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Expanding Sustainability Innovations in the Chemical Industry: Integration of Gender Dimensions into the Safe and Sustainable by Design Framework

Erweiterung von Nachhaltigkeitsinnovation in der chemischen Industrie: Integration der Geschlechterdimensionen in den Rahmen für Sicherheit und Nachhaltigkeit durch Technik

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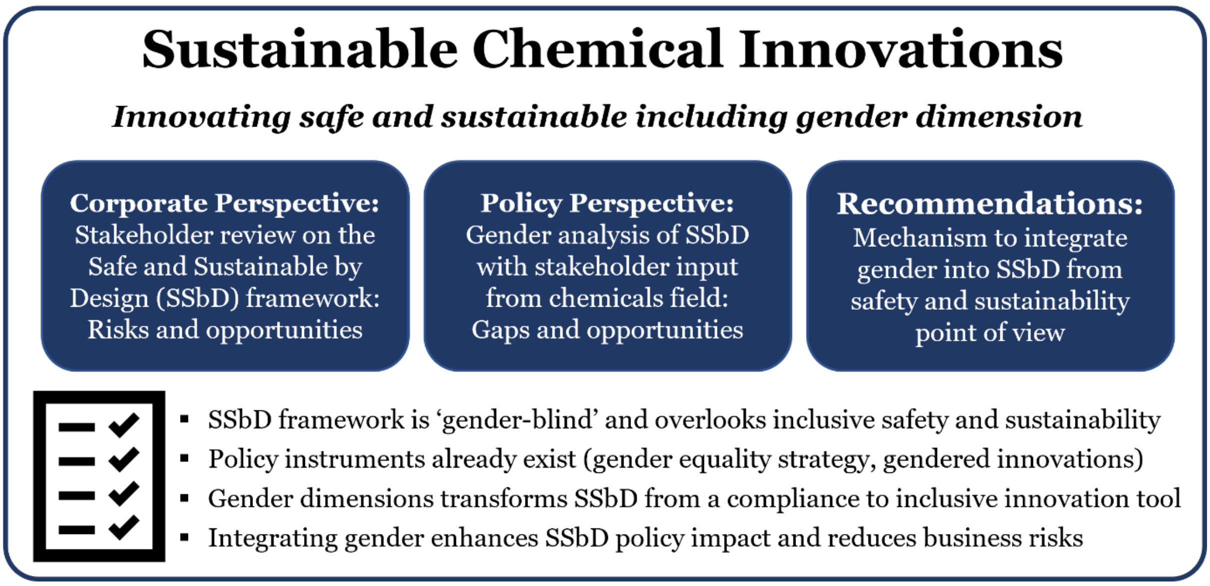
Abstract

Having exceeded several of the planetary boundaries, the world is facing mounting environmental crises such as climate change, biodiversity loss and chemical pollution. As one of the most resource-intensive sectors, the chemical industry contributes significantly to greenhouse gas emissions and chemical pollution. Through sustainable innovation processes, integrating environmental, social and economic considerations from the earliest stages of product development, the industry can reduce its impacts. To facilitate this process, the Safe and Sustainable by Design (SSbD) framework, a premarket innovation process proposed by the European Commission, aims to align innovation with safety and sustainability. However, a crucial element of responsible innovation is still missing: The gender dimension.

This thesis examined the current state of the SSbD framework, identifies relevant stakeholders and performs a gender analysis of this policy instrument. Furthermore, the positions of stakeholders from the gendered chemicals field were analysed and strategies for integrating gender dimensions are developed. By considering gendered toxicological profiles, respecting behavioural differences and socioeconomic impacts, this policy can support companies in mitigating risk, while also developing products that are more inclusive and competitive. Finally, the opportunities and risks for applying the SSbD framework with gender dimensions in policy and corporate context are assessed.



Key words: Chemistry, Sustainability, Gender, Innovation, Safety, Equity

Kurzusammenfassung

Nachdem bereits mehrere planetare Grenzen überschritten wurden, sieht sich die Welt mit zunehmenden Umweltkrisen wie Klimawandel, Verlust der biologischen Vielfalt und chemischer Verschmutzung konfrontiert. Als einer der ressourcenintensivsten Sektoren trägt die chemische Industrie erheblich zu Treibhausgasemissionen und chemischer Verschmutzung bei. Durch nachhaltige Innovationsprozesse, die ökologische, soziale und wirtschaftliche Aspekte bereits in den frühesten Phasen der Produktentwicklung berücksichtigen, kann die Industrie ihre Auswirkungen reduzieren.

Um diesen Prozess zu erleichtern, zielt das von der Europäischen Kommission vorgeschlagene Rahmenwerk „Safe and Sustainable by Design" (SSbD), ein Innovationsprozess vor der Markteinführung, darauf ab, Innovation mit Sicherheit und Nachhaltigkeit in Einklang zu bringen. Ein entscheidendes Element verantwortungsvoller Innovation fehlt jedoch noch: die Genderdimension.

Diese Arbeit untersucht den aktuellen Stand des SSbD-Rahmenwerks, identifiziert relevante Interessengruppen und führt eine Gender-Analyse dieses Policy-Instruments durch. Darüber hinaus werden die Positionen der Interessengruppen aus dem Bereich Gender und Chemikalien betrachtet und daraus Vorschläge zur Integration der Geschlechterdimension gemacht. Durch die Berücksichtigung geschlechtsspezifischer toxikologischer Merkmale, die Berücksichtigung von Verhaltensunterschieden und sozioökonomischen Auswirkungen kann diese Policy Unternehmen dabei helfen, Risiken zu mindern, aber auch Produkte zu entwickeln, die sicherer, integrativer und wettbewerbsfähiger sind. Abschließend werden die Chancen und Risiken der Anwendung der Geschlechterdimension im SSbD-Rahmenwerk in Policy und Firmen bewertet.

Stichwörter: Chemie, Nachhaltigkeit, Gender, Innovation, Sicherheit, Gleichstellung

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Abbreviations

ATC	Association of the European Self-Medication Industry
BfR	German Federal Institute for Risk Assessment
BUND	Bund für Umwelt und Naturschutz Deutschland
CEFIC	European Chemical Industry Council
CLP	Classification, Labelling and Packaging
CSDDD	Corporate Sustainability Due Diligence Directive
CSRD	Corporate Sustainability Reporting Directive
CSS	Chemicals Strategy for Sustainability
DEI	Diversity, Equity and Inclusion
DG	Directorate

DNEL	Derived No Effect Level
DPP	Digital Product Passport
EC	European Commission
ECHA	European Chemicals Agency
ECOSChem	Emerging Concepts in Sustainable Chemistry
EEA	European Environment Agency
EEB	European Environmental Bureau
EIGE	European Institute for Gender Equality
EP	European Parliament
ESPR	Ecodesgin for Sustainable Products Regulation
EU	European Union
EuChemS	European Chemical Society
GDCh	German Chemical Society
GEP	Gender Equality Plan
GHG	Greenhouse Gases
GIA	Gender Impact Assessment
HaDEA	European Health and Digital Executive Agency
IEA	International Energy Agency
IGO	Intergovernmental Organisation
ILO	International Labour Organisation
IPEN	International Pollutants Elimination Network
IRISS	International Research and Innovation Strategy for Sustainability
ISC3	International Sustainable Chemistry Collaborative Centre
ISO	International Organisation for Standardization
JRC	Joint Research Centre (of the European Commission)
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LCC	Life Cycle Costing

