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Optimisation of Water Consumption in Textile Dyeing Processes in a Sahelian Context: Industrial Audit, Scenario Analysis and Techno-Economic Assessment

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Abstract

Water scarcity is one of the most serious constraints on industrial development in the Sahel. Textile dyeing is among the largest industrial users of water, yet in low-income West African countries its water management is poorly documented and rarely optimised. This study reports an industrial audit of water use in a representative Burkinabe textile dyeing plant, together with mass-balance modelling and a scenario analysis of three optimisation pathways: (1) low liquor-ratio (LLR) dyeing technology, (2) LLR combined with 50% internal effluent recycling, and (3) full process optimisation that adds advanced effluent treatment to LLR and recycling. Baseline water intensity is 183 L/kg of textile, against an EU best-practice benchmark of 45 L/kg. Scenario 2 achieves a 45% water reduction (from 1100 to 605 m^3/day), corresponding to a water intensity of about 101 L/kg; Scenario 3 reaches a 57% reduction (79 L/kg). Estimated payback periods are reported in Section 4.3. A multi-criteria evaluation indicates that Scenario 2 gives the best balance of water savings, economic viability, and technical feasibility for small-to-medium enterprises in the Sahel. The results offer a practical roadmap for water stewardship in West African textile manufacturing.

Keywords

Water Optimisation, Textile Dyeing, Sahel, Liquor Ratio, Effluent Recycling, Water Stress, Industrial Ecology, Techno-Economic Analysis, Burkina Faso, Water Footprint

1. Introduction

Water scarcity is a major constraint on economic development across the Sahelian belt of West Africa. Annual renewable freshwater availability in Burkina Faso is roughly 700 to 1200 m^3 per capita, well below the international water-stress threshold of 1700 m^3/capita [1], and competition between agricultural, domestic, and industrial users is intensifying. Textile manufacturing is one of the most water-intensive industries, so its water use is a real sustainability problem, yet it has received comparatively limited scientific attention in the West African setting [2] [3].

Textile wet processing, which covers pre-treatment, dyeing, rinsing, and finishing, accounts for about 70 to 80% of total water use in textile manufacturing, and dyeing alone is responsible for 45 to 55% of plant-level withdrawals [4] [5]. Reported water use across the industry ranges from 17 to 200 litres per kilogram of processed textile, depending on fibre type, process design, and management practice [4]. The baseline audits carried out for this study put water intensity in Burkina Faso at 170 to 190 L/kg, among the highest recorded for the sector anywhere. This is largely because the plants use conventional high liquor-ratio (HLR) dyeing and almost no internal water recycling.

The literature describes three distinct ways to cut water use in textile dyeing. First, low liquor-ratio (LLR) dyeing reduces the volume of dye bath per kilogram of fibre from conventional ratios of 1:20 to 1:30 down to 1:4 to 1:8, with matching reductions in water use and effluent [5] [6]. Second, internal recycling systems treat and reuse rinsing and washing water, recovering 40 to 70% of it depending on effluent quality and the treatment technology [4] [7]. Third, advanced physico-chemical and biological treatment of dyeing effluent can recover even heavily contaminated bath water, although capital and operating costs are higher [8] [9].

Despite this knowledge, the peer-reviewed literature still lacks techno-economic assessments built around the constraints facing small-to-medium enterprises (SMEs) in low-income Sahelian countries, where access to capital is limited, technical capacity is weak, and energy supply is unreliable. This study addresses that gap with four contributions: (i) a systematic water audit of a representative Burkinabe textile plant; (ii) mass-balance modelling of water flows by process stage; (iii) a scenario analysis of three optimisation pathways; and (iv) a multi-criteria techno-economic evaluation calibrated to SME constraints in the Sahel. The main performance target is a water-use reduction of at least 30% relative to baseline, in line with UN Sustainable Development Goal 6.4, which calls for a substantial increase in water-use efficiency across all sectors by 2030.

To the authors' knowledge, this is among the first studies to combine industrial water auditing, process-level mass-balance modelling, optimisation scenario analysis, and multi-criteria techno-economic decision support in a single framework for textile water stewardship in a water-stressed Sahelian economy.

