



# The safe-and-sustainable-by-design concept: innovating towards a more sustainable future

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## Abstract

Safe-and-Sustainable-by-Design (SSbD) is a new concept proposed by the European Commission to support the urgent need to transition towards a more preventive and proactive approach in chemical and material innovation which supports a more sustainable future and in meeting the UN's Sustainable Development Goals. SSbD provides orientation and guidance by taking a system approach. SSbD building blocks were developed: regenerative corporate and societal strategic needs (considering service and function), risk and sustainability governance, competencies, and data management. This viewpoint brings these building blocks together in a holistic way to create an innovation landscape ensuring safer and more sustainable chemicals, materials, production processes and products in science, technology, and industry; starting from 'design' and that is fit for supporting a sustainable future.

**Keywords** Innovation · Building blocks · 'By-design' · Corporate strategy · Governance · Competencies · Data management · Lifecycle thinking

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## Urgency for transitioning to a safer and more sustainable way for innovation

The transition towards safer and more sustainable chemicals, materials, production processes and products is a key aspect of the EU Chemicals Strategy for Sustainability (EU-CSS) (European Commission 2020) and contributes to the Sustainable Development Goals (SDGs) by working towards zero pollution and a non-toxic environment ambitions. There is an urgency for action given that six out of the nine planetary boundaries have already been crossed (Stockholm Resilience Centre 2024).

Safe-and-Sustainable-by-Design (SSbD) is central to EC-CSS and aims to reduce chemical pollution, protect our ecosystems, use our resources responsibly, and prevent human health problems; and promotes a proactive and preventive mindset. The European Commission's Joint Research Center (EC JRC) has published a SSbD framework (Caldeira et al. 2022) along with a recommendation (European Commission 2022) and Methodological Guidance (Abbate et al. 2024) to support research and innovation for safer and more sustainable chemicals and materials. SSbD is a preventive

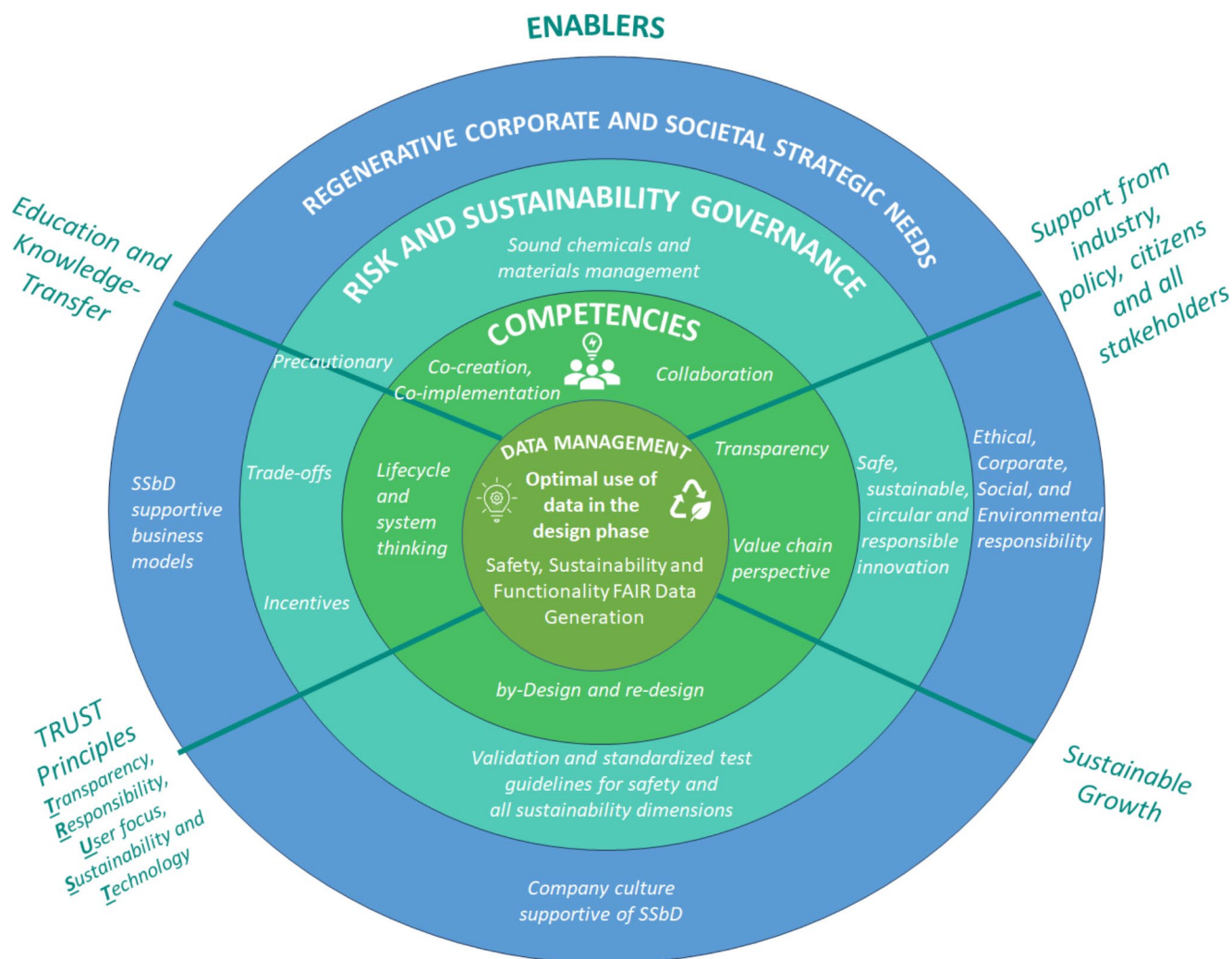
approach that promotes social responsibility and facilitates economic growth and innovation by integrating safety, sustainability, and circularity with functionality in the innovation and design phase of chemicals and materials for the entire lifecycle of the final product.