LCIA	Life Cycle Impact Assessment
LCSA	Life Cycle Sustainability Assessment
MSP	Multi-Stakeholder Partnership
NAMs	New Approach Methodologies
NGO	Non-Governmental Organisation
NOAEL	No Observed Adverse Effect Level
OECD	Organisation for Economic Co-operation and Development
PARC	(European) Partnership for the Assessment of Risks from Chemicals
PFAS	Per- and Polyfluoroalkyl Substances
PPE	Personal Protection Equipment
R&D	Research and Development
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RRI	Responsible Research and Innovation
RTO	Research and Technology Organisation
SAICM	Strategic Approach to International Chemicals Management
SDGs	Sustainable Development Goals
SMEs	Small and Medium-Sized Enterprises
SSbD	Safe and Sustainable by Design
SVHC	Substance of Very High Concern
TNO	Netherlands Organisation for Applied Scientific Research
TRL	Technology Readiness Level
UBA	German Environment Agency
UN	United Nations
UNDP	United Nations Development Programme
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
VCI	German Chemical Industry Association
WBCSD	World Business Council for Sustainable Development

WCED	World Commission on Environment and Development
WECF	Women Engage for a Common Future
WHO	World Health Organisation
WICF	Women's International Chemical Forum

1. Introduction

Modern society and its advancement depend significantly on innovations and products that originate, both directly and indirectly, from the field of chemistry. Products such as fertilisers, pesticides, polymers, lubricants, purified metals and solvents serve as an enabling factor for the production of agricultural goods, energy or pharmaceuticals (O'Reilly, 2005), facilitating modern life in its current form. The importance of the chemical industry in Europe is evident, as it contributes to 96% of all manufactured goods, 1.2 million jobs directly and 19 million jobs across the supply chain, with €665 billion turnover in 2023 (EC, 2025c).

Yet, despite its economic and societal relevance, the global chemical sector is highly resource-intensive and ranks among the leading contributors to greenhouse gas (GHG) emissions and environmental pollutants, thereby presenting significant risks to both human health and ecological systems (Papafloratos et al., 2023). In detail, the chemical sector demanded 30% of the global industrial energy use, including 9% of natural gas and 14% of crude oil, while releasing 13% of direct GHG emissions in 2020 (IEA, 2022; Vass et al., 2021). Beyond energy consumption and emissions, a largely underestimated environmental threat is the gradual release of synthetic chemical products into ecosystems through air, soil and water (Persson et al., 2022; UNEP, 2019). These pollutants, often originating from industry directly or waste handling malpractice, accumulate over time, displaying a risk to human health and ecosystems. The WHO estimates that environmental exposures of this kind contribute to approximately 12.6 million deaths each year (WHO, 2016). The core of this problem has been identified as the linear business practices of the chemical sector. To overcome this practice, Systems Level (P. T. Anastas & Zimmerman, 2021) or Life Cycle Thinking (Wu et al., 2023) rather than isolated fixes, as in 'Middle of the Road' scenario (O'Neill et al., 2017; UNECE, 2019), must be applied in the chemical industry to comply with sustainable development.

At the same time, the chemical industry drives key technological innovation (Thormann et al., 2021) and remains a key contributor to achieve global sustainable development, particularly in the context of the UN Sustainable Development Goals (SDGs) (P. Anastas et al., 2021; P. T. Anastas & Zimmerman, 2018). However, this key role is accompanied by risks as chemicals have been identified as a source of potential harm to both people and ecosystems (vide supra). This dual responsibility requires the sector to reduce its negative impacts while emphasising the development of sustainable chemical products. This is not only limited to cutting process-related emissions and decoupling itself from reliance on fossil fuels (Meng et al., 2023) but also enhancing other critical aspects of sustainability, such as improving social well-being and minimising toxicity.

Addressing those aspects becomes increasingly important as the global production of chemicals is expected to grow 50% from 2020 to 2050 (Meng et al., 2023) in a 'business-as-usual' scenario. This growth underlines the dual role of the sector: It is both, a major source of environmental pollution but also the potential to drive change (Mitchell et al., 2024) by overcoming its own industrial rigidities (McKim, 2018). Pursuing sustainable development enables the chemical industry to reduce its impacts, improve human well-being and further regain its relevance within society.

1.1.Sustainability Context

The concept of sustainable development emerged from the idea that economic growth can be achieved while respecting environmental limits and promoting social justice and fairness as described by the Brundtland report *'[…] development that meets the needs of the present without compromising the ability of future generations to meet their own needs*' - WCED (WCED, 1987). This sustainability concept focuses on preserving a system within specific limits to prevent irreversible changes.

Early thoughts about the extensive consumption of natural resources in relation to the growth of population had been raised by economists such as David Ricardo and Thomas Malthus and later also John Stuart Mill (Zweig, 1979) who can be seen as pioneers about the natural limits to growth. However, the most modern debate around the concept of sustainability rose in the 1960s by uprising environmental catastrophes and pop cultural references such as the non-fictional book 'Silent Spring' (Carson, 1962) which deals with the massive use of pesticides and its consequences or the report 'The Limits to Growth' (Meadows et al., 1974) by the Club of Rome. The latter raised concerns over declining natural resources and sparked a critical re-evaluation of consumption habits and economic models. This shift in focus has shaped the debate ever since.

Despite strengthened environmental movements, global environmental activism (Environmentalism) in the 1970s (Dryzek et al., 2003), did not led to a diminishing of the variety and quantity of synthetic chemicals being produced and emitted to the environment, driving a **global disruption** (Bernhardt et al., 2017). Trends of the 'Global Change' since the 1970s are characterised by an increase in carbon dioxide emissions and a steeply increasing world population, as well as emitted phosphorus fertiliser. Distressingly, the amount of released nitrogen fertiliser nevertheless increases to a dramatic extent. Complementary, the amount of agricultural land stays the same but the loss of biodiversity is significant in the same period, indicating intense agriculture, see Figure 1 a.

