

Towards Safer and More Sustainable Water-Repellent Textiles: Life Cycle Assessment of PFAS-Free Alternatives

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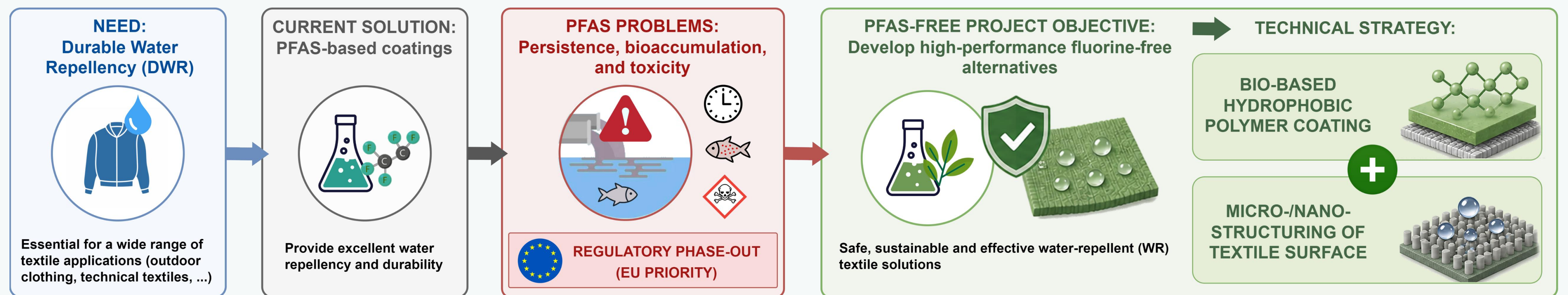


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Introduction

The Belgian project **PFAS-FREE** aims to develop safe and sustainable water-repellent textile solutions as alternatives to per- and polyfluoroalkyl substances (PFAS), offering superior performance compared to currently available fluorine-free products.



Methodology

Goal & Scope

- **Safe and Sustainable by Design (SSbD)** approach
- **Comparative cradle-to-grave LCA** (ISO 14040/44)
- **Functional unit (FU):** Provision of durable water repellency (DWR) to 1 m² of woven polyester fabric, achieving a spray rating of at least 4 (0–5 scale) maintained after 20 washing cycles, over a service life of 4 years.
- **Scenario 1 (reference):** PFAS-based benchmark (**S0-PFAS**),
Scenario 2 (study case): PFAS-FREE bio-based polyurethane dispersion (**S1-PUD**)
- **System boundaries:** See **Figure 1**

Environmental Impact Assessment

- **Simapro** v.10.2.0.3 software
- **Ecoinvent** v.3.11 database (adapted for Simapro)
- **Environmental Footprint (EF)** v.3.1
- Addition of **characterization factors** for PFAS degradation product emissions [1]

