An Integrated Approach to Evaluate the Safety of Innovative Materials for Water Treatment According to the SSbD Framework

4.08 - From Nanomaterials to Advanced Materials: Ensuring Safety in Innovation

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As nanomaterials (NMs) gain widespread use, quantitative frameworks integrating functionality, safety and sustainability considerations across their life cycle are needed. Since current sustainability methods overlook nano-specific hazards, strategies to incorporate toxicity data into Life Cycle Assessment (LCA) are required. Approaches based on Key Decision Factors (KDFs) and Key Performance Indicators (KPIs) allow linking design options to multidimensional performance, supporting early identification of safer and more sustainable configurations.

This study applies such a methodology, focusing on safety aspects, to novel NMs applicable to nano-enabled products (NEPs) such as water filtration membranes (WFM), and proposes a preliminary strategy to integrate the data into sustainability frameworks. Two case studies are presented: nanoforms and NEPs based on copper oxide nanoparticles (CuO NPs) and perovskite nanoparticles (Pv NPs), both applicable for antimicrobial/antifouling filtration systems. CuO-enabled WFM with or without a chemical binding (PVB) represent two design options, while four Pv NP types were analysed based on different synthesis parameters, defined according to a design of experiment (DoE).

Aquatic toxicity was assessed using zebrafish embryos (OECD 236) and larval behavior assays, while *in vitro* skin sensitization (OECD 442D) was also evaluated for CuO-WFM. The analyses generated primary data to support the development of nano-specific Effect Factors (EFs) for LCA. Interpreted through the KDF–KPI perspective, results indicate the PVB-containing WFM as the best design option. PVB enhanced antibacterial stability, improved NPs retention within the polymeric matrix and reduced *in vitro* toxicity while maintaining ecotoxicological safety. All tested Pv nanoforms showed promising application potential due to their favorable safety profile.

The findings show how structured KDF–KPI analyses enable comparison of design alternatives also according to a DoE, while the generated toxicity data build the quantitative basis needed for future nano-specific impact categories in LCA. Integrating a DoE approach into the KDF–KPI framework could further relate NM performance to synthesis-related KDFs, improving the derivation of EFs for LCA studies considering different synthesis routes.

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