Starting from previous work (Apel et al. 2024), the following SSbD building blocks were developed: regenerative corporate and societal strategic needs (considering service and function), risk and sustainability governance, competencies, and data management. This viewpoint brings these building blocks together in a holistic way (Figs. 1 and 2) to create an innovation landscape ensuring safer and more sustainable chemicals, materials, production processes and products in science, technology, and industry; starting from ‘design’ and that is fit for supporting a sustainable future.

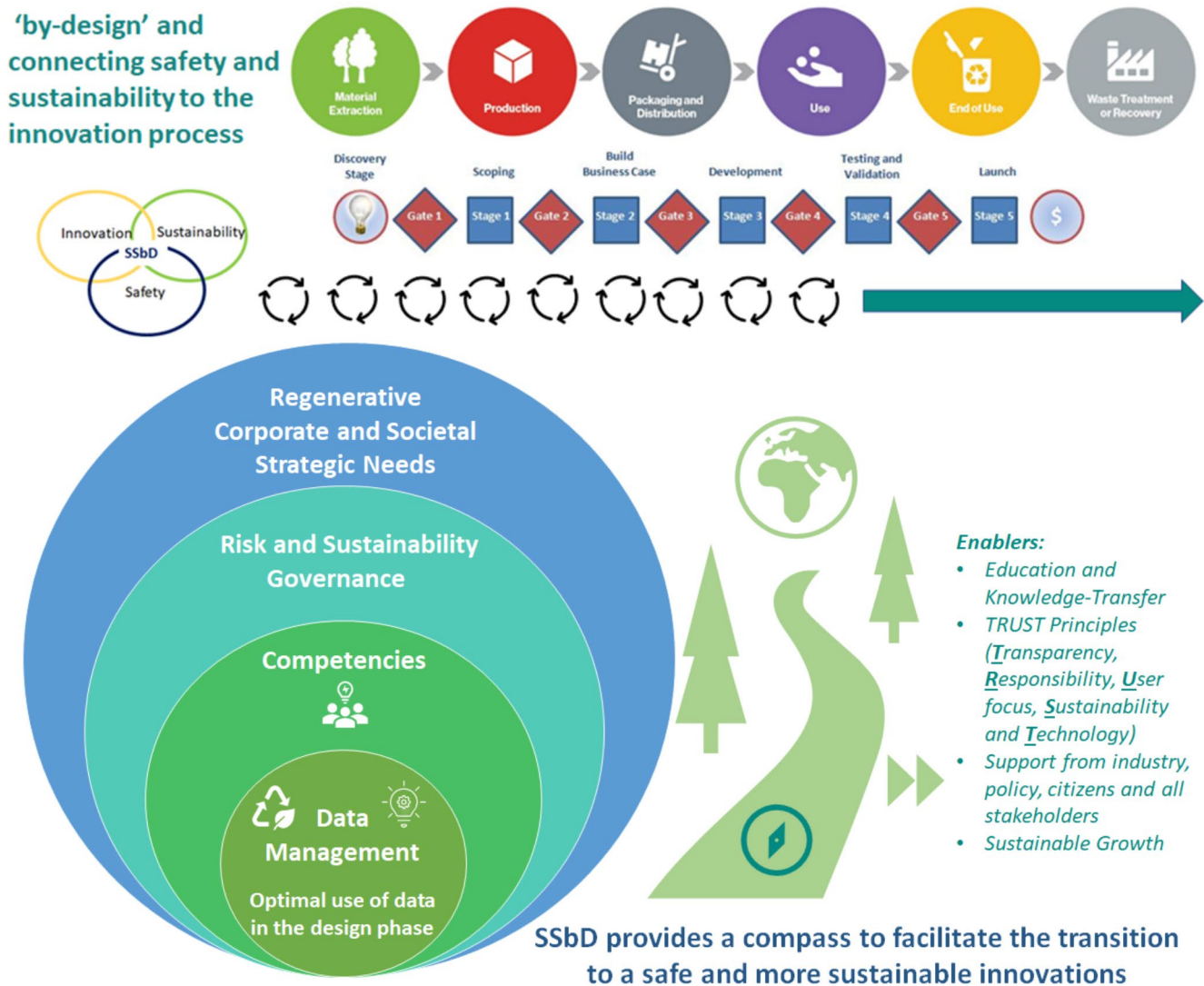
## Building blocks for SSbD

### Regenerative corporate and societal strategic needs: Embedding SSbD in Corporate Strategies

A regenerative and SSbD-minded corporate culture embeds ethical, corporate social and environmental responsibility in their business models and supports the practical applicability of SSbD. SSbD supportive business models aim to deliver a certain service or function in the most sustainable way with a net positive impact across all stakeholder levels (nature, societies, customers, suppliers and partners, shareholders and investors, and employees). There is a need for strong policy frameworks and mindset shifts that stimulate the adoption of regenerative business models which incorporate regenerative leadership, co-creative partnerships with nature, and justice and fairness. These should include supply chain due diligence, carbon and environmental/



**Fig. 1** SSbD building blocks consisting of regenerative corporate and societal strategic needs (considering service and function), risk and sustainability governance, competencies, and data management



**Fig. 2** Conceptual framework on how SSbD provides a compass to facilitate the transition to a safer and more sustainable way of innovation by taking a systems approach

true pricing, nature rights, and animal rights. Regenerative leadership and business models are needed for the development of an innovation landscape whose value proposition is based on planetary health and societal wellbeing (Hutchins and Storm 2019; Konietzko et al. 2023).