2. Literature Review

2.1. Water Consumption in Textile Wet Processing: Global Patterns

Textile wet processing is consistently ranked among the three most water-intensive manufacturing sectors [10]. In dyeing, water dissolves the dyes and auxiliary chemicals, carries the colorants from the bath to the fibre, and then rinses out whatever does not fix [11]. Together these uses give specific water consumption that runs from as little as 17 L/kg in highly optimised European continuous dyeing to more than 350 L/kg in old batch plants with no water recovery [4] [10]. Dyeing and rinsing together account for 65 to 75% of total plant withdrawals [3] [5]. A factory-level survey of 18 Bangladesh dyeing plants found average water consumption of 164 L/kg and identified high reprocessing rates as the main driver of excess use [12], close to the 183 L/kg baseline measured in the present Burkinabe audit. A Turkish integrated textile mill showed specific consumption of 126 to 963 L/kg [13], which illustrates how widely values vary with process design and management quality.

2.2. Low Liquor-Ratio Technology: Mechanisms and Documented Savings

Liquor ratio, the volume of dye bath in litres per kilogram of textile, is the process parameter that most strongly governs water consumption in exhaust dyeing [14]. Conventional high liquor-ratio (HLR) jet dyeing runs at ratios of 1:15 to 1:30, while modern low liquor-ratio (LLR) machines reach 1:4 to 1:8 by using turbulent circulation at lower bath volumes. The relationship is close to linear: cutting the liquor ratio from 1:20 to 1:8 uses about 60% less water per cycle, with matching reductions in salt, auxiliary chemicals, and thermal energy [6] [14]. A critical review of water conservation in textile wet processing reported water savings of 30 to 60% from LLR adoption in studies from India, Pakistan, and Türkiye, alongside energy co-savings of 20 to 35% from lower steam use [15]. That review also showed that LLR cuts water mainly in the dyeing stage, not in rinsing. This is why the present study pairs LLR with an internal loop that recycles rinsing water, so that total savings can exceed 30%.

2.3. Effluent Recycling and Wastewater Treatment for Reuse

The chemical make-up of textile dyeing effluent varies widely because of the range of dye classes, auxiliary chemicals, and process conditions. The parameters that determine whether it can be recycled include colour (ADMI units), chemical oxygen demand (COD), total dissolved solids (TDS), pH, and conductivity [8] [9]. Rinsing and washing effluents carry residual alkali and unfixed dye at low concentrations, so they are the easiest to recycle internally and can usually be reused after sand filtration, activated carbon adsorption, and UV disinfection, a treatment train that costs little to build [4] [16]. Spent dyeing baths, by contrast, contain high TDS (2000 to 12,000 mg/L), residual reactive dyes, and salt, so recycling them without advanced treatment is impractical for SMEs. A survey of water reuse across the European textile sector found that plants with structured internal recycling reached average reuse rates of 30 to 55%, and that the best performers exceeded 70% in continuous finishing [16]. For sub-Saharan Africa, a study of textile wastewater management in Tanzania found almost no internal recycling and too little effluent characterisation data to design treatment trains systematically [3], the same gap that the present audit method addresses for Burkina Faso.

2.4. Water Scarcity and Industrial Water Governance in the Sahel

The Sahel is among the most water-stressed regions in the world, with renewable surface water projected to fall by 10 to 30% by 2050 under moderate climate scenarios [1] [17]. Burkina Faso's renewable freshwater resources, about 12.5 km^3/year, are spread unevenly, and the industrialised Ouagadougou region draws heavily on groundwater aquifers where recharge rates are falling. Industrial withdrawals account for about 11% of total freshwater use in the country, a share expected to grow under the PNDES-II industrialisation agenda [18]. For the textile industry in Burkina Faso, water management is constrained by rising scarcity and limited wastewater-treatment infrastructure. The only Africa-focused study of textile wastewater management found in this review is the Tanzanian work [3], whose findings on weak regulatory capacity and missing effluent characterisation data apply directly to Burkina Faso. Limited access to finance is a major barrier to cleaner-production technologies across African manufacturing. It is especially binding for textile SMEs in Burkina Faso, where the upfront capital for water-saving equipment often exceeds the self-financing capacity of an individual firm. This sets the context for the scenarios analysed in Section 3.

