, the study only considers blue water consumption, meaning the volume of surface and groundwater used in the laundry process that is not returned to its original source. The AWARE method was chosen because it is recommended by the UNEP-SETAC initiative as a standard water footprint method at the midpoint level that incorporates spatial water scarcity. All LCIA calculations (both carbon and water footprints) are conducted through the SimaPro software using the IPCC 2021 and AWARE methods available therein, ensuring consistency in calculations and minimizing manual errors.

Interpretation

The interpretation stage is the final phase of Life Cycle Assessment (LCA), where the quantitative data and results from the Life Cycle Inventory (LCI) and Life Cycle Impact Assessment (LCIA) are re-evaluated to draw conclusions relevant to the study's objectives. Interpretation is used to identify hotspots, assess data reliability (including uncertainty), and evaluate methodological consistency (Hauschild et al., 2018). Recommendations or proposed solutions are formulated based on the results of this interpretation. Thus, the interpretation phase provides a more comprehensive basis for decision-making, particularly in relation to company policies or sustainability strategies in the laundry industry.

RESULT AND DISCUSSION

Goal and Scope

Functional Unit

The determination of the functional unit is crucial in conducting a Life Cycle Assessment (LCA) as it serves as the basis for comparing systems and calculating their impacts quantitatively (Umbu Lolo et al., 2023). The functional unit employed is 1 ton of laundry processed in this system. All input and output inventory data are normalized to this 1 ton of laundry, allowing the LCA results to be compared consistently and objectively for each ton of laundry serviced. Establishing a clear functional unit is essential for maintaining consistency in calculations and ensuring the validity of environmental performance comparisons.

System Boundary

The system boundary begins when the dirty laundry is received and weighed, followed by washing, drying, and ironing, and ends once the clean laundry is packaged for return to the customer, as can be seen in Figure 2. The washing process involves using water, detergent, and electricity to operate washing machines. Dirty clothes entering this stage are mixed with detergent to loosen dirt and stains, then rinsed using clean water. The main outputs of this process are clean but still wet clothes, as well as wastewater that contains residual detergent. After washing, the wet clothes undergo the drying process. This stage typically uses dryers that require energy to heat the air and evaporate water from the clothes, although natural sun drying is still practiced in some areas. Wet clothes inside the dryer continuously tumble until the moisture content is optimally reduced. The output of this stage is dry clothes ready for ironing.

Once dry, clothes often go through the ironing process to smooth the fabric and remove wrinkles. At this stage, dry clothes are ironed using steam irons, with temperatures adjusted according to fabric type. The main inputs are electricity to heat the iron and, in some cases, a small amount of water if the steam function is used. The output is neatly pressed clothes. The final stage is packaging, where the ironed clothes are neatly folded and wrapped before being delivered to customers. Inputs in this process include ironed garments, packaging materials (usually plastic bags or plastic wrap), and additional fragrance (perfume or air freshener). The clothes are placed into plastic packaging with an identification slip or receipt and lightly sprayed with perfume before sealing. The output of this stage is a clean, well-packaged bundle of clothes ready for customer pickup.

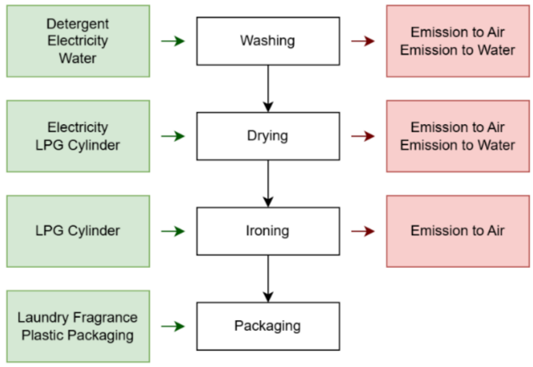

Figure 2 Laundry Process Flow Diagram

Life Cycle Inventory

The Life Cycle Inventory phase focuses on systematically collecting and quantifying all relevant input and output data associated with a product or process. In this study, both primary and secondary data are meticulously gathered at specific intervals throughout 2024. All input and output data are recorded and categorized based on the following process categories:

