IWA 17th SWWS AND 9th ROS
10th–14th November, 2024
Curitiba-Brazil

Performance, optimization, socio-economic acceptance, and drivers of a low-tech solar-driven pilot laundry facility (LaundReCycle) in South Africa

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Highlights:

- Satisfactory COD and turbidity removal in the biofilter with maximum effectiveness after a retention time of three days
- Water self-sufficiency reached 93 % in an extrapolated scenario, and energy self-sufficiency reached 91.6 % indicating high levels of self-sufficiency
- Cultural factors play a significant role in shaping the attitudes of potential users indicating the need for tailored communication strategies

Keywords: Greywater treatment; Wastewater reuse; Self-sufficiency

INTRODUCTION

In response to the global water crisis, innovative approaches like decentralized water systems, rainwater harvesting and greywater treatment are gaining traction (Koop & van Leeuwen, 2017). Laundry machines are a major household greywater source, contributing 14% of total wastewater in countries like Greece and Denmark, and up to 34% in the USA (Noutsopoulos et al., 2018). Depending on the type of laundered material and cleaning agents used, laundry effluent can contain surfactants, organic dyes, nitrogen, phosphorus, alkalis, bleach, fillers, suspended solids, micro-fibres, pathogens, micro-plastics and xenobiotic compounds which can seriously threaten environmental and aquatic health if released untreated (Sharma et al., 2020). As a result, there has been a growing interest in exploring methods to recycle laundry wastewater to mitigate the dual challenges of wastewater disposal and freshwater conservation. The majority of research in this domain has been oriented towards developing advanced treatment methods designed for industrial applications, often associated with significant capital and operational expenses (Bering et al., 2018; Ciabatti et al., 2009; Patil et al., 2020). In contrast, the LaundReCycle pilot plant in Cape Town exemplifies a low-tech, cost-efficient approach to the treatment and reuse of laundry effluent aiming for complete water and energy self-sufficiency. This study evaluates the plant's real-life performance, focusing on treatment performance, water and energy self-sufficiency, and consumer acceptance and preferences for greywater reuse.

METHODOLOGY

The LaundReCycle pilot plant is a unique laundromat that integrates a near-closed water cycle based on greywater treatment and reuse, and rainwater harvesting (Buehler et al., 2020). This low-tech greywater treatment consisted of a pre-treatment settling tank, biofilter, sediment and activated carbon filter, and disinfection with a UV lamp. After treatment, the water was reused for the next wash cycle. Rainwater from the roof of the facility was collected and used to compensate water losses. The energy used to run the system was supplied from the off-grid solar system on the roof of the facility, equipped with $LiFePO_4$-battery. The system was operated from 12 October 2022 to 25 April 2023 and was monitored for 21 water quality parameters including COD, TP, TN, TOC, turbidity, DO, pH, EC, temperature, surfactants, dissolved and suspended solids, certain metals, ions and microbial parameters. Water and energy self-sufficiency were assessed using both measured data and simulations designed to explore optimized scenarios. These analyses were complemented by a socio-economic survey, conducted in South Africa and the other in Switzerland designed to gather information about attitudes of potential users towards greywater reuse.

RESULTS AND CONCLUSIONS

The removal rates in the biofilter for COD (82 %) and turbidity (95 %) were satisfactory, with the biofilter showing maximum effectiveness after a retention time of three days (Figure 1). However, some challenges persisted, such as residual coloration and stable organic compounds in the treated water indicating the need for optimization, such as scheduling of water transfers, or additional treatment steps. The treated water generally adhered to at least one of the applied guidelines, yet at times exceeded limits set by others, underscoring the necessity for more standardized and universally applicable water quality guidelines for the reuse of laundry wastewater.

During the monitoring period, the water self-sufficiency rate improved from 20% to 62%. In the extrapolated scenario for one year, using climatological rainfall data, the self-sufficiency rate reached 93% (Figure 2). To achieve complete self-sufficiency, a 6 m^2 increase in rainwater collection area may already suffice. The system achieved an energy self-sufficiency rate of 91.6 % with 7 daily washing cycles. By doubling the daily washing cycles to 14 and improving the energy efficiency of the water treatment system, this economically and technically optimized scenario achieved a 90.8% self-sufficiency rate while reducing the average daily energy consumption from 6.3 kWh to 4.0 kWh, demonstrating that high energy self-sufficiency and an economically viable operation are both achievable.

The socio-economic analysis highlighted cultural differences in attitudes towards greywater reuse. Respondents from South Africa displayed a more favourable view compared to those from Switzerland, likely due to their experience with water scarcity and active governmental campaigns promoting water conservation. The results underscore the need for communication strategies that emphasize environmental benefits while addressing health and safety concerns to enhance public acceptance and adoption rates. Overall, this study provides valuable insights into sustainable water management, showcasing both the practical feasibility and the challenges of implementing a nearly closed water cycle system like the LaundReCycle.