2.5. Techno-Economic Frameworks for Cleaner Production in Developing Economies

Techno-economic assessment (TEA) of cleaner-production investments typically combines capital expenditure, operating expenditure, and payback-based performance metrics within an integrated decision-support framework [19] [20]. The multi-criteria decision analysis (MCDA) used in Section 3.4 combines economic indicators (CAPEX, OPEX, simple payback period) with qualitative judgements of technical feasibility, scalability, and institutional capacity, following an established framework [21]. The TEA literature on textile water efficiency shows that intermediate-scale interventions consistently beat both minimal (LLR only) and maximal (full advanced treatment) options on cost per cubic metre saved, because they avoid the steeply rising marginal cost of treating the dirtiest effluent fractions [7] [9]. The simple payback periods recomputed for this plant (under 1.5 years; Section 4.3) sit at or below the lower end of the range reported for comparable low-liquor-ratio and recycling investments elsewhere, from 2.1 to 3.5 years in Bangladesh [12] to 1.8 to 2.9 years in Türkiye [13]. The shorter periods here follow from the large operating-cost reductions assumed relative to capital outlay; their exact position depends on how the plant's avoided water cost is valued and should be confirmed against its pumping and discharge records.

3. Materials and Methods

3.1. Study Site and Industrial Audit Protocol

The study was carried out at a medium-scale textile dyeing plant in the industrial zone of Ouagadougou, Burkina Faso, which produces about 6000 kg of dyed cotton fabric per day over three shifts. The plant runs conventional high liquor-ratio jet dyeing machines (LR 1:20 to 1:25) and has no internal water recycling. The audit followed the ISO 14046:2014 water footprint framework and the UNEP/SETAC Guidelines for Water Footprint Assessment. It combined continuous flow metering (electromagnetic flowmeters, ±2% accuracy), timed volumetric sampling, and process material-balance cross-checks over a 21-day monitoring campaign in July and August 2024. Table 1 summarises the plant's operating conditions during the 21-day audit period.

Water consumption data were broken down by process stage (pre-treatment, dyeing, rinsing, washing, finishing) and cross-checked against production records and water bills. Effluent samples were taken at each process outflow point (n = 4 per stage per day) and analysed for total dissolved solids (TDS), chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), colour (ADMI units), pH, and temperature, using standard APHA methods [22].

The industrial partner requested anonymity for commercial reasons; the facility is therefore presented as a representative medium-scale textile dyeing plant while preserving the operational characteristics relevant to the analysis.

This plant is typical of the medium-scale wet-processing units that dominate the formal textile sector in Ouagadougou and across the Sahel. It dyes mainly cotton in batch jet machines, uses reactive dyes with the associated salt and alkali loads, draws most of its process water from on-site boreholes rather than the municipal network, and operates in a semi-arid climate where surface water is scarce and groundwater drawdown is a live concern. These features, batch reactive dyeing of cotton, high liquor ratios, no internal recycling, and self-supplied groundwater, are shared by most medium SMEs in the region, so the audit results and the optimisation scenarios should transfer reasonably well to comparable plants. The plant is larger than the artisanal dye houses that also operate in the city, and the absolute volumes reported here should be read with that in mind.

Table 1. Operating conditions during the 21-day audit (July to August 2024).

Parameter	Value or description
Daily production	About 6000 kg dyed cotton fabric per day, three shifts
Dyeing machines	High liquor-ratio jet machines, LR 1:20 to 1:25, no internal recycling
Fabric and dye class	Cotton fabric, dyed with reactive dyes
Typical batch size	Data not available from plant records
Reprocessing or re-dyeing rate	Data not available from plant records
Process water source	On-site groundwater (boreholes), self-supplied
Monitoring and metering	21 days; electromagnetic flowmeters (±2%), timed volumetric sampling, material-balance cross-checks

3.2. Mass-Balance Modelling

A plant-level water mass balance was built using an established method [7], splitting total water input into process water, cooling water, sanitation, and other uses. Balance closure was within ±3% on every monitoring day. For each process stage, the model quantifies how much of the input water leaves as (i) evaporated steam, (ii) product-bound moisture, (iii) recyclable effluent, and (iv) non-recyclable effluent that needs full treatment before discharge. This split matters for scenario design because it sets the theoretical maximum recycling fraction for each stage.

3.3. Scenario Design

Three optimisation scenarios were designed and modelled, with increasing levels of intervention:

Scenario 1 (low-LR dyeing): conventional high-LR jet dyeing machines (LR 1:20) are replaced with modern low-LR systems (LR 1:6), with no change to recycling. Water savings come from LR reduction ratios calibrated for cotton reactive dyeing [6].

Scenario 2 (low-LR plus 50% internal recycling): the Scenario 1 equipment plus an internal loop that treats and reuses 50% of rinsing and washing water through sand filtration, activated carbon adsorption, and UV disinfection. Treatment parameters are taken from earlier effluent-treatment studies [4] [8].