Table 1 Inventory Data

No	Process	Inventory	Amount	Unit
1	Washing	**Input**		
		Dirty Clothes	18	Ton
		Detergent	0.3	Ton
		Water	180,000	L
		Electricity	29,400	kWh
		Output		
		Wet Clothes	18	Ton
		CO2	24.99	Ton
		Wastewater	144,000	L
2	Drying	**Input**		
		Wet Clothes	18	Ton
		Electricity	12,600	kWh
		LPG Cylinder	0.072	Ton
		Output		
		Dry Clothes	18	Ton
		CO2	10.77	Ton

No	Process	Inventory	Amount	Unit
		Wastewater	36,000	L
3	Ironing	**Input**		
		Dry Clothes	18	Ton
		LPG Cylinder	1.08	Kg
		Output		
		Ironed Clothes	18	Ton
		CO2	0.907	Ton
4	Packaging	**Input**		
		Ironed Clothes	18	Ton
		Plastic Packaging	0.072	Ton
		Laundry Fragrance	120	L
		Output		
		Clothes Ready for Pickup	18	Ton

Life Cycle Impact Assessment

In the Life Cycle Impact Assessment (LCIA) phase, the environmental impact of each process was analyzed using SimaPro Developer software, version 9.5. The selected methods, IPCC 2021 and AWARE, are both internationally accepted frameworks designed to assess environmental impacts associated with products or processes. The IPCC and AWARE methods provide a dual perspective on environmental impacts, focusing on both carbon emissions and water usage.
Table 2 presents the results of the Life Cycle Impact Assessment (LCIA) for each stage of the process, including washing, drying, ironing, and packaging. The assessment covers two key environmental impact categories: carbon footprint (GWP100) and water footprint (Water Use). In the carbon footprint category, the washing process is the highest contributor, with 3.469,556 kg CO_2-eq, followed by drying and ironing. Similarly, for the water footprint, washing has the largest impact, requiring 654.080 m^3 of water, significantly more than the other stages.

Table 2 The Result of Environmental Impact Assessment

Impact Category	Unit	Washing	Drying
GWP100	kg CO2-eq	3,469.556	1,479.740
Water Use	m3	654.080	25.896
Impact Category	**Unit**	**Ironing**	**Packaging**
GWP100	kg CO2-eq	109.436	13.199
Water Use	m3	4.957	2.406

Interpretation

This study focused on Global Warming Potential (as CO_2-equivalents) and Water Use as the primary impact categories for the laundry's life cycle assessment. These impact categories are commonly assessed in laundry LCA studies because laundry operations are both energy-intensive and water-intensive processes. GWP captures the climate change impact from energy use, while Water Use reflects the enormous volumes of tap water consumed in washing.
The carbon footprint analysis in Figure 3 shows that the washing process contributes approximately 65% of total greenhouse gas emissions, followed by drying (25%), ironing (9%), and packaging (1%). This distribution reflects the high energy intensity of washing and drying activities. The significant carbon footprint from washing is primarily due to energy consumption for operating washing machines, which aligns with the findings of John, et al. (2024), who reported that gas use for heating accounts for 75.7% of greenhouse gas emissions in hospital laundry facilities.

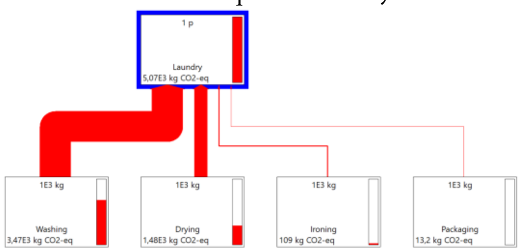

Figure 3 Result of Carbon Footprint

The water footprint analysis in Figure 4 reveals a pattern similar to that of the carbon footprint, with the washing process accounting for approximately 95% of the total water footprint. This high water footprint reflects not only the volume of water directly consumed during the process but also the impact of pollutants in wastewater on local water availability within the operational area.

Boulay et al. (2018), in their study on the water footprint of a single laundry cycle, identified that the use phase—particularly tap water consumption—is the primary contributor to the overall water footprint. In the context of laundry MSMEs in Indonesia, the common practice of repeated rinsing to more effectively remove detergent residues significantly contributes to the high water footprint, in contrast to modern laundry practices that utilize optimized washing cycles.

