Carbon Footprint Reduction in Continuous Fabric Washing:

A Comparative Life-Cycle-Assessment-Based Analysis of Solvent and Water-Based Technologies

Contents

Introduction

Fabric washing is one of the most resource-intensive stages in textile manufacturing, contributing significantly to energy consumption, water use, and greenhouse gas emissions. This study presents a comparative environmental assessment of two continuous open-width washing technologies: a solvent-based closed-loop system using perchloroethylene (PCE) and a conventional water-based washing process followed by thermal drying.

A Life Cycle Assessment (LCA)-based screening approach was applied using a functional unit of 1 kg of processed fabric. The analysis includes operational energy use, water consumption, solvent and chemical inputs, and associated waste treatment within a defined system boundary. In the solvent-based configuration, process air is recirculated and treated

in a closed-loop system through activated carbon filtration, effectively eliminating solvent emissions during normal operation.

Under the operational assumptions used in this process-level model, the solvent-based configuration shows a substantially lower estimated CO_2-equivalent emission intensity than the reference aqueous washing and drying configuration.

The analysis highlights the strong link between water consumption and thermal energy demand in textile processing, particularly due to the energy required to evaporate water during drying.

These findings illustrate how process configuration and thermodynamic constraints can significantly influence the carbon intensity of textile finishing operations.

Keywords: textile washing, carbon footprint, LCA, perchloroethylene, solvent cleaning, waterless processing, textile finishing, scouring

Data and Calculation Procedures

Functional Unit

The functional unit used for comparison is 1 kg of processed greige fabric.

The comparison assumes equivalent cleaning performance between the two process configurations.

Process Inventory

Table 1 shows the simplified process inventory used for the carbon footprint calculations.

TABLE 1: Process Inventory per kg of Fabric

Parameter	Unit	Solvent system	Water system
Electricity consumption	kWh/kg fabric	0.115	0.287
Steam consumption	kg/kg fabric	3.3	6.0
Water consumption	L/kg fabric	0	15
Wastewater generation	L/kg fabric	0	15
PCE make-up	g/kg fabric	6	–
Surfactant consumption	g/kg fabric	–	32

These values represent typical operating conditions used for the screening model and allow transparent reconstruction of the carbon footprint results.

The reference aqueous process assumes conventional thermal drying without advanced heat recovery systems.

System Boundaries

The system boundary includes:

- operational electricity consumption
- thermal energy consumption (steam generation)
- chemical inputs (solvent or surfactants)
- water supply and wastewater treatment
- waste disposal from distillation residues

Upstream textile production and capital equipment manufacturing are excluded.

The analysis focuses on operational process impacts.

Emission Factors

The following emission factors were applied:

• Electricity: 289 g CO_2e/kWh (ISPRA, 2023 — Italian national electricity mix)

• Thermal energy from natural gas (steam generation): 204 g CO_2e/kWh

• Compressed air: emissions calculated from electricity consumption (0.08–0.15 kWh/Nm^3) using the national electricity emission factor

• PCE production: 6.34 kg CO_2e/kg (Ecoinvent v3.11, IPCC 2021 method)

• Surfactants: 2.5 kg CO_2e/kg (typical cradle-to-gate industrial average)

• Water supply: 378 g CO_2e/m^3

• Wastewater treatment: 0.567 kg CO_2e/m^3

• Sludge disposal: up to 0.5 kg CO_2e/kg, depending on disposal route

These parameters were applied to estimate indirect CO_2e emissions associated with energy consumption, material inputs, water use, and waste treatment within the defined boundary.

Carbon Footprint Methodology

Electrical and thermal energy consumption were converted into CO_2e emissions using the emission factors described above.

Material-related emissions were calculated using cradle-to-gate emission factors applied to net solvent and surfactant consumption.

The analysis represents a simplified process-level carbon footprint estimate rather than a full multi-impact life cycle assessment.

Results and Discussion

Table 2 shows the contribution of thermal and electrical energy to the total carbon footprint.

TABLE 2: Contribution of thermal and electrical energy (kg CO_2e per kg of fabric)

