

From microfibers to nanodiamonds: Assessment of the added environmental/social and economic benefits of a combined process for upcycling and reusing washing machine wastewater

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Keywords: Biofilter, Life Cycle Assessment, Microplastics, Nanodiamonds, Textile Microfibers, Up-cycling, Washing Machine Wastewater

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Microplastics are released throughout the whole plastics value chain, from production, transport and use, to end of life, and they are generally divided into primary (i.e. that are directly released into the environment as plastic particles) or secondary (i.e. that are formed by the breakdown of larger plastic items littered in the environment). The wearing and washing of textiles made from synthetic fibers is one of the recognized sources for primary microplastics release in water bodies (EEA, 2022). It has been estimated that about 8% of the microplastics released to oceans in Europe derive from the washing of synthetic textiles, since most households are connected to a sewage and wastewater treatment system, however globally this figure is estimated to be significantly higher, 16-35% (EEA, 2022). Specifically, the laundering of synthetic textiles leads to the release of microplastic fibers that are defined by the European Chemicals Agency as materials consisting of solid polymer-containing particles, to which additives or other substances may have been added and that present a length of $3\text{nm} \leq x \leq 15\text{mm}$ and length to diameter ratio of >3 (ECHA, 2019). As recently reviewed by Sheikhi et al. (2024), in-drum systems and out-drum filters have been developed for removing microfibers shed during textiles washing directly at the source. The first type removes them during the washing cycle inside the machine by the use of washing bags or Cora balls; the second type uses filters for extracting the microfibers from the washing machine wastewater and can be embedded in the machine or placed externally (Sheikhi et al., 2024). Several types of filters are commercially available, but an aspect that has not been addressed up to now is the valorization potential of the collected fibers to produce high-value products.

In a research project financed by the Italian Ministry of the Environment and Energy Security, an integrated treatment is being tested by a multidisciplinary team lead by the Department of Biology of the University of Rome Tor Vergata to allow to up-cycle the microfibers shed by domestic washing machines as well as to reuse the produced wastewater for non-potable household applications. A specific type of filter is being designed to allow to maximize the capture of microfibers, whereas a hydrogen plasma pyrolysis unit is being tested for the synthesis of nanodiamonds to be used for a wide range of applications. As for wastewater treatment, a bioremediation system is being developed through the engineering of an ad hoc microbial consortium including a phototroph cyanobacterium and heterotrophic bacteria working synergically to remove nutrients and other characteristic contaminants of washing machine wastewater.

Incorporating an eco-design perspective, the project prioritizes resource efficiency, extended product lifespan, and easy maintenance through modular component replacement. Moreover, a life cycle assessment (LCA) study is being conducted to evaluate the potential environmental benefits, alongside a baseline scenario analysis to assess social and economic impacts. This methodology based on individual expert consultations, and consumer surveys aims to define the existing environment in which the project operates by identifying future risks and opportunities before developing and designing practical solutions for its implementation.

With specific regard to the life cycle assessment evaluation, the goal is to attain a first assessment of the environmental sustainability of the process and to identify potential critical issues to consider in the development of the single units that constitute it. Since additional impacts are associated to the microfiber valorization step, with regard to the transport but especially to the upcycling unit, it is fundamental to adequately model the impacts that may be avoided by implementing the proposed processes. For this reason, the baseline case of washing machine wastewater discharge and conventional treatment must be evaluated, as well as the current methodologies that are employed for producing nanodiamonds and the impacts related to tap water consumption. Figure 1 reports a scheme of the three scenarios that are being analyzed. In Scenario zero, that represents the current business as usual case, it is assumed that the wastewater generated during household laundering of textiles is discharged without further treatment in the sewage system (a) and reaches the Wastewater Treatment Plant (WWTP) where it undergoes treatment before being discharged into the receiving water body (c). In this case it is assumed that tap water is employed for domestic uses such as plant irrigation (d-e). Scenario 1, assumes instead that a filter is installed to remove a significant percentage of the microfibers shed by the washing of the textiles (f); the pre-treated wastewater follows the same pathway as the one described in scenario 0 (b-c); while the captured microfibers are collected and transported to a facility where they undergo upcycling via hot plasma technology, converting them into nanodiamond powder (g-h). Also in this case it is assumed that tap water is used for domestic

uses (d-e). Finally, Scenario 2 includes the same textile microfiber capture and upcycling processes as the ones considered in the previous scenario (f-g-h). However, it also assumes that the pre-filtered wastewater is treated in a biofiltration process (i) that allows it to be directly reused for non-potable domestic uses (e), thereby reducing overall water consumption and avoiding to send it to the WWTP.