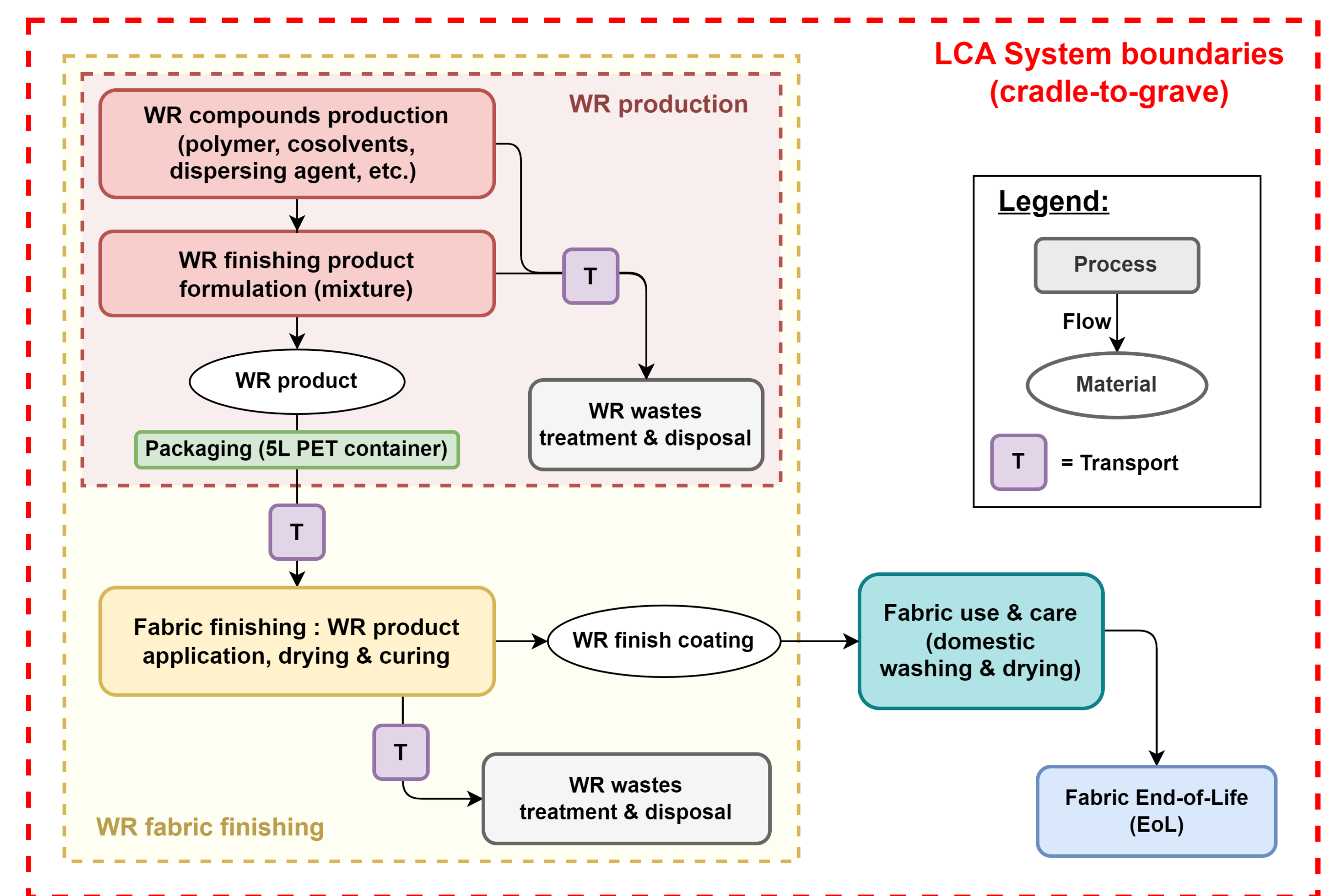


Figure 1 – Water-repellent (WR) Life Cycle Assessment (LCA) system boundaries

Results

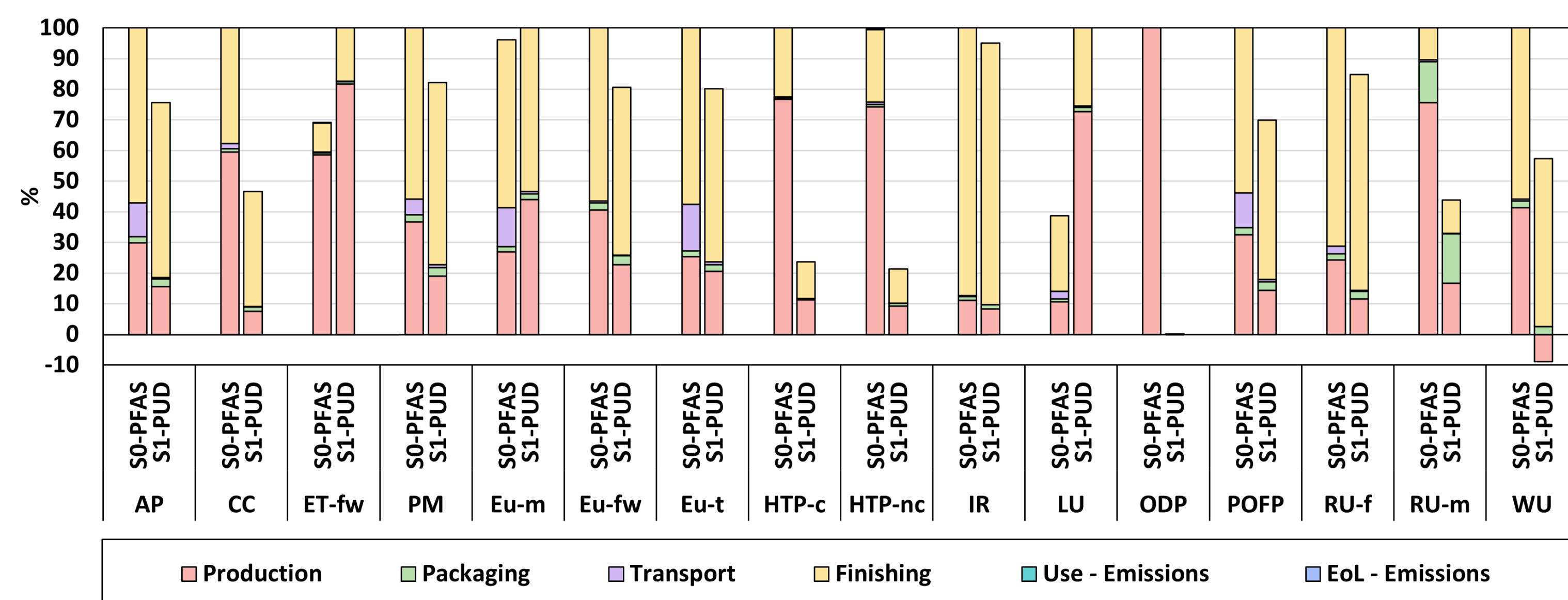


Figure 2 – Comparative life cycle