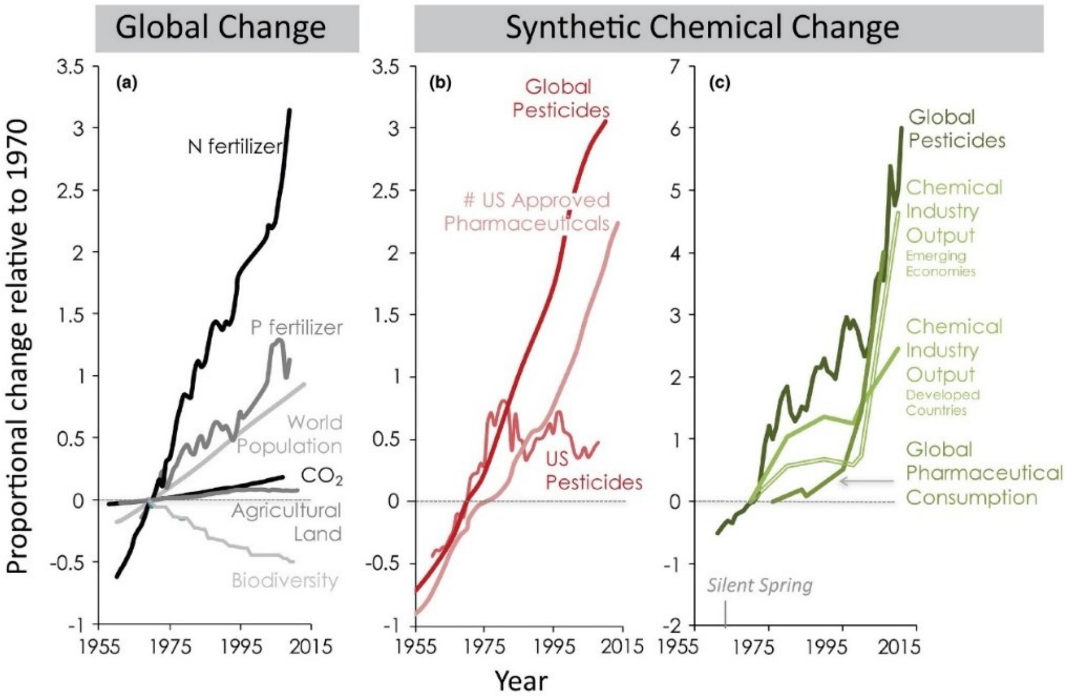

Figure 1: a) Trends in global environmental change drivers, b) increases in US and global pharmaceutical and pesticide as well as approved pharmaceuticals, c) global trade values of synthetic chemicals split into pesticides and pharmaceuticals. Figure from (Bernhardt et al., 2017).

Focusing on synthetic chemicals ('Synthetic Chemical Change'), the amount of produced pesticides stabilised in the last semicentennial period. In contrast, the number of approved pharmaceuticals and globally produced pesticides has massively increased, see Figure 1 b. This is most likely as a result of increased chemical industry activity in emerging and developing economies. It is expected that the global chemical industry is to quadruple between 2020 and 2050 (Cayuela Valencia, 2013), implying a further increase of 'Global Change' and 'Synthetic Chemical Change', see Figure 1 c.

In a similar fashion but more holistically, the concept of planetary boundaries allows to quantify the extent of anthropogenic disturbance that the Earth remains in a 'Holocene-like' state (safe operating space) (Richardson et al., 2023). Moving the earth outside of its safe operating space by overstepping climate change, biodiversity loss and land use change offers significant risks to both the ecosphere and human well-being. Moreover, the increasing presence of novel entities, anthropogenic substances, raises concerns about unknown long-term impacts. As most of the environmental harm that is foreseen is a direct result of how humankind acts within the planetary boundaries (Figure 2) (Richardson et al., 2023).

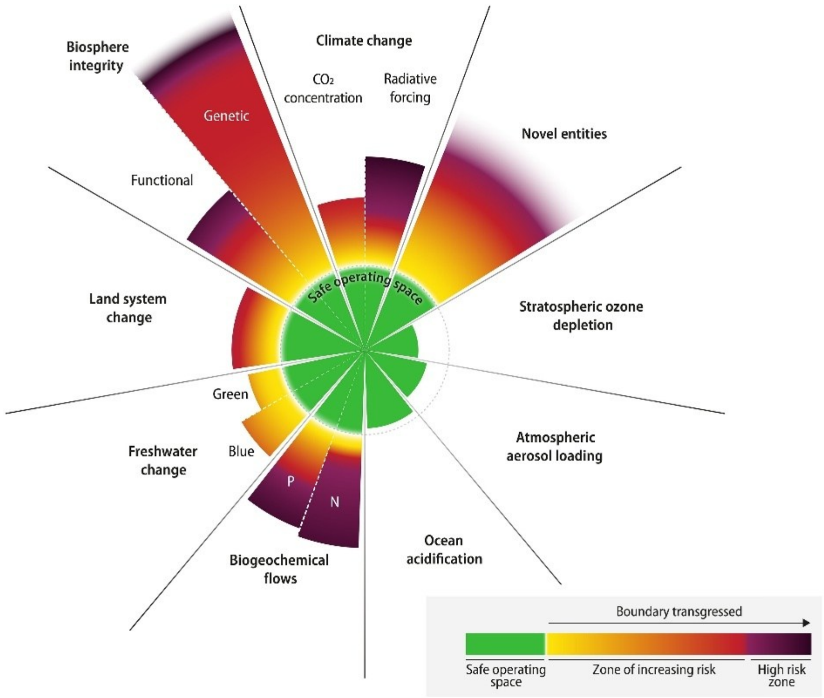

Figure 2: Planetary boundaries as described by (Richardson et al., 2023). Adapted with permission.

As one of the oldest industries globally, the modern chemical industry has profoundly influenced human development through its products and innovations. This industrial sector faces growing pressure to reduce its malpractices and embrace sustainable practices. Hence, its transition to a cleaner and more sustainable industry is a key priority. As emissions of novel entities correlate with increasing industrial activity (Persson et al., 2022), companies that produce these chemicals are being called upon to implement corporate sustainability strategies to address these challenges and the SDGs.

1.2. Policy Context

A milestone for sustainable development has been the SDGs proposed by the UN in 2015 (UN, 2015) as part of the Agenda 2030. The 2030 Agenda for a Sustainable Development covers the different dimensions of sustainability principles and references for policy at different levels as well as for corporate decision makers. The herein proposed 17 SGDs, including 169 targets and 231 indicators, are set out from a perspective for a sustainable future of the global society. In recent years, the academic and political community has been moving away from the 'triple bottom line' model (Elkington, 1997) for sustainability, equal consideration of economic, environmental and social dimensions, to models where the focus is on environmental and societal domains while considering economics. This prioritisation is reflected in the doughnut model (Raworth, 2017) and the wedding cake model (Rockström & Sukhdev, 2016):

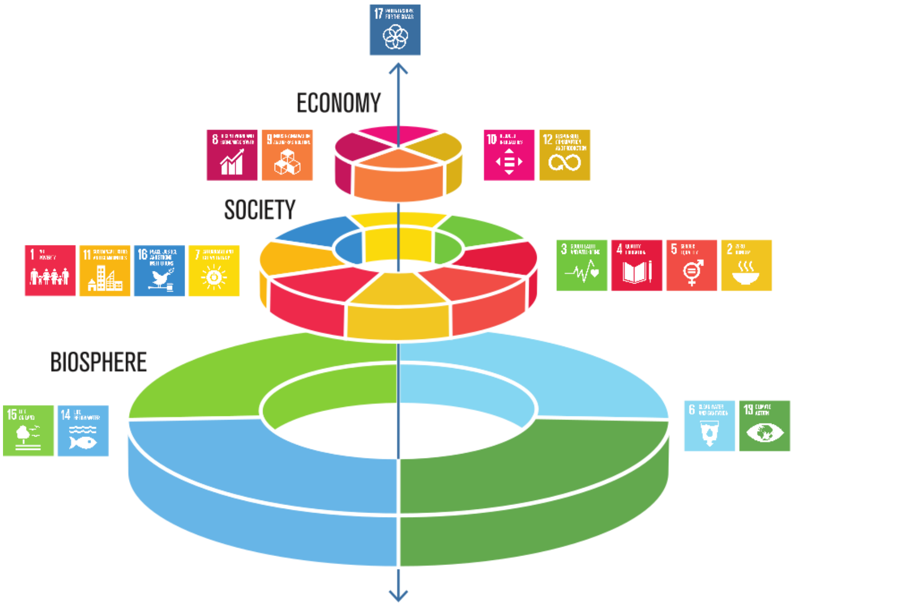

Figure 3: Illustrated model for the UN SDGs displaying biosphere, society and economy (Rockström & Sukhdev, 2016) by Azote for Stockholm Resilience Centre (CC BY 3.0).

