

Learning from Safe-by-Design for Safe-and-Sustainable-by-Design: Mapping the current landscape of Safe-by-Design reviews, case studies, and frameworks

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With the introduction of the European Commission's "Safe and Sustainable-by-Design" (SSbD) framework, the interest in understanding the implications of safety and sustainability assessments of chemicals, materials, and processes at early-innovation stages has skyrocketed. Our study focuses on the "Safe-by-Design" (SbD) approach from the nanomaterials sector, which predates the SSbD framework.

In this assessment, SbD studies have been compiled and categorized into reviews, case studies, and frameworks. Reviews of SbD tools have been further classified as quantitative, qualitative, or toolboxes and repositories. We assessed the SbD case studies and classified them into three categories: safe(r)-by-modeling, safe(r)-by-selection, or safe(r)-by-redesign. This classification enabled us to understand past SbD work and subsequently use it to define future SSbD work so as to avoid confusion and possibilities of "SSbD-washing" (similar to greenwashing). Finally, the preexisting SbD frameworks have been studied and contextualized against the SSbD framework.

Several key recommendations for SSbD based on our analysis can be made. Knowledge gained from existing approaches such as SbD, green and sustainable chemistry, and benign-by-design approaches needs to be preserved and effectively transferred to SSbD. Better incorporation of chemical and material functionality into the SSbD framework is required. The concept of lifecycle thinking and the stage-gate innovation model need to be reconciled for SSbD. The development of high-throughput screening models is critical for the operationalization of SSbD. We conclude that the rapid pace of both SbD and SSbD development necessitates a regular mapping of the newly published literature that is relevant to this field.

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