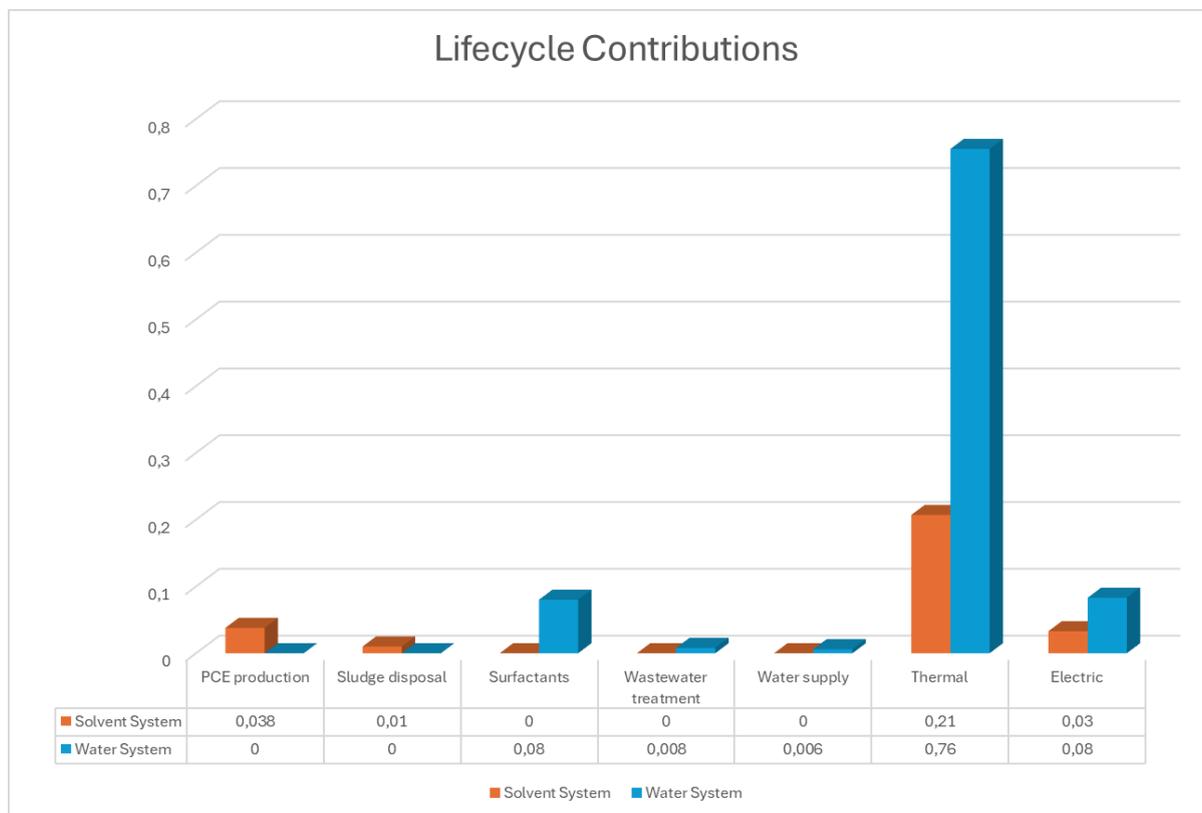| Process	Thermal	Electric	Total
Solvent system	0.207	0.033	0.240
Water system	0.755	0.083	0.838

Table 3 shows the additional lifecycle contributions.

TABLE 3: Additional lifecycle contributions (kg CO_2e per kg of fabric)

Contribution	Solvent System	Water System
PCE production	0.038	–
Sludge disposal	0.010	–
Surfactants	–	0.080
Wastewater treatment	–	0.008
Water supply	–	0.006

These contributions represent a smaller portion of the total carbon footprint compared with thermal energy demand.

FIGURE 1: Process Energy Demand and Additional Lifecycle Contributions ($kg\ CO_2e$ per kg of fabric)

	PCE production	Sludge disposal	Surfactants	Wastewater treatment	Water supply	Thermal	Electric
■ Solvent System	0,038	0,01	0	0	0	0,21	0,03
■ Water System	0	0	0,08	0,008	0,006	0,76	0,08

As shown in Figure 1, the results highlight the strong coupling between water consumption and energy demand in textile washing processes.

The results show that thermal energy demand dominates the carbon footprint in both configurations.

Approximately 80–85% of the difference between the two processes is associated with thermal energy required to evaporate water during drying in the aqueous process.

The latent heat of vaporisation illustrates this relationship:

Fluid	Latent heat
Water	~2255 kJ/kg
PCE	~210 kJ/kg

Because evaporating water requires substantially more energy than evaporating PCE, processes relying on large-scale water evaporation inherently require higher thermal energy.

Conclusions

This comparative process model indicates that solvent-based continuous washing systems based on Best Available Techniques (BAT) can exhibit lower operational carbon intensity than conventional aqueous washing followed by thermal drying.

The difference is primarily driven by the thermal energy required for water evaporation during drying.

The results therefore highlight the strong relationship between water consumption, thermal energy demand, and carbon emissions in textile washing processes.

While the exact magnitude of the difference depends on local energy mixes, heat recovery systems, and operating conditions, the thermodynamic constraints associated with water evaporation remain a key factor.