Following that prioritisation, the European Commission proposed the **European Green Deal** (EC, 2019) to approach the environmental crisis as presented above. The focus areas of the Green Deal (EC, 2019) can be described as:

- Sustainable transport systems and conservation and restoration of ecosystems and biodiversity as well as 'farm to fork' (sustainable food systems)
- Climate neutrality and clean, reliable and affordable energy
- Resource-efficient construction and renovation
- 'Zero pollution and toxins'

The European Green Deal focuses foremost on climate neutrality until 2050, nature conservation and the transition to a circular economy by committing to conclude strategies such as 'Circular Economy Action Plan', 'Climate Neutrality', 'Zero Pollution Action Plan' and other polices that affect the chemical industry, see Annex Ia. As part of the latter, the 'Chemicals Strategy for Sustainability' (CSS)(EC, 2020b) originated.

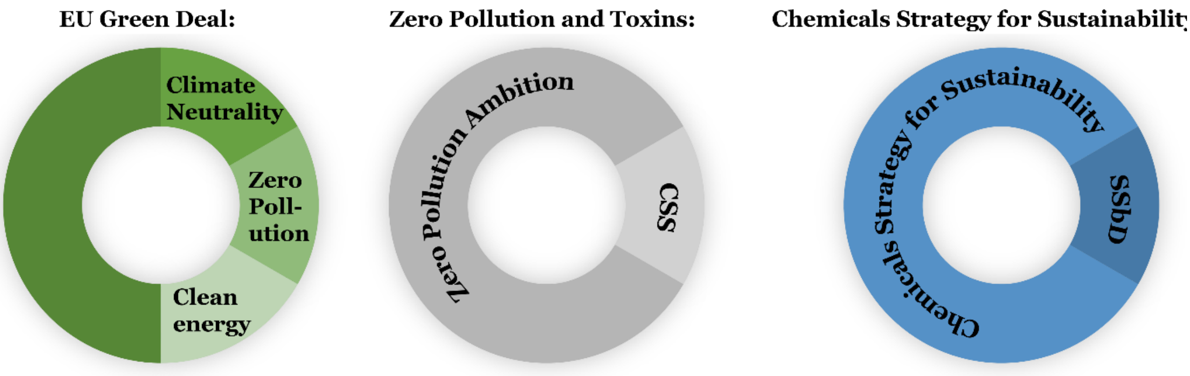

Figure 4: Policy-dimension of the SSbD framework.

Key points of the CSS are to protect health and the environment as well as to boost innovation for safe and sustainable chemicals in pursuit of a long-term vision for a toxin-free environment. Hence, a key action of the CSS is the development of a 'Safe and Sustainable by Design' (SSbD) framework. This pre-market approach supports the early stage development of novel materials, chemical products and processes by assessing safety and sustainability throughout their entire lifecycle and reducing the respective environmental and societal impacts. If potential risks are identified early in the development of novel chemicals and materials, the large-scale production of substances that are harmful to human health or the environment can be limited. While the focus of SSbD is strongly based on human toxicity effects, the socioeconomic dimension of this strategy aims to provide a solution to present issues:

'This strategy is an opportunity to reconcile the societal value of chemicals with human health and planetary boundaries as well as to support industry in producing safe and sustainable chemicals.' - EC (EC, 2020b)

While the SSbD concept primarily focuses on reducing human and environmental risks through early development, it also aims to lay the foundation for systemic change. By aligning innovation with sustainability goals, SSbD also holds opportunities for industries to more effectively meet regulatory expectations and societal demands. However, addressing the global crisis requires more than just technical solutions; it requires a fundamental shift in corporate governance. In this context, the concept of corporate sustainability has gained importance as a complementary and essential approach.

1.3. Corporate Sustainability

Every synthetic chemical detected in the environment is ultimately attributable to human activities, particularly corporate behaviour, unsustainable production systems or mismanagement of waste. It is a direct consequence of conscious human choices and the inadequate implementation of sustainability management principles. These shortcomings are reinforced by systemic industry structures, such as weak environmental policies and the externalisation of ecological costs. It became increasingly evident that a reorientation of current production and consumption practices in the chemical industry is essential to ensure operating within the safe operating space (Meng et al., 2023). Chemical industries, given their extensive history of introducing hazardous substances and their predominant role in the proliferation of synthetic chemicals (referred to as 'novel entities', see Figure 2), bear primary responsibility for fundamentally reforming their business practices.

Sustainability management plays a crucial role in addressing the socioeconomic demands placed on chemical companies, including societal expectations, legal regulations and market pressures. It aligns closely with the three pillars of sustainability: Economy, environment and society (triple bottom line) (Elkington, 1997). Given the significant leverage companies hold, systemic change is most effectively achieved by integrating sustainable policies directly into corporate management frameworks.

Sustainable development on societal level can be applied via three strategies: Efficiency, consistency and sufficiency (Oertwig et al., 2017; Schaltegger et al., 2003). While efficiency measures aim to reduce resource/emissions per output, consistency intents to align production cycles with ecological regenerative capacities and sufficiency is targeting to limit consumption itself. Those three complementary basic strategies of sustainability can be adapted for chemical innovations as:

- By identifying and promoting novel chemicals with improved safety and sustainability profiles, the chemical industry would enhance resource **efficiency** and limit potential environmental and socioeconomic impacts.
- By promoting defossilisation of the chemical industry and focusing on alternative raw materials streams in combination with renewable energy, the chemical industry would ensure **consistency**.
- Providing novel chemicals with improved performance or novel business models such as chemical leasing (Jakl et al., 2003), could promote the reduction of materials consumption or even substitution of whole material classes to promote the **sufficiency** strategy.

Since the root of the described problems lies within corporate activities, sustainability concepts that aim to optimise processes and products represent one of the most influential drivers of systemic change. In this context, the concept of corporate sustainability, particularly corporate social responsibility, has gained increasing attention, as it emphasises the integration of environmental and socioeconomic sustainability into business strategies. Effective **corporate sustainability management** (CSM) is therefore essential to transform these challenges into meaningful change.

Tackling the above-presented sustainability challenges of the chemical industry requires embedding environmental and social considerations from the very beginning of the process or product design. Product design serves as a strategic leverage point for enhancing sustainability performance throughout the entire value chain. A key driver to support sustainable development are concepts like **sustainable innovation management**, **sustainable corporate strategy** but also **business model for sustainable innovation** (Lüdeke-Freund & Schmalleger, 2023).