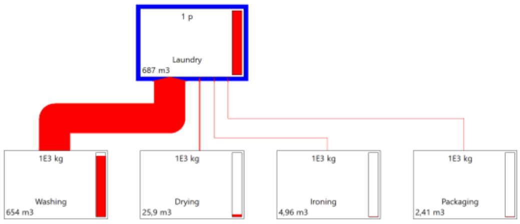

Figure 4 Result of Water Footprint

This finding is strongly supported by prior LCA research on laundry systems. The act of washing (i.e., the use phase involving running the washing machines with water and detergent) is known to drive the majority of impacts in clothing care. For example, a comprehensive LCA of domestic clothes washing found that the use phase contributes ~73% of the total GWP and 92% of water use in the life cycle. The reasons are clear: washing machines consume large amounts of electricity and water every cycle. Most of the laundry's carbon footprint comes from energy use during washing, particularly if water is heated. Heating water for laundry has a huge impact; a European study reported that heating the wash water accounted for around 60% of the carbon footprint of laundry. In our SME laundry, the washing stage likely involves drawing electricity from a coal-dominated grid to agitate and possibly heat water, hence the high GWP share. Meanwhile, virtually all of the water consumption occurs in washing (water filling, rinsing) since subsequent processes like drying or ironing use negligible water. The 95% contribution of washing to Water Use is expected because laundries require large volumes of water to clean clothes. Essentially, the combination of electricity consumption (for motors and any water heating) and water usage in the washing machines makes this step the dominant contributor to both climate change impact and water resource depletion in the laundry's life cycle. Other stages (drying, ironing, transportation, etc.) tend to be less intensive or are absent in a gate-to-gate scope, so their impact is comparatively minor. Thus, the data and literature consensus both point to washing operations as the critical hotspot that dictates the environmental profile of laundry services.

To reduce the environmental footprint of laundry MSMEs, especially from the washing process, several effective mitigation strategies can be adopted. Electrifying water heating systems through heat pumps offers major carbon reductions, especially as national grids transition to cleaner energy, as shown by Na et al. (2020) in their industrial electrification study. On the water side, implementing small-scale greywater recycling systems can reduce freshwater demand by up to 45%, with studies by Shi et al. (2018) highlighting safe and effective reuse in laundry applications. Additionally, decentralized wastewater treatment using constructed wetlands or biofilters can remove over 90% of pollutants from laundry effluents, enabling safe discharge or reuse, as demonstrated by Lutterbeck et al. (2020). Collectively, these strategies support the transition of laundry MSMEs toward more sustainable, low-emission, and water-efficient operations.

CONCLUSION

Based on the Life Cycle Assessment (LCA) of the laundry MSME using a gate-to-gate approach, the washing process is identified as the main contributor to environmental impact, accounting for approximately 65% of total greenhouse gas emissions and 95% of water use. This makes it the most critical stage in terms of sustainability challenges.

The high carbon footprint from washing, 3,469.56 kg CO_2-eq per ton of laundry, is largely due to significant electricity use, likely from a coal-based grid. The water footprint, measured at 654.08 m^3 per ton, stems from the high volume of water used during washing and rinsing, as well as wastewater containing detergent residues. These factors significantly affect local water resources.

In contrast, the impacts from other stages are relatively minor. Drying contributes 1,479.74 kg CO_2-eq and 25.90 m^3 of water use, ironing adds 109.44 kg CO_2-eq and 4.96 m^3, while packaging contributes only 13.20 kg CO_2-eq and 2.41 m^3. This highlights the need to prioritize the washing stage for environmental improvement. Implementing energy and water-efficient machines, reducing rinse cycles, and adopting renewable energy sources are potential strategies to reduce impacts.

Further research should include upstream and downstream activities, such as detergent production and waste handling, to provide a full life cycle perspective. Scenario modeling of green alternatives (e.g., solar dryers, biodegradable detergents, greywater reuse) could identify sustainable options. Expanding the scope to include additional impact categories like toxicity and resource use, along with economic analysis, will help design effective and feasible sustainability interventions for laundry MSMEs.

ACKNOWLEDGMENT

The authors would like to express their sincere gratitude to PT Sinergi Enviro Nusantara for generously providing access to the SimaPro Developer 9.5 Version software. This valuable support significantly contributed to the successful execution of the Life Cycle Assessment conducted in this research.

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