impact assessment of PFAS-based (S0-PFAS) and PFAS-free (S1-PUD) scenarios

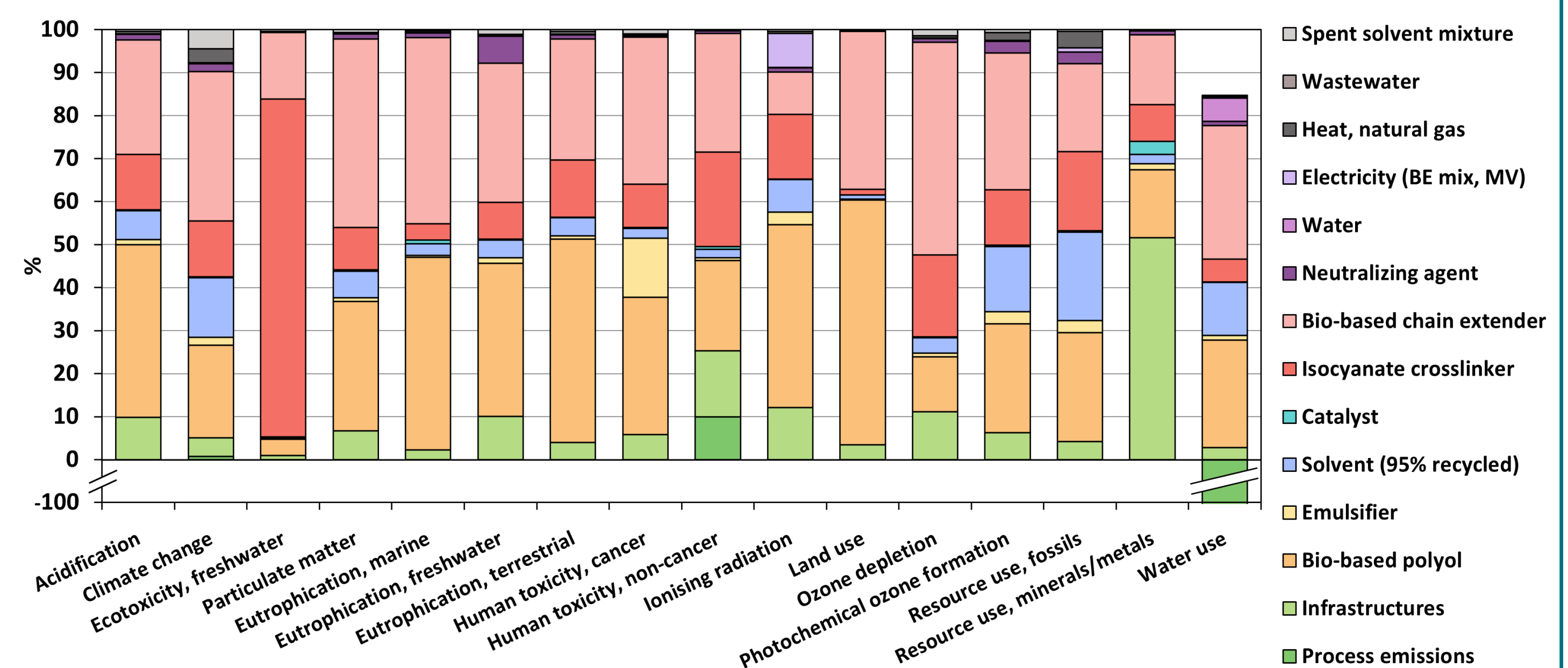


Figure 4 – Characterization of PFAS-free bio-based PUD Water-repellent production (S1-PUD)