1.4. Sustainable Innovation Management

The essence of a company is adapting and turning innovation into commercial success. Hence, effective management of innovation is critical, as it shapes the future of the company by evaluating risks that could potentially lead to a loss of market share or expose the company to legal challenges. Consequently, the integration of sustainability considerations becomes essential at this juncture, not only to mitigate procurement risks but also to maintain competitiveness in an increasingly diligent market. The strategic coordination of processes that drive the development of concepts, services and products aimed not only at enhancing an organisation's economic performance but also at aligning with environmental responsibility and social well-being can be described as corporate **Sustainable Innovation Management** (Dodgson et al., 2014). It can be classified into three approaches: Operational optimisation, organisational transformation and system building (Adams et al., 2016) (Figure 5):

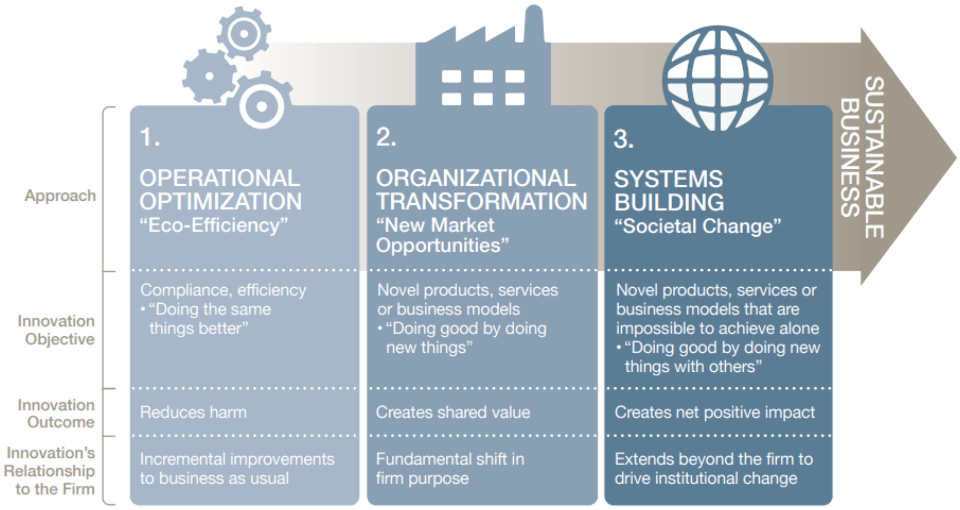

Figure 5: Model for a sustainable innovation process according to (Adams et al., 2016).

The three different attempts can be detailed as:

- The **operational optimisation** focuses strongly on the idea that the corporate sustainability of organisations can be achieved by optimising their products and processes, neglecting the means to alter their business model. Actions like improving energy-efficiency or emission reduction can be an output of this innovation approach.
- The **organisational transformation** is an approach that includes repurposing of the company's philosophy by innovating its products or even business model. The optimisation primarily occurs within the organisation but can also extends to other stakeholders, thus creating shared value. A classical transformation approach, would to shift to a service-dominant business models ('servitisation') (Hansen et al., 2009) which is specifically in the chemical sector the integration of 'chemical leasing' approaches (Jakl et al., 2003).

- To drive societal change by reshaping entire systems or industries, **systems building** includes collaboration with other stakeholders. Using value co-creation through collaboration, products and services can be improved to together achieving a net positive impact on socioecological factors (Schaltegger et al., 2022).

Integrating those approaches of **Sustainable Innovation Management** into a corporate philosophy can provide the foundation for the development of a resilient business model but also limit environmental and socioecological impacts. In detail, improved corporate competitiveness (Hermundsdottir & Aspelund, 2021) but also higher-quality intellectual property outputs (Flammer & Kacperczyk, 2016) are accessed. Nevertheless, the popularity of sustainable innovations often remains limited, due to the investment and risks associated to research and development activities (Rennings, 2000).

Another major driver to shift the innovation process to a sustainable operation, remains with the mitigation of risk. Proactively addressing potential environmental and health impacts helps to secure market position and avoid costly disruptions from litigation, regulatory changes or reputational damage (Petersen & Buhr, 2022b). Most recent cases highlight that due to misconceptions in the innovation process and mismanagement of chemicals, Italian companies linked to PFAS pollution in Veneto prison sentences and faced fines exceeding €6.5 million for executives (France24 24, 2025); 3M decided to exit the production of fluoropolymers (3M, 2022) due to the public backslash for the pollution of various sites with potentially harmful PFAS and DuPont and other companies achieved a $2.0 billion settlement with the State of New Jersey for the contamination (DuPont, 2025); Bayer's acquisition of Monsanto resulted in a significant loss of confidence and market capitalisation due to litigation risks related to Glyphosate (Ritsos-Kokkinis, 2020).

As a substantial amount of the environmental and socioeconomic impacts are predefined in the early product design phase, the selection of raw materials, supply chains, energy consumption, production ways and potential End-of-Life pathways in the design phase are most likely to persist throughout the innovation and production process, e.g. pharmaceuticals (Kümmerer, 2007). Hence, this phase represents the most significant levers for the integration of sustainability principles. Proactively incorporating safety and sustainability considerations during the design phase of a product enables firms to limit impacts throughout the product lifecycle representing a lesser burden to the environment and human health.

1.5. Safe and Sustainable by Design Framework

As part of the EU's zero pollution for a non-toxic environment by 2050 plan, the Chemicals Strategy for Sustainability (CSS) (EC, 2020b) has been announced as part of the EU's Green Deal (EC, 2019). To achieve a toxin-free environment, innovation for safe and sustainable chemicals are promoted within the CSS. To support companies in developing intrinsically safe and sustainable chemicals, the European Commission's Joint Research Centre (JRC) published the **Safe and Sustainable by Design (SSbD) framework** (EC, 2022), which provides guiding principles for chemical design, assessment criteria and methodological recommendations.

The **SSbD framework** is a **voluntary approach** to integrate safety, sustainability and functionality of chemical products in an innovation process by considering the chemical's entire life cycle, mitigating environmental and socioeconomic impacts. This includes innovating for novel substances, products, processes and services, as well as the potential redesign of existing ones strongly focuses on improving the sustainability of companies on a **product level**, see operational optimisation (Figure 5). However, the EC's focus is on prioritising **innovation over substituting** harmful substances (EC, 2022). In this context, systemic solutions like organisation transformations (Figure 5), sufficiency-oriented innovations or business model innovation, e.g. chemical leasing, are potentially favoured.

In detail, the SSbD framework is designed to not compromise on safety aspects during the innovation stage following the 'zero pollution and toxins' action (vide supra). Accordingly, it adopts a hierarchical strategy that prioritises safety, followed by environmental and socioeconomic considerations to prevent interdimensional trade-offs (Figure 6).

Figure 6: Principles of the SSbD framework in a hierarchical order as proposed by the JRC (EC. JRC, 2022b).

Innovating within the SSbD idea can follow a sequence of steps to identify the most suitable candidate for further development. Conceptually, the process begins with defining functional requirements of the chemical innovation, continues with assessing potential impacts and selecting a chemical with minimum toxicity and sustainability considerations (Figure 7).