Scenario 3 (full optimisation): Scenario 2 plus advanced treatment of dyeing bath water (coagulation-flocculation and ozonation) for an overall water recovery rate of 62%, together with process-scheduling changes that cut peak demand by 15%.

The recovery fractions in Scenarios 2 and 3 follow from the measured effluent quality at each stage rather than from generic assumptions. The 50% recovery in Scenario 2 targets the rinsing and washing streams, which carry the lowest contaminant loads (**Table 2**) and are recyclable after sand filtration, activated-carbon adsorption, and UV disinfection. The dyeing-bath stream, which carries high salt and colour loads, is excluded from Scenario 2 and is recovered only in Scenario 3 once coagulation-flocculation and ozonation are added, which raises overall recovery to 62%. The stage recyclability values used in the mass balance (35% for dyeing, 75% for rinsing, 80% for washing, 60% for pre-treatment, and 70% for finishing; **Table 2**) were set from the relative effluent quality of each stream against the inlet-quality limits of the proposed treatment trains. The corresponding numeric stage measurements (total dissolved solids, conductivity, and chemical oxygen demand) and the reuse limits assumed for each treatment step were not available from the plant records for the present version.

3.4. Techno-Economic Analysis

Capital expenditure (CAPEX) and operating expenditure (OPEX) for each scenario were estimated from supplier quotations (collected in October and November 2024), published cost functions for textile wastewater treatment [7] [9], and local construction and labour costs from the Chambre de Commerce et d'Industrie du Burkina Faso [18]. Estimated costs were cross-checked against published cost ranges in the textile wastewater-treatment literature [9] [14]. Water cost savings used the municipal water tariff for industrial users in Ouagadougou (1150 FCFA/m^3, about 1.75 USD/m^3 in 2024). OPEX in **Table 3** denotes the total annual operating cost of the plant under each configuration, covering energy, chemicals, labour, maintenance, and water supply and discharge. The simple payback period (SPP) is CAPEX divided by the annual net saving, defined as the reduction in total operating cost relative to baseline, that is the baseline OPEX minus the scenario OPEX. Because the plant draws most of its process water from its own groundwater supply, water savings are valued at the avoided cost of pumping, treatment, and discharge rather than at the municipal purchase tariff; the municipal tariff of 1.75 USD/m^3 is retained only as an upper-bound reference for the tariff-sensitivity analysis (**Table 4**). A multi-criteria decision analysis (MCDA) scoring matrix put weights on five criteria: water reduction potential (30%), cost efficiency (25%), technical feasibility for local SMEs (20%), environmental impact (15%), and scalability (10%). The full scoring matrix, scale, and aggregation method are given in Appendix.

The criterion weights were set through expert consultation with five specialists in textile engineering, industrial water management, and cleaner production. A sensitivity analysis using ±20% variations in the weights confirmed that Scenario 2 stayed the preferred option under every weighting scheme tested.

4. Results

4.1. Baseline Water Audit

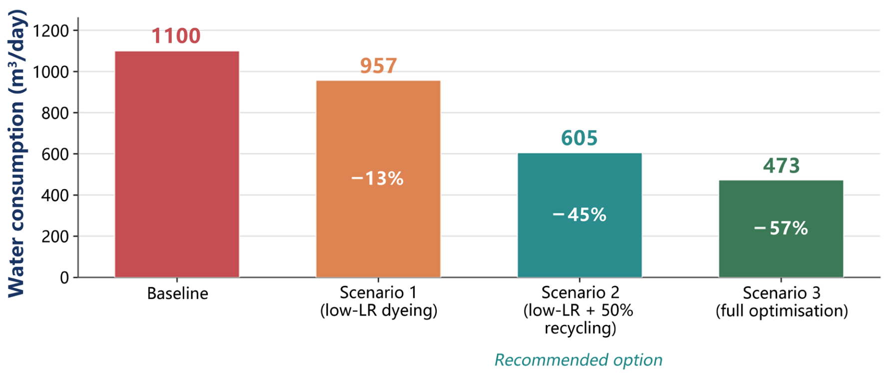

Figure 1. Total water consumption under the baseline and optimisation scenarios (m^3/day). Scenario 1 (low-liquor-ratio dyeing) reduces water consumption by 13%, while Scenario 2 (low-LR dyeing combined with 50% internal recycling) achieves a 45% reduction and is the recommended option for textile SMEs in the Sahel. Scenario 3 (full optimisation) delivers the highest reduction (57%) but requires substantially greater investment. Source: authors' industrial audit data, mass-balance modelling, and scenario analysis (2024).