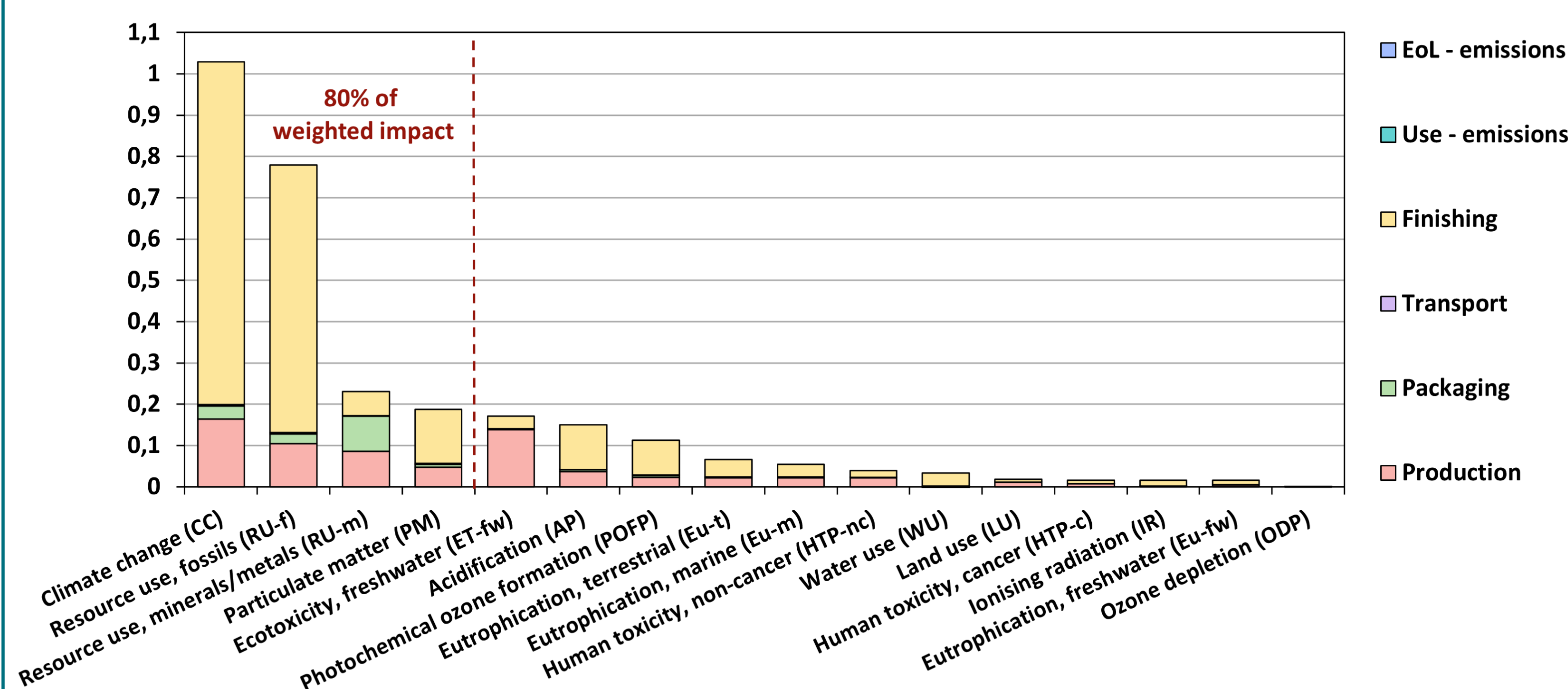


Figure 3 – Life cycle impact assessment weighting of PFAS-free bio-based PUD Water-repellent (S1-PUD)