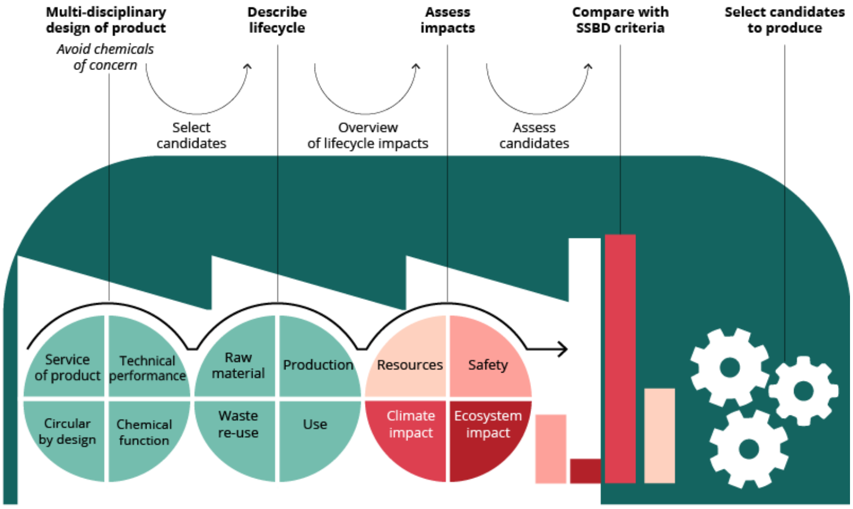

Figure 7: A workflow for redesigning chemical products using the SSbD approach (EEA, 2023).

Depending on the practices of the organisation, the availability of data, the tools used and the specific purpose of the assessment, the steps may also be carried out in parallel.

However, the JRC proposes to guide the development and redesign of novel chemical products in an iterative stage-gate process consisting of five steps. At each step of the innovation process, compliance with the discontinuation criteria is reviewed to prevent further development:

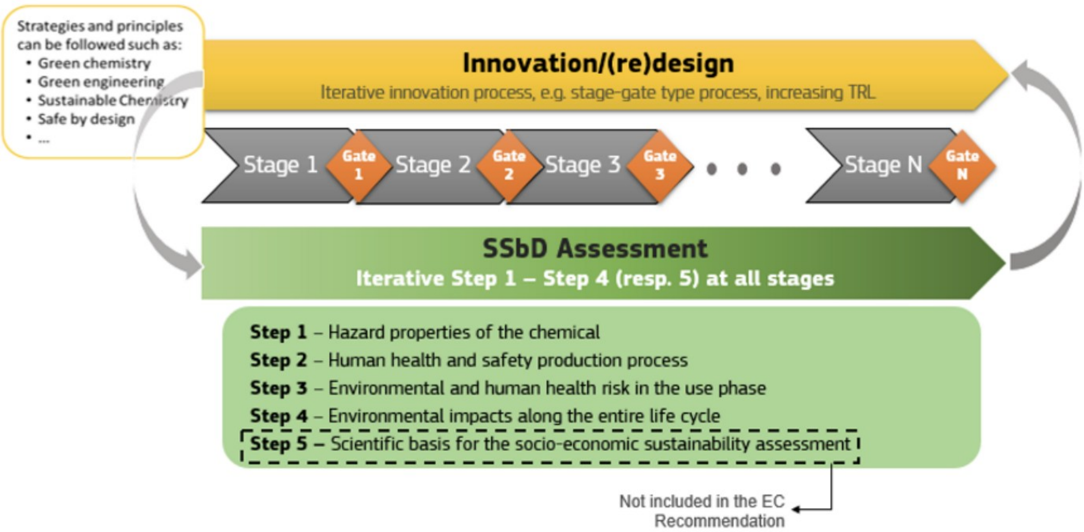

Figure 8: Stage-gate workflow within the SSbD framework from (EC. JRC, 2024).

Nevertheless, a novel chemical or material is considered to meet the framework's criteria only if it outperforms existing solutions in both safety and environmental sustainability justifying the substitution efforts and uncertainties. For this, a weighting is carried out using multi-criteria decision analysis comparing safety and sustainability scoring (EC. JRC, 2022a).

In general, the SSbD approach aims to support the substitution of Substances of Concern (SoC) in both production and use, going beyond regulatory requirements. Also, it broadens the scope of basic (re)design principles from green chemistry (P. T. Anastas et al., 2000) and circular chemistry (Keijer et al., 2019), and includes holistic sustainability derived from sustainable chemistry (ECOSChem, 2023). These guiding principles provide the foundation for a holistic sustainable design of chemicals and materials. Among them, **Sustainable Innovation** plays a central role, referring to innovations that successfully integrate economic, social and environmental objectives to create a 'win-win-win' outcome (Afeltra et al., 2021). Similar approaches have already been reported. Since 2013, the EC's **Responsible Research and Innovation** (RRI) (EC. DG RTD, 2013) plan emphasises ethical, inclusive and anticipatory approaches to innovation, ensuring that scientific and technological advancements align with the needs and values of the European society. Similar approaches have been already reported by OECD's **Safe(r) and Sustainable Innovation Approach** (SSIA)(OECD, 2022) that embedded the SSbD idea but enhance it to regulatory preparedness and trusted environments. However, a recent study further evaluates the implementation of both the JRC's SSbD framework and the OECD's SSIA, highlighting key challenges and offering recommendations from an industry perspective to better enable sustainable innovation (Rajagopal et al., 2025).

In the following, the key focus areas within the SSbD framework, scoping analysis, safety and sustainability assessment will be introduced.

1.5.1 Scoping Analysis

Recently introduced, the scoping phase is a foundational step of the SSbD framework (EC. JRC, 2024), establishing the direction and boundaries for subsequent assessments. This phase has been integrated to define why an assessment is needed, the **purpose of the innovation** and what system is under study (chemical, process, product). It is closely related to Life Cycle Thinking, Systems Thinking and stakeholder engagement. Moreover, it considers the innovation's objectives, redesign needs and potential impacts across the value chain.

1.5.2 Safety Aspects

To comply with the 'toxic-free' vision of the EC, the intrinsic safety properties of novel chemical or material must be assessed. This can relate to aspects of intrinsic acute or chronic toxicity but also other physical hazards (flammability, stability). Hence, physicochemical properties which are relevant to estimate exposure pathways, such as physical form, solubility, octanol/water partition coefficient and biodegradability have to be assessed to describe the risk to human health and the environment. The safety of materials and processes is described in SSbD on an intrinsic material level (**Step 1** SSbD) and on the occupational/environmental risk level (steps 2 and 3). However, novel chemicals should be inherently 'safe by design' to comply with unforeseen uses in potential future life cycles but also in case of unintentional release of the material. Whilst the handling of exposure risk is well regulated in Europe, see Seveso directive (EP and Council, 2024b), Industrial Emissions Directive (EP and Council, 2024a) or the Waste Framework Directive (EP and Council, 2018), assessing the unforeseen emission of material within the SSbD approach is expanding companies responsibilities.

A starting point for assessing the hazard profile of chemicals and materials is the existing EU chemicals legislation Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), the Classification, Labelling and Packaging (CLP) and their associated guidelines. As stated in the ESPR and CSS, hazard classes can be divided into three groups: harmful (H1), of concern (H2) and other hazards (H3). A strict hazard assessment will define the maximum level from hazard endpoints by applying protection factors that can be deducted from 'Derived No Effect Level' (DNEL) and 'No Observed Adverse Effect Level' (NOAEL). They indicate the upper limit for human beings exposed to a chemical that might lead to adverse effects. Identification as a harmful chemical (H1) incentivises the innovation process to substitute this compound directly. Ultimately, the goal is to replace substances that pose risks to human health or the environment, including those that are mutagenic, reprotoxic, endocrine disrupting, carcinogenic, persistent, bioaccumulative or mobile and may impact the immune, neurological or respiratory systems. Within the SSbD approach, the objective extends beyond the REACH framework and the SVHC logic, aiming instead to ensure the development and use of non-toxic, safe materials throughout their entire life cycle.