In the contribution to the conference, details on the units of the innovative process will be provided, as well as a discussion on the first results of the scenario analysis. In particular, both environmental impacts by LCA and socio-economic aspects considering the application of the proposed process in two different Italian Provinces assuming different business models based on either public led initiatives, private only enterprises or mixed solutions, will be presented and compared. The results will indicate which business models are best suited to the future market and regulatory context.

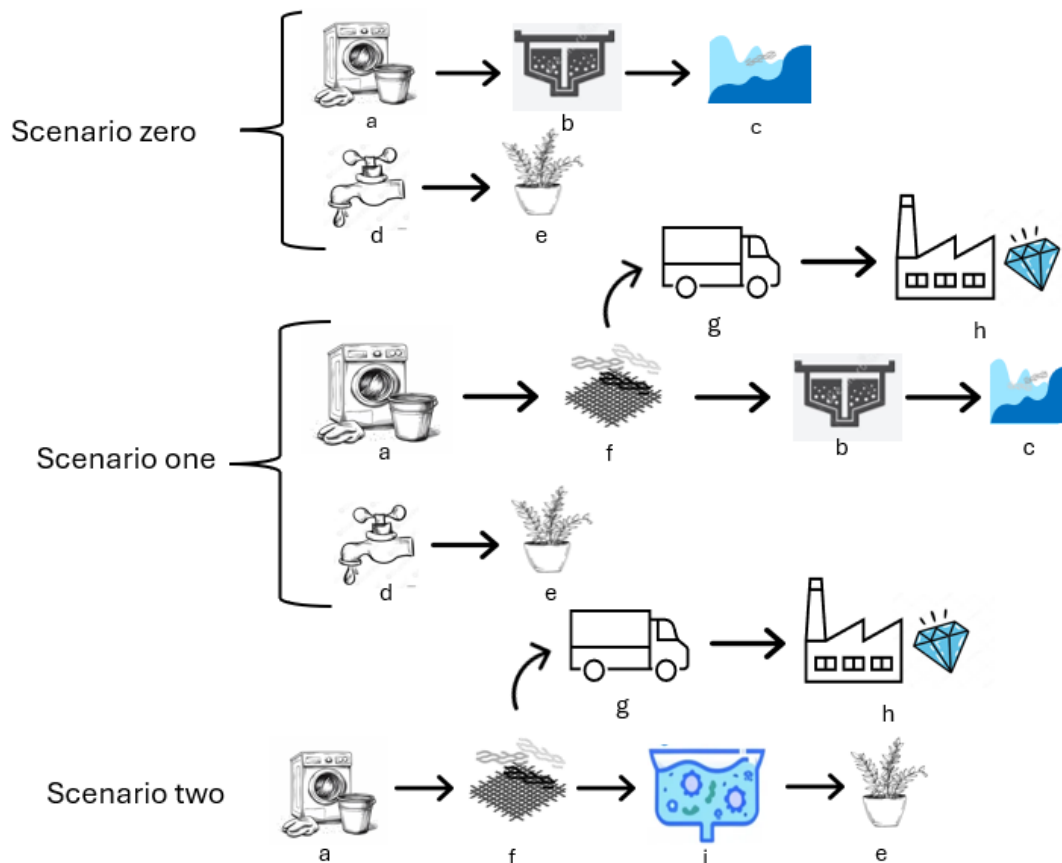


Figure 1 – Main units of the three scenarios considered in the study: scenario 0 – no collection of microfibers from washing machine wastewater and use of tap water for domestic non-potable uses; scenario 1 – collection of the fibers through filters, up-cycling of the fibers to nanodiamond powders and use of tap water for domestic non-potable uses; scenario 2 - collection of the fibers through filters, up-cycling of the fibers to nanodiamond powder and reuse for domestic non-potable uses of treated washing machine wastewater by biofiltration.

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