**Risk and sustainability governance: The need for processes and infrastructures to facilitate SSbD in a lifecycle thinking approach and bringing all the value chain stakeholders together to co-create solutions**

A comprehensive risk and sustainability governance addressing “who”, “how”, and “what” is necessary (infrastructure, process and content). In terms of “who,” it emphasizes the importance of establishing a robust infrastructure, ensuring that responsibilities and accountability

as well as its limitations and/or collective responsibility are clearly defined along the entire value chain and lifecycle. It is imperative to have an infrastructure to allow co-creation and knowledge sharing along the whole lifecycle. Regarding the “how”, the *precautionary principle* (European Commission 2000) is key to all innovation processes to avoid future harm caused by lack of knowledge. It underscores the need for well-defined processes that prioritize hazard and sustainability assessment and mitigation, ensuring that actions and decisions align with safety and sustainability objectives. It also promotes to address potential safety and sustainability risks and balance them with the potential benefits. Lastly, the “what” refers to the knowledge, skills, tools, and technologies employed, urging the adoption of beyond state-of-the-art-approaches to address potential safety and sustainability risks. Support, training and *incentives* for

industry, in particular for small and medium-sized enterprises (SMEs) are needed.

SSbD demands sound chemical and material management<sup>1</sup> and sustainability management to ensure good risk and sustainability governance, as well as the harmonization of the assessments integrating innovation with safety and sustainability as a whole. Transparent communication of *trade-offs* is needed particularly when going from lab to upscale (OECD 2021), and along the entire life cycle of product development. *Trade-offs* have to be identified and communicated while being in line with regulatory processes or even demonstrating how existing regulations have to be developed to improve sustainability.