Next to the direct exposure to chemicals, health and safety aspects for processes encountered throughout the product's life cycle are taken into account (**Step 2** in SSbD). This is particularly important as some final chemical materials are considered safe but the production pathways of chemicals used highly adverse compounds. Hence, the assessment follows from the raw material extraction to production, processing and End-of-Life treatment (recycling and waste management). At each step, the handling of the novel chemical must ensure safe conditions, linking to Occupational Safety and Health (OSH) and exposure risk assessment.

Step 3 in SSbD highlights the safety of materials during their application. Hence, use-specific environment and human health risks (i.e., combination of the hazards and the exposure pathways) are assessed. For this, information on the final application with details on the amount of chemical or material used, as well as duration and frequency of the exposure, must be defined. This is in particular complicated for 'platform chemicals' that are found chemically modified in the final product, e.g. polystyrene is made from carcinogenic styrene.

Under the most recent draft of the SSbD framework, steps 1-3 of the 2022 framework are merged into one safety step for the sake of clarity (EC. JRC, 2025). This will be recognised if it appears in the official recommendation's text.

1.5.3 Environmental Sustainability

To assess the environmental sustainability of products and processes in **Step 4**, the JRC recommends performing the well-established Life Cycle Assessment (LCA) methodology. This technique evaluates the potential environmental impacts that occur during all stages of a product's life cycle (from cradle-to-grave) and is standardised under ISO 14040/14044 (ISO, 2006). It assesses the emission and resource use from the point of raw material extraction, processing, production of the product as well as its use, up until its End-of-Life, see Figure 9.

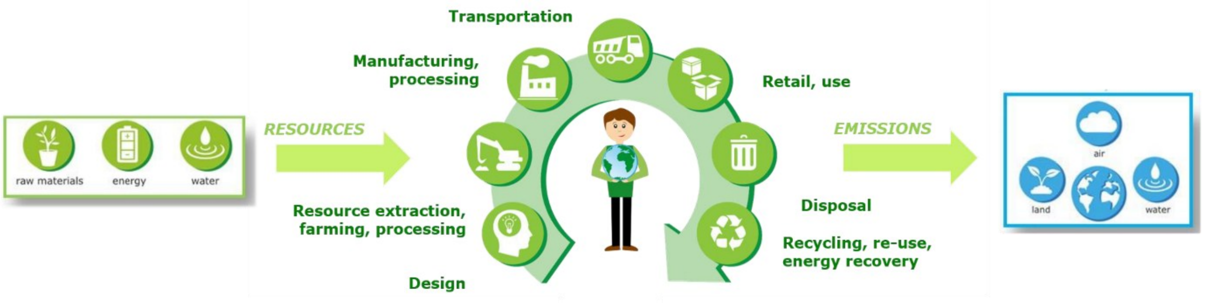

Figure 9: Considering the resource use and emissions throughout a product's life cycle by the JRC (EC. JRC, 2019).

Different variants of LCA are used to evaluate various sustainability dimensions: Environmental impacts through environmental LCA (or simply LCA); Social impacts via social Life Cycle Assessment (sLCA) and economic impacts through Life Cycle Costing (LCC). Life Cycle Sustainability Assessment (LCSA) integrates all three approaches to provide a comprehensive sustainability evaluation. Each approach for assessing the individual dimensions of sustainability adheres to a general methodological framework, based on ISO 14040 and ISO 14044 standards (ISO, 2006), comprising four phases:

- Goal and scope definition
- Inventory analysis, leading to Life Cycle Inventory (LCI)
- Impact assessment, also called Life Cycle Impact Assessment (LCIA)
- Interpretation

Nonetheless, in the chemical sector product carbon foot printing (PCF), see GHG protocol (Ranganathan et al., 2023) or ISO 14067 (ISO, 2018), is the most prominent method. In contrast, LCA goes beyond climate change but focuses on several environmental categories such impacts on ozone layer, particulate matter, resource use, acidification, eutrophication as well as land and water use, see environmental footprint method (EC. JRC, 2019). Results can be expressed at the midpoint level, focusing on specific impact categories, e.g. acidification or water usage, at the endpoint level by assessing potential damages to areas of protection like human health, ecosystems and resources. Endpoint results are particularly valuable at the policy level to guide decision-making (EC. JRC, 2016).

The strength of LCA lies in holding a diverse perspective on environmental impacts, preventing potential trade-offs and displaying impacts along the whole supply chain. This allows for identifying hotspots within products/processes, more informed decision-making and endorses strategies that minimise overall environmental harm.

Lately, policymakers promote the integration of LCA in decision-making processes to promote sustainable development and inform policies related to environmental protection, resource management and product design (EC. JRC, 2016).

1.5.4 Socioeconomic Dimensions

The socioeconomic assessment of novel materials, processes and chemicals is **Step 5** in the SSbD framework and is meant to stay **optional** as the methods used within this assessment are less mature. To ensure a comprehensive assessment of socioeconomic impacts, the framework draws on a variety of methodologies such as social LCA, LCC, Criticality Assessment (of raw materials) but also monetisation of externalities (extended environmental impact assessment).

As a method to assess the economic sustainability of a product/process, the JRC focuses strongly on using Life Cycle Costing (LCC) on a product level. This assessment method calculates the total costs associated with the entire value chain of the assessed system. It accounts for all costs associated with activities along the value chain that fall within the defined system boundary, including those related to sourcing, production, use, disposal and recycling. Commonly, LCC focuses on the producer's perspective, lacking societal and environmental costs (externalities) as well (Rödger et al., 2018). Hence, the JRC also emphasises utilising emerging methods like 'environmental Life Cycle Costing' (eLCC) that are designed to include externalities such as hidden and indirect costs (EC. JRC, 2024).

For a sustainable chemical to be viable, even the most innovative solutions must remain economically competitive and meet market pricing expectations. The JRC's SSbD framework does not consider such dimensions as they are hard to quantify by methods like LCC. Hence, the European chemical industries, represented by CEFIC, own SSbD approach has integrated a market-orientation by considering other criteria such as product performance and stakeholder requirements (customer performance), transparency, economic and technical sovereignty (profitability) and value-chain collaboration (supplier relationship) (CEFIC, 2022)(see Figure 10).

Figure 10: CEFIC's own SSbD approach (CEFIC, 2022).

While this industry-focused perspective emphasises economic and technical feasibility, the social dimension is less prominent. The SSbD framework focuses on the social dimension of sustainability and focuses on how products and processes affect a broad group of stakeholders, including a wide range of viewpoints by assessing the full spectrum of both positive and negative social impacts. This comprehensive approach requires navigating complex relationships between different stakeholders and understanding the larger societal consequences of these systems. To create a comprehensive social impact assessment, the JRC's SSbD framework relies on social Life Cycle Assessment (sLCA) to assess the social performances and social risk along the complete life cycle. Although it differs in content, sLCA follows the core principles outlined in the ISO 14040 and 14044 standards. Although, the sLCA methodology is still evolving and remains less scientifically developed and applied than its environmental counterpart, it also consists of goal and scope definition, inventory analysis, impact assessment and interpretation. Recently, a sLCA standard (ISO 14075) has been published recently (ISO, 2024) which could improve its uptake.

