

# RSC Sustainability

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## Sustainability spotlight

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To ensure planetary health and human well-being, innovations need to consider to be safe and sustainable-by-Design (SSbD) from the very beginning of the development of new chemicals, materials, products, and processes. In this context, our roadmap provides recommendations on how to bring SSbD to practical applicability and thereby contributes to the Sustainable Development Goals (SDGs). With the acceleration of the transition towards SSbD, a positive impact is expected in 'good health and wellbeing' (SDG3), 'water quality' (SDG6), 'decent work and economic growth' (SDG8), 'responsible consumption and production' (SDG12), 'climate action' (SDG13), 'life below water' (SDG14), and 'life on land' (SDG 15). Furthermore, through the specific agendas, our roadmap also contributes to 'quality education' (SDG4), 'Gender Equality' (SDG5), 'industry, innovation and infrastructure' (SDG9), and 'partnership for the goals' (SDG17).



# 1                                    **Safe-and-Sustainable-by-Design Roadmap:**

## 2                                    **Identifying Research, Competencies, and Knowledge Sharing Needs**

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17



18 **Abstract**

19 The European Chemicals Strategy for Sustainability introduces the Safe-and-Sustainable-by-Design (SSbD)  
20 concept. It goes beyond current regulatory compliance and aims to ensure the safety and sustainability  
21 of novel chemicals, materials, products, and processes. It starts at early-innovation stages and follows the  
22 chemicals and materials throughout their entire lifecycle. This perspective paper presents an SSbD  
23 roadmap that explores current needs and gives recommendations for the practical operationalization of  
24 SSbD in industrial operations and processes. This roadmap was co-created including different SSbD  
25 stakeholders and encompasses three interlinked agendas on (i) research needs, (ii) skills, competencies,  
26 and education needs, and (iii) knowledge and information sharing needs. An overarching need is the  
27 development of a common understanding of SSbD with clear definitions, terminology, and criteria. In  
28 addition, SSbD operationalisation needs to be pragmatic and applied as early as possible in the innovation  
29 process. From a research needs perspective, it is essential to integrate the different fields of innovation,  
30 safety, and sustainability. From a skills, competencies and education perspective, targeted training is  
31 needed that balances the depth and breadth of SSbD required for a specific audience. These trainings  
32 should not only convey hard/technical skills, but also soft/social skills to support more sustainability-  
33 oriented decisions on all levels. From a knowledge and information sharing perspective, a strategic plan  
34 and a trusted environment are needed to support dialogue between all SSbD stakeholders while at the  
35 same time protecting intellectual property (IP). The roadmap should help to coordinate planning for the  
36 implementation of SSbD at industrial, academic, policy, and regulatory level by defining actions and raise  
37 strategic efforts.

38

39 **Keywords:** SSbD, Research needs, Skills and Competencies, Education and Training, Knowledge sharing



## 40 Sustainability spotlight

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42 sustainable-by-Design (SSbD) from the very beginning of the development of new chemicals, materials,  
43 products, and processes. In this context, our roadmap provides recommendations on how to bring SSbD  
44 to practical applicability and thereby contributes to the Sustainable Development Goals (SDGs). With the  
45 acceleration of the transition towards SSbD, a positive impact is expected in 'good health and wellbeing'  
46 (SDG3), 'water quality' (SDG6), 'decent work and economic growth' (SDG8), 'responsible consumption and  
47 production' (SDG12), 'climate action' (SDG13), 'life below water' (SDG14), and 'life on land' (SDG 15).  
48 Furthermore, through the specific agendas, our roadmap also contributes to 'quality education' (SDG4),  
49 'Gender Equality' (SDG5), 'industry, innovation and infrastructure' (SDG9), and 'partnership for the goals'  
50 (SDG17).