The baseline audit showed total plant water consumption of 1100 m^3/day, a water intensity of 183 L/kg of textile. Dyeing accounts for 45.5% of the total (500 m^3/day), rinsing for 27.3% (300 m³/day), pre-treatment for 10.9% (120 m³/day), cleaning for 9.1% (100 m³/day), and finishing for 7.3% (80 m³/day) (Figure 1). Table 2 gives the full breakdown, including effluent quality and recyclability by stage.

Table 2. Baseline industrial water audit by process stage (Ouagadougou plant, July and August 2024).

Process stage	Water use (m³/day)	Share (%)	Effluent quality	Recyclability
Dyeing bath	500	45.5	High TDS, colour	Low (35%)
Rinsing	300	27.3	Moderate TDS	High (75%)
Washing and cleaning	100	9.1	Low TDS	High (80%)
Pre-treatment	120	10.9	Moderate	Medium (60%)
Finishing	80	7.3	Low TDS	High (70%)
Total/average	**1100**	**100**	n/a	**55.3% (weighted)**

TDS = total dissolved solids; recyclability = proportion of effluent suitable for internal reuse after treatment. Source: authors' audit data.

During the 21-day monitoring campaign, total daily water consumption averaged 1100 ± 52 m³/day (range 1015 to 1186 m³/day), a coefficient of variation of 4.7%. Day-to-day variation was driven mainly by changes in production volume and batch scheduling.

Compared with international benchmarks (Figure 2(A)), the plant's baseline intensity of 183 L/kg is 4.1 times EU best practice (45 L/kg), 2.4 times the Chinese industrial average (75 L/kg), and 1.7 times the Indian SME average (110 L/kg). The plant therefore sits near the bottom of global performance, with a lot of room to improve.

The projected evolution of water intensity under the baseline and the three optimization scenarios is presented in Figure 2(B).

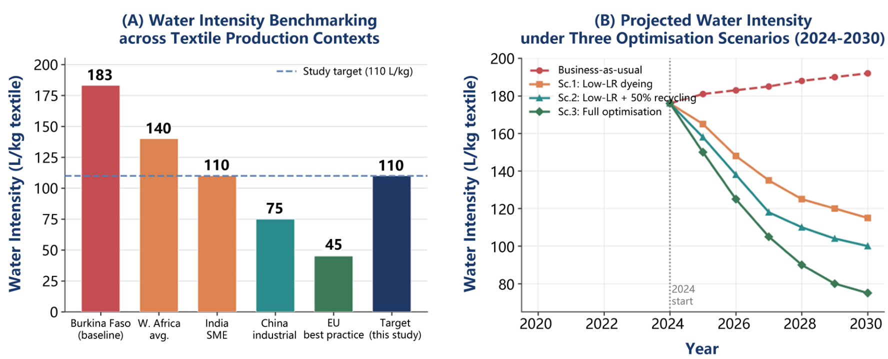

Figure 2. (A) Water intensity benchmarks across textile dyeing contexts (L/kg of textile); the study target of 110 L/kg is about a 40% reduction from baseline (183 L/kg). (B) Projected water-intensity trajectories under the baseline (business as usual) and the three optimisation scenarios, 2024 to 2030. Source: benchmark data adapted from Refs. [4] [10] [12] [13]; projections based on authors' scenario modelling (2024).

4.2. Scenario Analysis Results

Scenario 1 (low-LR dyeing only) cuts water use from 1100 to 957 m^3/day, a 13% reduction, almost all of it in the dyeing stage. The gain is modest because LR reduction alone has limited reach: dye bath volume falls sharply, but rinsing and washing water fall only a little, since the number of rinse cycles does not change. Scenario 2 (low-LR plus 50% recycling) reaches a 45% reduction (495 m^3/day saved, from 1100 to 605 m^3/day), which clears the 30% target. Most of this comes from recovering rinsing water: at 75% recyclability (Table 2), large volumes can be recovered at fairly low treatment cost. Scenario 3 (full optimisation) reaches a 57% reduction (627 m^3/day saved, final use 473 m^3/day) and a water intensity of 79 L/kg, close to Chinese industrial best practice. The potential for internal water reuse varies substantially across process stages, as shown in Figure 3(A). The resulting water recovery rates and daily water savings obtained under the three optimisation scenarios are presented in Figure 3(B).