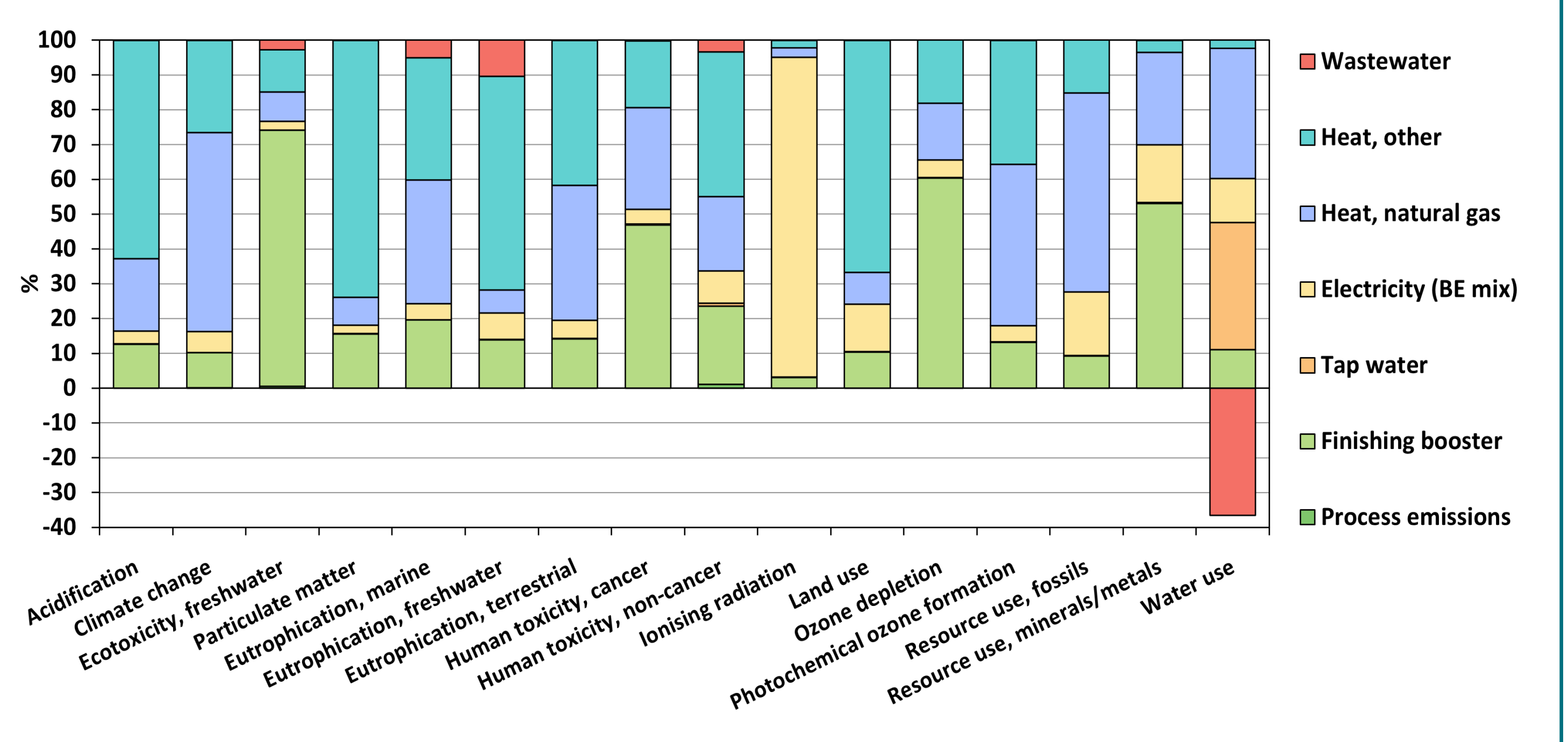


Figure 5 – Characterization of PFAS-free bio-based PUD Water-repellent finishing (S1-PUD)

Conclusions & Recommendations

The comparative LCA shows that replacing PFAS-based water repellents with PFAS-free PUD formulations can significantly reduce major environmental impacts, including **~50% lower climate change (CC)** impacts and an **ozone depletion (ODP) reduction of nearly four orders of magnitude (Figure 2)**. These benefits are mainly driven by avoiding fluorinated chemistry. A main trade-off is **increased land use (LU)**, linked to bio-based feedstock.

Hotspot analysis (**Figure 3**) identifies the **textile finishing** as the dominant contributor to overall impacts, largely driven by **drying and curing energy demand (Figure 5)**, making energy efficiency a key improvement lever.

Reference

[1] Holmquist, H., et al. (2020). An (Eco)Toxicity life cycle impact assessment framework for per- and polyfluoroalkyl substances. Environ. Sci. Technol., 54(10), 6224–6234. <https://dx.doi.org/10.1021/acs.est.9b07774>

At formulation level, impacts of the **PUD-based water repellent (WR) (Figure 4)** are mainly driven by polymer building blocks (bio-based polyol, chain extender, crosslinker), with the **isocyanate crosslinker** as a major hotspot (~80% of freshwater ecotoxicity).

Key recommendations: (i) optimize bio-based precursor sourcing and solvent management; (ii) develop non-isocyanate polyurethane (NIPU) alternatives; (iii) select low-impact finishing boosters; (iv) reduce finishing energy demand.

Finally, PFAS substitution remains strongly justified, as **PFAS toxicity and persistence-related risks are not yet fully captured by standard LCA toxicity indicators**.