51



## 52 Introduction

53 We are currently operating outside the planetary boundaries where six out of the nine planetary  
54 boundaries have been crossed.<sup>1</sup> With regards to the novel entities planetary boundary, urgent action is  
55 recommended in order to keep pace with safety related assessments and monitoring in a world where  
56 there is an increasing rate of production and releases of larger volumes and higher numbers of novel  
57 entities with diverse risk potentials.<sup>2</sup> In reaction to this, the European Chemicals Strategy for  
58 Sustainability, a core element under the European Green Deal, calls for a transition to safer and more  
59 sustainable chemicals and materials to support the goals of zero-pollution, a toxic-free environment.<sup>3</sup> To  
60 achieve these goals, it introduces the Safe and Sustainable-by-Design (SSbD) concept. Going beyond  
61 current regulatory compliance, the SSbD concept promotes the (re)design of chemicals, materials, and  
62 products, while comprehensively accounting for their manufacturing, use, and end-of-life management  
63 so that these innovations do not adversely affect human and environmental health at any point in their  
64 lifecycles. At the same time, SSbD promotes circularity, aims to meet societal needs, and to contribute to  
65 social and economic resilience.

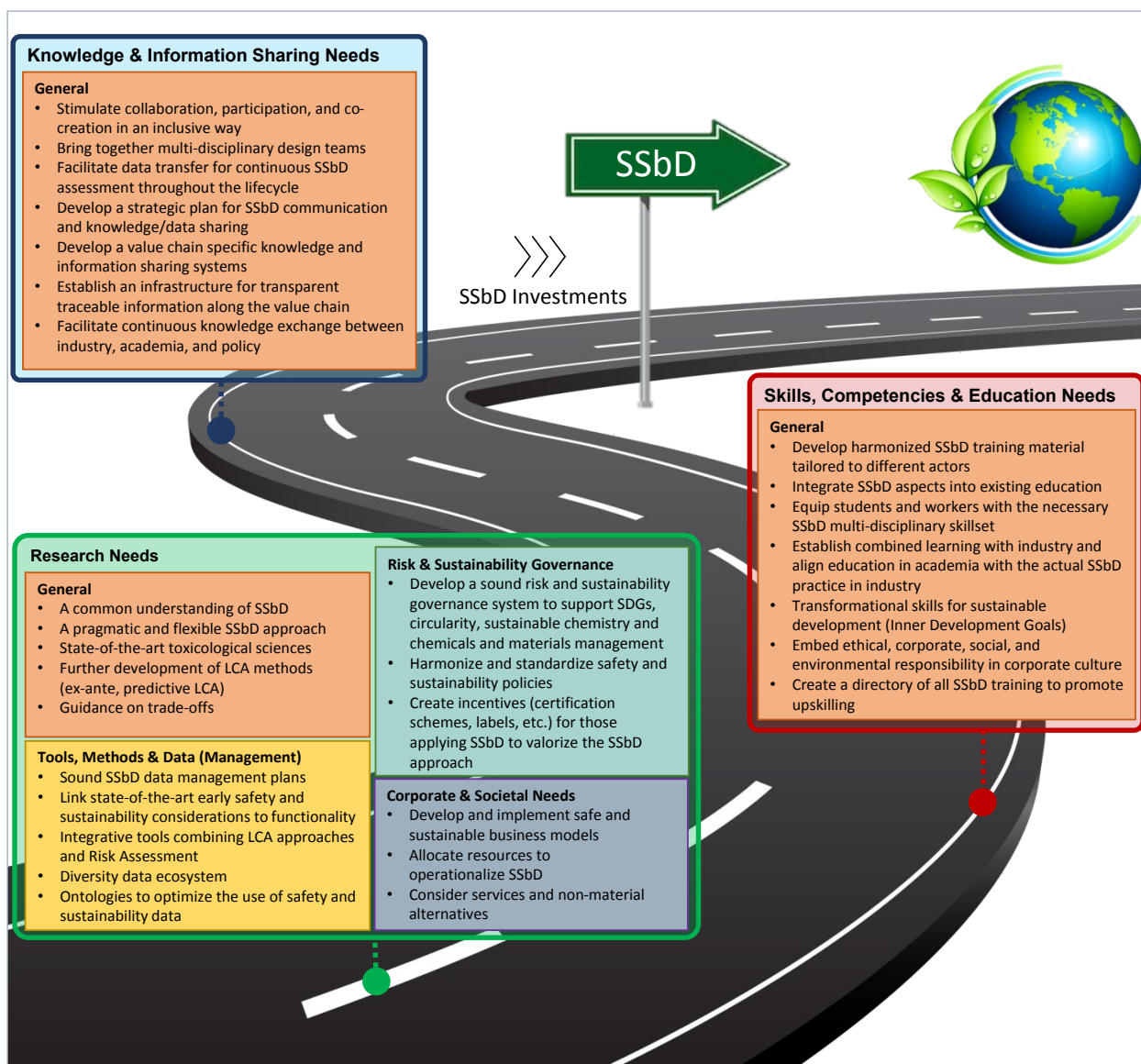
66 The SSbD framework and methodological guidance published by the European Commission is a  
67 holistic Research and Innovation (R&I) approach,<sup>4,5</sup> but to achieve the operationalization of SSbD,  
68 further necessities, requirements and barriers need to be addressed and overcome. SSbD needs to  
69 be translated from a policy ambition to a practical, operational and implementable concept in industrial  
70 operations and processes, including training and education. The EU-funded IRISS project is developing an  
71 SSbD roadmap in co-creation which is a collaborative process of creating new value together with external  
72 experts and stakeholders, i.e. industry representatives, participants of webinars and scientific  
73 conferences, and regulators.<sup>6</sup> The roadmap encompasses three agendas addressing needs for (i)  
74 research, (ii) skills, competencies and education, and (iii) knowledge and information sharing that  
75 are strongly interlinked. While developing the roadmap agendas, the leading questions were: *What is*  
76 *needed to bring SSbD into practice? How can SSbD be implemented in practice?* This perspective  
77 presents the developed roadmap to support the SSbD implementation.