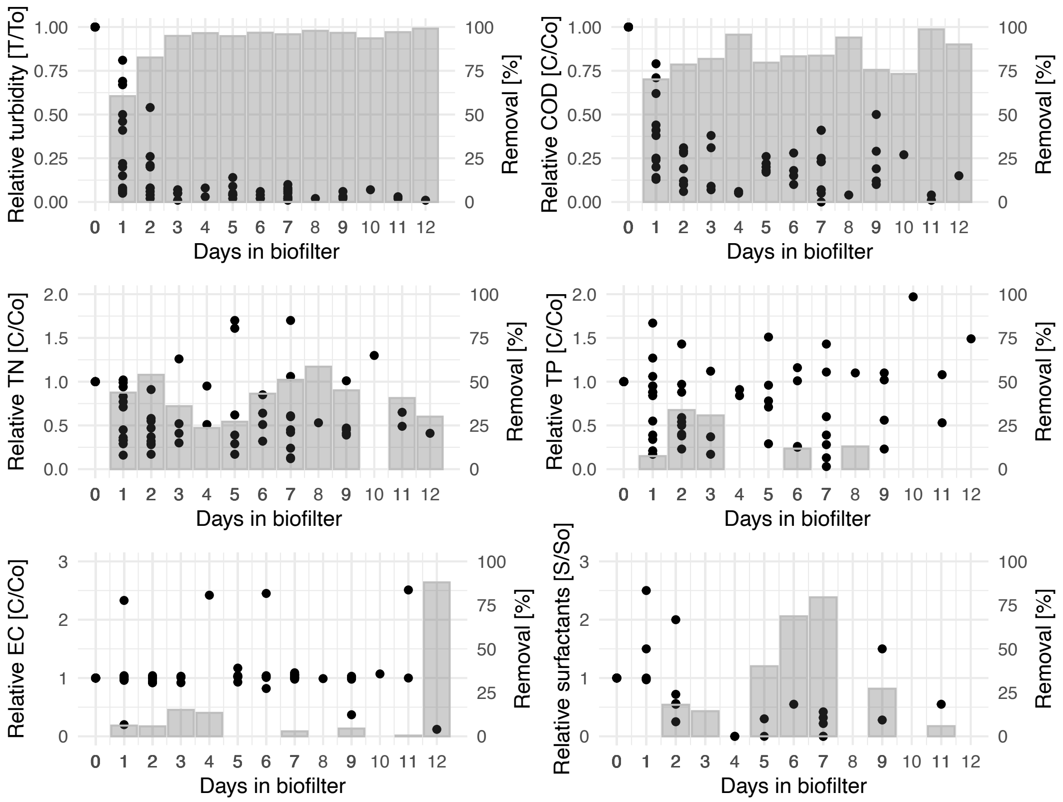

Figure 1: Biofilter performance over 12 days. Relative values for turbidity, COD, TN, TP, EC and surfactants (black dots) alongside the removal rates on the corresponding day versus day 0 (grey bars).

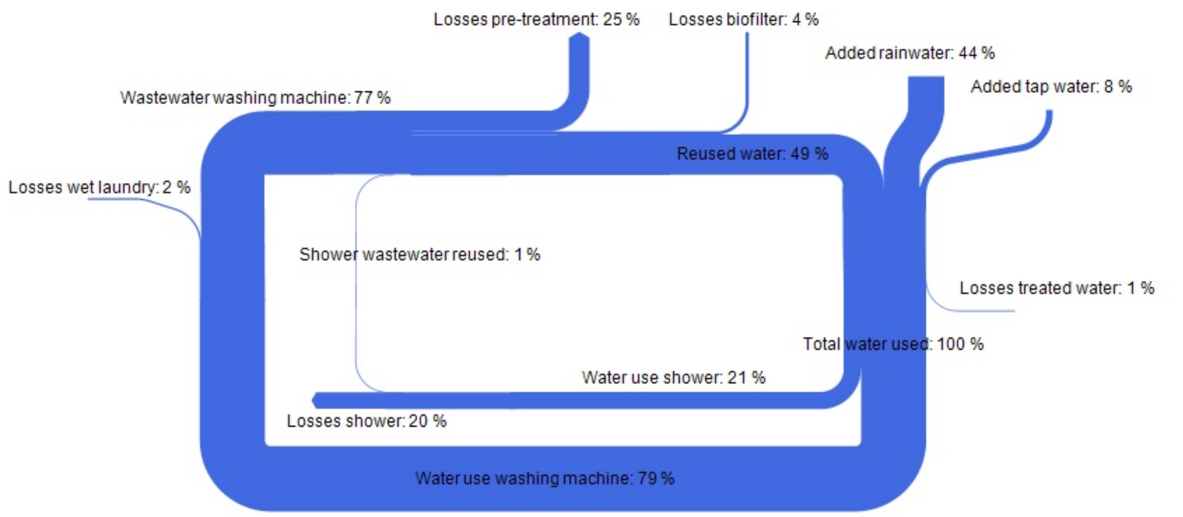

Figure 2: Extrapolated water balance for one year based on the measured data from January to April 2023 with climatological rainfall data for Cape Town, South Africa. Source: authors' elaboration.

Acknowledgements

The research was funded by REPIC, an interdepartmental platform of the Swiss federal offices SECO, SDC, FOEN, SFOE for the promotion of renewable energy, energy and resource efficiency in developing and transition countries, in the scope of project no 2018.2 “LaundReCycle – A water and energy self-sufficient laundromat”. Matthias Frei, Bernard Wessels, Pascal Hauser, Khulisa NPO, and all other project partners are gratefully acknowledged for their support.

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