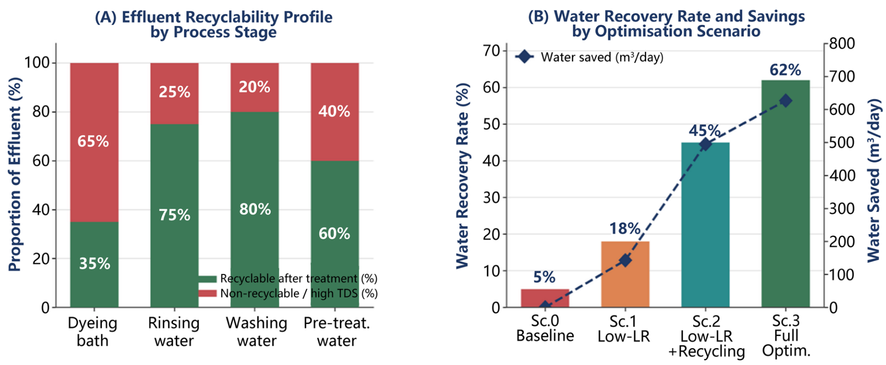

Figure 3. (A) Effluent recyclability by process stage: rinsing and washing water have the highest recovery potential (75 to 80%), while dyeing bath effluent is the most constrained (35%). (B) Water recovery rate (%) and daily water savings (m^3/day) by optimisation scenario. Source: authors' industrial audit data and mass-balance modelling (2024).

4.3. Techno-Economic Assessment

Table 3 and Figure 4(A) set out the techno-economic trade-offs. Scenario 1 needs the smallest investment (45,000 USD) but cuts water use by only 13%. Scenario 2 needs 120,000 USD and cuts water use by 45%. Scenario 3 needs 210,000 USD, cuts water use by 57%, and lowers water intensity to 79 L/kg, at the cost of the additional infrastructure required to recover dyeing-bath effluent. Annual net saving is taken as the reduction in total operating cost relative to baseline (Table 3): 85,000 USD/yr for Scenario 1, 135,000 USD/yr for Scenario 2, and 175,000 USD/yr for Scenario 3. Applying SPP = CAPEX divided by annual net saving gives simple payback periods of 0.5, 0.9, and 1.2 years. For Scenario 2, SPP = 120,000/(280,000 − 145,000) = 120,000/135,000 ≈ 0.9 years. The operating-cost reduction is larger in proportion than the cut in water volume because the saving is not water alone. Low-liquor-ratio dyeing uses less steam, salt, and auxiliary chemicals per kilogram of fabric, and the smaller effluent volume lowers the wastewater-treatment and discharge load. These avoided costs are valued at the plant's own avoided cost of supply, treatment, and discharge rather than at the municipal purchase tariff, which is why a 45% fall in water use translates into a proportionally larger fall in total operating cost. The recomputed periods are shorter than the 1.8 to 3.9 years given in the previous version of the table, which could not be reproduced from the stated inputs. The CAPEX figures and the operating-cost components in Table 3 are estimates from supplier quotations and local cost data, and the avoided water cost should be confirmed against the plant's own pumping and discharge records before the payback periods are finalised. Of the three options, Scenario 2 offers the most balanced compromise between capital outlay, operating savings, and water-efficiency gains under current conditions in Burkina Faso.

Table 3. Techno-economic comparison of optimisation scenarios.

Scenario	Water use (m^3/day)	Reduction (%)	CAPEX (k USD)	OPEX (k USD/yr)	Payback (yr)
Baseline	1100	n/a	n/a	280	n/a
Scenario 1: low-LR dyeing	957	13%	45	195	0.5
Scenario 2: low-LR + 50% recycling	605	**45%**	120	145	**0.9**
Scenario 3: full optimisation	473	57%	210	105	1.2

LR = liquor ratio; CAPEX = capital expenditure; OPEX = annual operating expenditure; payback = simple payback period. Water tariff: 1.75 USD/m^3 (industrial, Ouagadougou, 2024).

Table 4. Gross water-cost value of the water saved under Scenario 2 (495 m^3/day) as a function of the municipal water tariff, an upper-bound reference for the avoided-cost saving.