78

## 79 SSbD Supportive Roadmap

80 The main recommendations to support SSbD implementation are shown in Figure 1. The  
81 recommendations are an extension to the SSbD building blocks that have been identified in a  
82 previous work.<sup>7</sup> These are *corporate and societal strategic needs, risk and sustainability governance,*  
83 *competencies, and tools, methods and data management.*





84  
85 *Figure 1 IRISS' SSbD roadmap comprising of three agenda: (i) research needs, (ii) skills, competencies and education needs, and*  
86 *(iii) knowledge and information sharing needs and giving recommendations for the operationalization of SSbD.*

87  
88 **Agenda for Research Needs**

89 Developing a *common understanding of SSbD* with clear definitions, terminology, and criteria and  
90 aligning goals and procedures both in concept and in practice is a key need, particularly as different  
91 fields of safety and sustainability need to be integrated. Harmonized methodologies and tools  
92 considering design thinking and lifecycle thinking are required for a *pragmatic and flexible SSbD*  
93 *approach*. This approach has to be in alignment with the innovation process in industry, needs to  
94 leave room for sector-specific considerations, and needs to also be applicable to secondary  
95 materials that are of constantly increasing importance within a Circular Economy. To achieve this, a  
96 dialogue on the topics and challenges including all stakeholders is needed, also to achieve  
97 acceptance on all levels. For this pragmatic and flexible approach, toxicological sciences need to be



98 revolutionized to be more open to accepting new methodologies that are required for SSbD. Also,  
99 the complexity for the required SSbD assessments needs to be translated to simple guidelines that  
100 innovators can easily apply in practice. In this regard, a comparison of different SSbD approaches  
101 has been performed and, recently, a practical guidance has been published.<sup>8,9</sup>

102 Research efforts should be directed towards *early-stage safety and sustainability (environmental,*  
103 *social, economic)* assessment, taking also into account political and legal aspects, and *integrating*  
104 *them with the functionality* of chemicals, materials, products, and processes, and services. For the  
105 same, engineering tools (e.g., digital twins) that allow the implementation of SSbD at the (re)design  
106 stage, having the life cycle in mind at the same time, are necessary. In addition, the different safety  
107 and sustainability approaches need to be *streamlined and complementary*. This is needed given that  
108 safety assessment is weight-of-evidence-based while sustainability assessment is a comparative  
109 approach.

110 For *early-stage human and environmental safety assessments*, optimization and use of predictive  
111 tools such as *in-silico* tools (QSARs, read-across, AI/Machine learning) along with the application of  
112 New Approach Methodologies (NAMs, including 3D-models, organoids, organ-on-a-chip, and virtual  
113 human platforms) are necessary.

114 For *early-stage sustainability assessments*, in addition to conventional lifecycle assessment (LCA),  
115 the development of ex-ante/predictive environmental and social lifecycle assessment (LCA and S-  
116 LCA) approaches taking into account functionality parameters and tailored to assess the impacts  
117 even at low Technology Readiness Level (TRL) and early-innovation phases are needed. An  
118 integration of S-LCA as part of the LCA methods would be preferable. Moreover, *further*  
119 *development of tools* is required for reliability, comparability, and cross-platform compatibility and  
120 accessibility of all relevant data.