### Competencies: embedding SSbD thinking in curricula

SSbD requires a certain skill profile to successfully incorporate safety and sustainability aspects along the whole life-cycle into the product design. Integration of SSbD thinking to vocational training and university programmes will equip future SSbD actors with the necessary skill profile to apply SSbD in practice. This includes for instance material scientists, engineers, product designers, chemists, sustainability experts, and decision-makers throughout the product's supply chain. Implementing a 'by-design' and lifecycle thinking system approach (Soeteman-Hernandez et al. 2023) is the most important competency for SSbD. Additional considerations include being responsible and also considering non-material alternatives and service-based approaches ("alternative business models") to stimulate less chemical, material or product use. 'Soft or human skills' for co-creation, co-implementation, collaboration and transparency

### Data management: maximizing the valorization of safety and sustainability data

The generation, management, and exploitation of safety, sustainability, circularity and functionality data following *FAIR (Findable, Accessible, Interoperable, and Reusable)* principles (Wilkinson et al. 2016) is at the core of SSbD. We need to maximize the valorisation of all safety and sustainability data, tools, and knowledge, particularly in the early design stages of the innovation process. Safety, sustainability, and functionality experts need to develop the necessary data, ontologies, and additional tools for assessment of reliability and comparability; thereby ensuring trusted data. For safety, there is a need to revolutionize Regulatory Sciences to be more open to accepting New Approach Methodologies (NAMs) (ECHA, 2023) including high-throughput testing,

<sup>1</sup> For instance the Strategic Approach to International Chemicals Management, SAICM; Sound Management of Chemicals and Waste, SMCW.

3D-models, organoids, organ-on-a-chip, and virtual human platforms for the development of better predictive methods that can be applied early in the innovation design process. For sustainability, the further development of ex-ante life cycle assessment (LCA; also known as prospective LCA) (Subramanian et al. 2023) approaches allow to assess the environmental impact of new chemicals, materials and products or processes even at low Technology Readiness Level (TRL). This also includes socio-economic assessment and considerations for closing the gender and vulnerable groups data gap and building a diversity data ecosystem.

### Enablers that accelerate and facilitate the implementation of SSbD

There are four key enablers for SSbD, that are linking all the above-mentioned building blocks: (i) *Education and knowledge-transfer* about SSbD, what it is, how to apply it and ensuring that all stakeholders talk to each other and all speak the same language; (ii) applying *TRUST (Transparency, Responsibility, User focus, Sustainability and Technology) principles* (Lin et al. 2020) for data generation and management, (iii) *Supported by industry, policy, citizens, and all relevant stakeholders* in the value chain and life-cycle, and (iv) *Enabling sustainable growth* (either incremental or disruptive improvements) with a forward-looking approach 'striving for doing better today than what was done yesterday'.

### Towards a holistic approach: An innovation landscape and ensuring safer and more sustainable chemicals, materials, production processes and products and that is fit for supporting a sustainable future

A systems approach is needed with processes and infrastructures to connect all value chain stakeholders and facilitate co-creation of SSbD solutions. For SSbD to be a truly reliable and usable compass, it is essential that all stakeholders work together in a synergistic way to define an implementable framework. Figure 2 depicts the conceptual framework of the building blocks needed for a regenerative innovation landscape whose value proposition is based on planetary health and societal wellbeing. For SSbD it is vital for: (i) policymakers to define and implement this voluntary framework (as done by EC JRC (Caldeira et al. 2022) and that this is consistent across the European Union as well as globally; (ii) regulators to be open to discuss acceptance of NAMs and novel predictive approaches where appropriate in the context of chemical safety assessment; (iii) science and industry to provide the knowledge, data, and tools needed; (iv) academia and related institutions to provide

high quality training and education on SSbD; (v) society to demand it; and (vi) industry to drive and implement it in a synergistic way.

## Reflections and next steps

A holistic and systems approach for SSbD is needed with processes and infrastructures to connect all value chain stakeholders and facilitate co-creation of SSbD solutions. Too often the discussions are on data and tools and not on building the necessary multi-disciplinary infrastructures and processes needed to build a system to address regenerative corporate and societal strategic needs (considering service and function), risk and sustainability governance, competencies, and FAIR data; as well as all the necessary stakeholders to co-create towards safer and more sustainable chemicals, materials, production processes and products. SSbD is a compass that gives direction to all stakeholders in a collaborative and co-creative way towards a more sustainable future.

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## Declarations

**Competing interest** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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