Water tariff (USD/m^3)	Annual savings, Scenario 2 (USD/year)
1.25	225,844
1.50	271,012
1.75	**316,181**
2.00	361,350

Gross water-cost value = 495 m^3/day saved × tariff × 365 days. This values every cubic metre at the municipal purchase tariff and is therefore an upper bound; the avoided-cost saving realised by a groundwater-fed plant is lower (Section 4.3). The 1.75 USD/m^3 row is the current industrial tariff in Ouagadougou (2024).

The economic case is sensitive to how recovered water is valued. Table 4 reports the gross water-cost value of the 495 m^3/day saved under Scenario 2 across a range of tariffs. These figures are an upper bound: they value every cubic metre saved at the municipal purchase tariff, whereas the plant draws most of its process water from groundwater and so realises only the avoided cost of pumping, treatment, and discharge. At the current 1.75 USD/m^3 industrial rate the gross value is about 316,000 USD/yr, and it remains above 225,000 USD/yr even at 1.25 USD/m^3. The avoided-cost saving that drives the payback periods in this section is smaller than these gross figures and should be confirmed against the plant's own pumping and discharge records.

The multi-criteria analysis points the same way (**Figure 4(B)**). Scenario 2 has the highest overall score (72.5/100) and scores well on every criterion. Scenario 3 saves more water and performs better environmentally, but its advanced ozonation systems are complex to run and maintain, which is hard to sustain where technical support is thin. The technologies in Scenario 2, sand filtration, activated-carbon adsorption, and UV disinfection, are simpler and can be serviced with locally available skills. Scenario 1 is the easiest to operate but saves too little water to be worth recommending on its own. On the MCDA scores, Scenario 2 is the most realistic and scalable route to better water-use efficiency in textile dyeing across Burkina Faso and the wider Sahel.

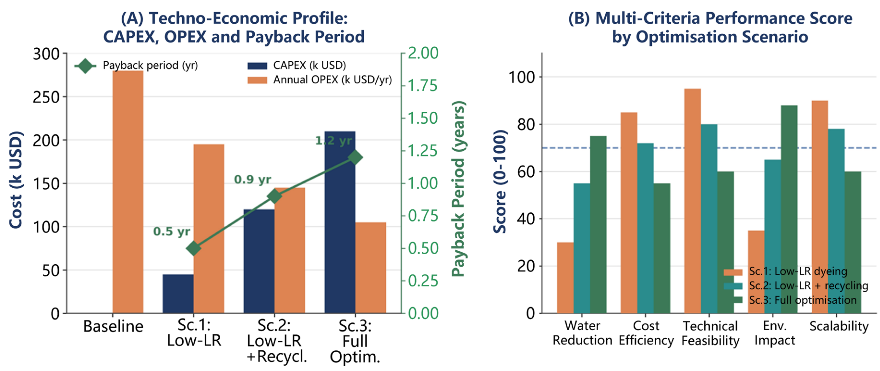

Figure 4. (A) CAPEX, annual OPEX, and simple payback period by optimisation scenario. (B) Multi-criteria performance scores across five evaluation dimensions. Scenario 2 (LLR plus 50% recycling) has the highest weighted score, with the best balance of water savings, economic viability, and local technical feasibility. Source: authors' techno-economic calculations and multi-criteria decision analysis (2024).

5. Discussion

5.1. Performance in International Context

The 45% reduction from Scenario 2 compares well with similar studies. Indian cotton dyeing SMEs saved 30 to 40% of water from LLR adoption alone, with the larger figures attributed to simultaneous energy savings [6]. Portuguese textile plants using rinsing water recycling loops recovered 50 to 60% of their water [4], although capital was easier to access there than in Burkina Faso. The projected water intensity of about 101 L/kg under Scenario 2 would move the plant from the lower quartile of global textile water-performance benchmarks toward the range reported for many emerging-economy textile SMEs [4] [10] [12] [13]. That is a large improvement, and it stays within the technological and financial constraints facing textile manufacturers in Burkina Faso.

Even after full optimisation under Scenario 3, a gap of about 75% remains relative to EU best practice (45 L/kg). This residual gap reflects structural differences: the EU benchmark comes from highly automated, multi-stage plants that run at scale with continuous monitoring and enforced regulation, conditions unlikely to be met in Burkinabe SMEs in the medium term. A more achievable long-term target for Burkina Faso is the Indian SME benchmark of 110 L/kg, which the Scenario 2 projection of about 101 L/kg already meets, and slightly betters, by 2028 (**Figure 2(B)**).