121 Furthermore, integrative tools are required that combine lifecycle methods: LCA which assesses  
122 environmental impacts, S-LCA which assesses social impacts, lifecycle costing (LCC) which assesses  
123 economic impacts, along with safety assessment methods which assess hazard and risk impacts. In  
124 the same context, it is necessary to further refine and quantify criteria for material performance.

125 To account for different behaviours, sensitivities, and impacts, a *diversity-data ecosystem*, including  
126 gender, sex, and vulnerable groups-aggregated data should be built and used for the above-  
127 mentioned assessments. *Ontologies* need to be developed to optimize the use of these data  
128 throughout the innovation process. This may be achieved by applying Findable, Accessible,  
129 Interoperable and Reusable (FAIR) principles<sup>10</sup> and Transparency, Responsibility, User focus,  
130 Sustainability, and Technology (TRUST) principles<sup>11</sup> to produce data.

131 SSbD will involve trade-offs between the safety, environmental, social, and economic sustainability  
132 domains. Thus, specific *guidance on managing these trade-offs for SSbD innovation* is necessary,  
133 also to have reliable certification and to avoid SSbD becoming a tool for green or sustainability  
134 washing.

135 The scientific community, industry, policy makers and regulators are needed to address current  
136 SSbD research needs. A sound *Risk and Sustainability Governance system* supporting SDGs,  
137 circularity, and sustainable chemistry along with *chemical, material, and product management* is  
138 needed. SSbD alignment to current and upcoming safety and sustainability regulations is vital to  
139 prepare industry for future compliance needs. Furthermore, it is critical to *harmonize safety and*





140 *sustainability policies* and their compliance while considering reporting, transparency, and  
141 contribution to regulatory preparedness. This is only possible after the *establishment of an*  
142 *infrastructure to support harmonization and standardization* that relies on validated and  
143 standardized test guidelines for all safety and sustainability dimensions. Finally, the governance  
144 system needs to establish incentives for the application of SSbD, i.e., certification schemes, labels,  
145 etc. that attract consumers and aid in marketing and funding SSbD products and research, thereby  
146 valorising the SSbD approach.

147 Additionally, research is required on business models. *Alternative business models* that incorporate  
148 SSbD need to be developed and implemented that support sustainable growth, allocate resources  
149 to operationalize SSbD in practice (e.g., money, time, expertise), and consider services and non-  
150 material alternatives (i.e. thinking beyond chemicals).

151

### 152 **Agenda for Skills, Competences, and Education Needs**

153 Education and training should be target-group-specific and balance the depth and breadth of SSbD  
154 that is needed for the specific audience. Therefore, *harmonized SSbD trainings for different SSbD*  
155 *stakeholders* need to be developed and conducted i.e., (re)design and LCA training for future  
156 engineers, constant updating of science, engineering and environmental knowledge for  
157 policymakers, and sustainability education for consumers. *University curricula* with a harmonized  
158 syllabus in SSbD are necessary to equip students and our future workforce with the prerequisite  
159 multi-disciplinary skillset (along with 'soft' or 'social skills' for communication, collaboration, co-  
160 creation, entrepreneurship), and support a common understanding of SSbD. In addition, SSbD  
161 aspects such as sustainability, circularity (including their limitations too), and hazard/risk awareness  
162 should be *integrated into existing curricula*. Furthermore, extra-occupational programmes and  
163 industrial (in-house) training courses are essential to guide and upskill current workers on the  
164 implementation on SSbD and to merge theory and expertise. All trainings should aim for a *combined*  
165 *learning with industry and authorities* and *align education in academia with the actual SSbD practice*  
166 *in industry* and vice versa. SSbD education should be further *tailored to specific industries and value*  
167 *chains* to accommodate their respective safety and sustainability idiosyncrasies.

