

Advanced processes for circular economy: textile waste valorisation

Abstract:

The rapid expansion of fast fashion over the past two decades accounts for approximately 10% of global greenhouse gas emissions (GHG) and is responsible for around 20% of global industrial water pollution (Ellen MacArthur Foundation, 2017).

The present thesis investigates the technical feasibility, process optimisation, and environmental sustainability of a biotechnological valorisation chain for post-consumer textile waste, with particular focus on blended fabric compositions representative of fast fashion waste streams. Alternative valorisation routes are examined, specifically hydrolysis and depolymerisation processes yielding raw materials for other industrial chains or finished products. This study is part of a broader research initiative funded under the National Recovery and Resilience Plan (PNRR), within the extended partnership called Made in Italy Circular and Sustainable (MICS) aimed at the reducing the environmental impact of three Italian manufacturing: apparel, furniture, and automation. The work is organised into the following structure.

Chapter 1 contextualises textile waste generation within the fast fashion sector through a structured environmental, economic, technical, and social analysis, identifying critical points in the disposal chain where valorisation technologies can be most effectively applied. Waste management legislation is examined across global, European, and national scales, with focus on extended producer responsibility (EPR) schemes, while a bibliometric analysis documents the trajectory of scientific engagement over the past decade. Established valorisation techniques are critically reviewed for their advantages, limitations, and applicability.

According with this results, Chapter 2 identifies enzymatic hydrolysis as a particularly promising approach. The chapter presents a systematic review of pretreatment, hydrolysis, and fermentation processes applied to cellulosic-blended textile waste, with fiber types classified by chemical composition, degree of polymerisation, and crystallinity. Each processing technique is assessed for yield, environmental impact, and scalability. A yield harmonisation procedure enables consistent cross-study comparison; Principal Components Analysis (PCA) identifies the parameters most significantly affecting glucose conversion yield, benchmarked against lignocellulosic and agri-food feedstocks.

Building on the outcomes of the systematic review, Chapter 3 investigates a step-wise biotechnological valorisation chain applied to blended post-consumer textile waste. Cold alkaline pretreatment with NaOH and urea is optimised to maximise enzymatic hydrolysis yield. Hydrolysis is applied to three textile substrates and orange-peel waste; the resulting glucose streams feed Polyhydroxybutyrate (PHB) biosynthesis by *Cupriavidus necator* 545. Two Life Cycle Assessment (LCA) studies compare PHB production impact against conventional PHB and fossil-based Polyethylene terephthalate (PET), and benchmark the valorisation pathway against landfill and incineration, identifying cold pretreatment and equipment scaling as principal environmental hotspots.

For this reason, Chapter 4 addresses three cellulase reuse strategies for the enzymatic hydrolysis of 50/50 cotton/polyester blended textile waste over 14 consecutive cycles, monitoring weight loss efficiency, reducing sugar concentration, residual protein content, and filter paper unit activity. Scenario C, supplementing 25% of the original enzyme dose every third cycle, provides the best balance between long-term degradation efficiency and enzyme consumption, as further supported by life cycle and economic assessments.

To further maximize blended-textile valorisation, Chapter 5 presents a sequential dual-recovery process targeting both fractions of viscose/PET waste. Enzymatic hydrolysis selectively degrades the cellulosic fraction, followed by hydrothermal liquefaction (HTL) of the PET residue at 340 °C, recovering TPA (73.96%) and EG (40.05%). The results demonstrate technical feasibility and identify cellulose accessibility as a critical parameter for process efficiency.

Finally, Chapter 6 critically evaluates the overall findings, identifying the main technical and environmental limitations to process scale-up and defining future research priorities. It also explores the integration of the developed approaches within the evolving international circular economy framework, highlighting their potential contribution to more sustainable and integrated textile waste management.