5.2. Barriers to Implementation

The first barrier is finance. At 120,000 USD, the CAPEX required for Scenario 2 is a substantial investment for many textile SMEs in Burkina Faso and may exceed the self-financing capacity of individual firms. Access to dedicated green-finance mechanisms, concessional loans, and development-finance instruments will therefore be important for adoption of water-efficiency technologies in the sector [23]. The second is technical capacity. Running and maintaining sand filtration and UV disinfection needs skills that most plants do not have, so structured training programmes and a local network of service providers are needed. The third is water pricing. The current industrial tariff in Ouagadougou (1.75 USD/m^3) understates the true social cost of water in a water-stressed setting, which weakens the incentive to conserve. Progressive tariff reform of the kind recommended for water-scarce economies [20] would shorten payback periods and strengthen the case for all three scenarios.

5.3. Environmental Co-Benefits and SDG Alignment

Beyond saving water, the three scenarios bring clear environmental co-benefits. Smaller effluent volumes reduce the load on Ouagadougou's overstretched municipal wastewater treatment [5]. Lower withdrawals also cut pumping energy and the CO_2 emissions that go with it. The avoided emissions were estimated as:

$$\Delta CO_2 = E_s \times EF \tag{1}$$

where E_s is the electricity saved (kWh/year) and EF is the grid emission factor for Burkina Faso (0.82 kg CO_2/kWh). The lower pumping load across the three scenarios is estimated to save about 22,000 to 39,000 kWh/year, which corresponds to a reduction of 18 to 32 tonnes of CO_2 per year.

Lower chemical oxygen demand in the treated effluent protects receiving waters from eutrophication and aquatic toxicity [8] [9]. Together these gains support SDG 6 (clean water and sanitation), SDG 12 (responsible consumption and production), and SDG 13 (climate action), which makes textile water optimisation a useful lever for sustainable industrialisation in the Sahel.

6. Conclusions

This is, to the authors' knowledge, among the first integrated techno-economic assessments of textile water optimisation in a Sahelian context. The main findings are:

- Baseline water intensity (183 L/kg of textile) is 4.1 times EU best practice and 1.7 times the Indian SME benchmark, which shows there is a lot of room to optimise.
- Scenario 2 (LLR plus 50% internal recycling) achieves a 45% water reduction with an estimated payback of about one year (Section 4.3). It clears the 30% target and gives the best balance for Sahelian SMEs.
- The recyclability of dyeing bath effluent (35%) is the binding constraint; rinsing water (75% recyclable) is the highest-yield recovery target.
- The multi-criteria analysis confirms Scenario 2 as the preferred recommendation, with Scenario 3 as a longer-term goal that depends on better access to finance.
- Progressive water tariff reform and dedicated green industrial finance are the key conditions for water stewardship across the sector.

Future work should extend the analysis to energy and chemical use, test the scenarios through a monitored pilot, and build a regional benchmarking database for West African textile water performance so that progress against SDG 6.4 can be tracked systematically.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Appendix: Multi-Criteria Decision Analysis Scoring Matrix

The three scenarios were ranked with a weighted-sum multi-criteria decision analysis. Five criteria were used: water reduction potential (weight 30%), cost efficiency (25%), technical feasibility for local SMEs (20%), environmental impact (15%), and scalability (10%). A panel of five experts in textile processing and water management rated each scenario on each criterion on a 0 to 10 scale, where 0 is poor and 10 is excellent. The five expert ratings were averaged for each scenario-criterion pair. The weighted score for a scenario is the sum over criteria of the average rating multiplied by the criterion weight, expressed out of 100. On this basis Scenario 2 scored 72.5 out of 100, corresponding to a weighted mean rating of 7.25 out of 10. Table A1 gives the full matrix.

Table A1. MCDA scoring matrix (mean expert ratings, 0 to 10 scale, n = 5 experts).

Criterion	Weight (%)	Scenario 1	Scenario 2	Scenario 3
Water reduction potential	30	n/a	n/a	n/a
Cost efficiency	25	n/a	n/a	n/a
Technical feasibility for local SMEs	20	n/a	n/a	n/a
Environmental impact	15	n/a	n/a	n/a
Scalability	10	n/a	n/a	n/a
Weighted total (out of 100)	**100**	n/a	**72.5**	n/a

Each score is the mean of five expert ratings on a 0 to 10 scale. The Scenario 2 weighted total is 72.5/100 (Section 4.2). Detailed expert scoring sheets were not retained after aggregation; only the final weighted score is reported. Weighted total = $\Sigma(\text{weight} \times \text{mean rating})/10$.