168 It is important that trainings also encourage an attitude and qualities that support more sustainable  
169 lifestyles and business behaviours. This is particularly important not just for the general public that  
170 would buy and consume future SSbD products, but also for leadership as the new mindset also  
171 needs to be embedded in the corporate culture. Without anchoring aspects such as *ethical, social,*  
172 *and environmental responsibility in corporate culture* in alignment with the concept of extended  
173 producer responsibility,<sup>12</sup> the mindset of the company itself and its employees will not change.  
174 These types of skills and qualities are defined in the Inner Development Goals (IDGs) framework to  
175 create a sustainable global society and includes for example *critical thinking* and *co-creation skills*.<sup>13</sup>

176 SSbD trainings should be easily accessible for everyone internationally and be specific mixture of  
177 several approaches and formats, for example online courses (e.g., massive open online courses  
178 (MOOCs)) and onsite trainings (e.g., summer schools or bootcamps). Accessibility is needed to  
179 support lifelong learning in alignment with the European Skills Agenda.<sup>14</sup> Finally, all the SSbD training  
180 (including but not limited to MOOCs, Summer Schools, events, etc.) should be traceably compiled  
181 into a directory.



182

### 183 **Agenda for Knowledge and Information Sharing Needs**

184 Successful SSbD implementation relies on *communication, participation* and *co-creation* in an  
185 *inclusive way*. *Design teams supporting multidisciplinary decision making* need to have full access  
186 to SSbD information and data (also meta data) of a new product from the entire value chain(s); this  
187 also includes related ones e.g. as for resources needed. Therefore, collaborations among the  
188 stakeholders along the entire value chain and across different value chain(s) are necessary to  
189 facilitate *transparent and traceable data transfer for continuous SSbD assessments*. This could be a  
190 direct feedback loop from end-of-life to (re)design along the value chain, also including feedback on  
191 data gaps. To realistically achieve such collaboration, a robust strategic plan for SSbD  
192 communication and knowledge/data sharing needs to be defined. Such a strategic plan should  
193 provide a general framework, but also include sector-specific considerations and take into account  
194 the realities within the sector's supply chains. It should also include how best to reach and engage  
195 with small and medium-sized enterprises (SMEs) within value chains and encourage data sharing for  
196 downstream users. Also, a *platform enabling continuous exchanges* between industry, authorities,  
197 academia, NGOs, and policy needs to be established and nurtured specifically for SSbD. Such a  
198 platform should be a safe data-sharing space to protect intellectual property (IP; e.g. blockchain)  
199 and act as a trusted environment that can be used not only for direct knowledge/data exchange,  
200 but also to share experiences, best practices, lessons learned, and discuss success factors and  
201 pitfalls. Furthermore, both *SSbD Help Desks* and *Expertise Center* at national and European level to  
202 support the SSbD implementation are required.

203

### 204 **Conclusions**

205 The development of a common understanding of SSbD with clear definitions, terminology, and  
206 criteria is an overarching need. In addition, SSbD operationalisation needs to be pragmatic and  
207 applied as early as possible in the innovation process.

208 From a research needs perspective, it is essential to develop and promote SSbD data management  
209 following FAIR and TRUST principles, to develop a sound risk and sustainability governance system  
210 to support harmonization and standardization of safety and sustainability methods and results, and  
211 to develop business models that are supportive of SSbD (corporate & societal needs).

212 For the skills, competencies and education needs, harmonized training material is needed, adapted  
213 to different audiences (industry, academia, policy makers, regulators). This targeted training needs  
214 to balance the depth and breadth of SSbD required for a specific audience by not only conveying  
215 hard/technical skills, but also soft/social skills to support more sustainable decisions on all levels.

216 For the knowledge and information sharing needs, a coordinated and easily accessible network and  
217 platform is urgently needed to bring all the different initiatives in innovation, safety, sustainability,  
218 and circularity together for the practical application of SSbD. For this, a strategic plan and a trusted  
219 environment are needed to support dialogue and co-creation between all SSbD actors while at the  
220 same time protecting IP.

221 To ensure planetary health and human well-being, and avoid any additional damage, innovations  
222 need to consider SSbD at very early stages of development of new chemicals, materials, products,  
223 and processes. It is acknowledged that a learning by doing approach is needed to translate the JRC



224 SSbD framework to business operations. Thus, this roadmap provides recommendations on how to  
225 bring SSbD to practical applicability with the synergistic efforts of industry, academia, NGOs, policy  
226 makers, regulators and all stakeholders along the life cycle.

227

## 228 **Conflicts of interest**

229 There are no conflicts to declare.

230

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250

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## Data Availability Statement

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No primary research results, software or code have been included and no new data were generated or analysed as part of this review.