In contrast to LCA and LCC, sLCA can be conducted using either qualitative or quantitative approaches. Regardless of the method used, the intend of an sLCA is to safeguard individual rights while maximising societal benefits by providing detailed social hotspots along the supply chain. However, it is important to note that sLCA studies often rely on a broad array of indicators to assess social performance or risk. This is opposed to environmental LCA logic, where cause-effect relationships and actual impacts can be deduced.

To conduct an sLCA, first a **Materiality Assessment** has to be performed to identify the most important social topics from the 40 impact subcategories and six stakeholder groups. This process commonly involves active engagement such as discussions with trade unions, NGOs and community representatives to ensure the results are relevant and unbiased. To perform the impact assessment, the UNEP sLCA guidelines (C. Norris et al., 2020) propose six key stakeholder categories: Local communities, consumers, workers, value chain actors, society and children.

While the focus within manufacturing sectors, like the chemical industry, is often on occupational risk and consumer protection, other stakeholders, e.g. children, local communities and other value chain actors, are likewise relevant as recognised by UNEP and WBCSD. This discrepancy is due to the fact that some social aspects are often directly controlled by companies, e.g. such as occupational safety and workplace injury rates through safety measures. Nevertheless, the UNEP/SETAC guidelines (C. Norris et al., 2020) identify all relevant social indicators, linking them through pathways and using scientific assessment methods to assess social impacts. The selection of social metrics can be inspired from:

- Handbook for Product Social Impact Assessment (Goedkoop et al., 2020)
- UNEP/SETAC guidelines for sLCA (C. Norris et al., 2020)
- PSILCA Handbook (Maister et al., 2020)

As primary data (from companies and affected communities) are less available for sLCA than for eLCA, secondary sources like social hotspot databases (C. B. Norris et al., 2011) or the PSILCA database (Maister et al., 2020), have a higher priority in sLCA and fill gaps.

Nonetheless, assessing social dimensions of any innovation, in particular chemicals, is often overlooked as effects along the supply chain are hard to measure and visualise. Among these dimensions, gender aspects play a crucial role, as chemical can pose harm to individuals but also potentially hold other societal impacts through their intrinsic hazard.

1.6. Gender Dimension in Innovation

This thesis follows the sex and gender definition as proposed by the European Commission (EC. DG RTD, 2020) *and sources herein where 'sex' refers to biological characteristics such as genetic, hormonal, physiological and anatomical features of male, female and intersex individuals in humans and 'gender' refers to sociocultural norms, identities and relations that shape and define what is considered feminine and masculine behaviour and structure societies and institutions.* Other gender-relevant definitions are derived from the UNICEF glossary (UNICEF, 2017).

1.6.1 Definitions and Policy Context

In a wider context, **gender norms** are social and cultural expectations about appropriate roles and behaviours based on culture, media or on institutions. **Gender identity** is how individuals recognise and express themselves in relation to these norms. **Gender relations** refer to how interaction with other people or institutions based on our sex or gender develop (EC. DG RTD, 2020) (see Figure 11).

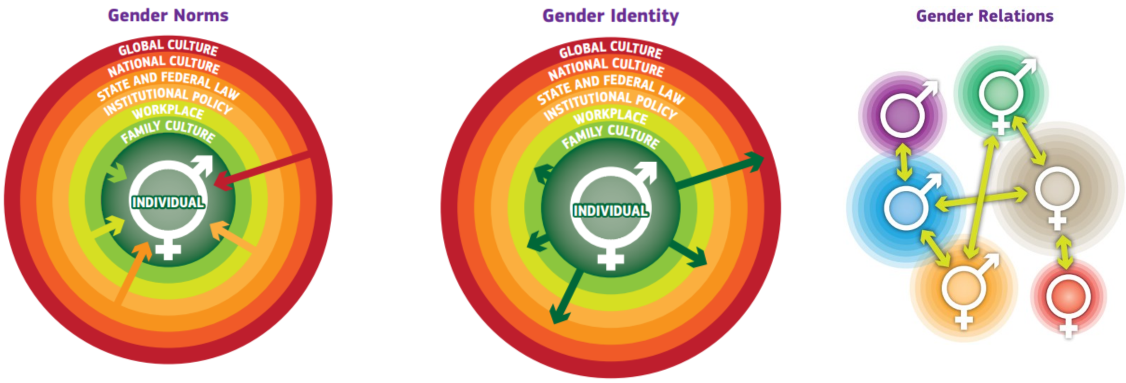

Figure 11: Depiction of Gender Norms, Gender Identity and Gender Relations from (EC. DG RTD, 2020, p. 14).

With regard to the UN SDGs, the gender equality and empowerment of women and girls is a major challenge to achieve global equity. Notwithstanding global pledges, progress towards gender equality falls short of expectations as a recent UN report shows: Merely 15.4% of the SDG5 indicators are achieved, enduring inequalities remain as child marriage, legal inequities and gender-based violence persist, women hold less than a third of leadership roles, nearly half of married women lack full reproductive autonomy and legal protections for land rights are still inadequate. With the current rate, it is projected that gender disparities will persist far beyond 2030 and this calls for urgent action from policymakers (UNDESA, 2023).

On policy level, the SDGs hold a gender perspective, particularly through SDG5 (UN, 2015), yet this perspective requires further integration across their implementation (UN Women Africa, 2022). The European perspective still lag behind and the subsequent actions under the EC's Gender Equality Strategy (EC, 2020a) remain limited. However, on the forefront of **Gender Mainstreaming**, the integration of gender dimensions into EC's research and innovation activities is notable. An analysis of the 'She Figures 2018' report (EC. DG RTD, 2019) highlighted the impact and efficiency of implemented policies based on quantifiable markers. Initial attempts had been made to integrate gender equality in research and innovation, see EU Gender Equality Strategy 2020-2025 (EC, 2020a). It forms the overarching framework for gender equality policy in all EU areas by pursuing a dual approach:

- **Gender Mainstreaming** by integration of the gender perspective into various policy areas (horizontal implementation)
- **Intersectionality and targeted actions** with targeted measures to eliminate existing inequalities, e.g. the consideration of overlaps with other grounds of discrimination such as socioeconomic status, age, ethnicity, disability or sexual orientation (vertical implementation)

The first has been prominently established as European research projects require integrating the gender dimension into their research and for participating partners to hold a Gender Equality Plan, see 'She Figures 2018' report (EC. DG RTD, 2019). At the moment, scientific methods like the Gender Impact Analysis (GIA) (EC. DG EMPL, 1998), an analysis conducted prior to the implementation of a law, policy or programme to evaluate its likely impact on gender equality, are not frequently conducted in European research projects.

Although a wide range of policies exist at the European level for the chemical sector, none explicitly address gender dimensions and links to the EC's Gender Equality Strategy. Instead, it is mainly global policy actors, such as UNEP and UNDP, who have addressed this issue, most remarkably through UNEP's Global Framework on Chemicals (UNEP, 2024).

1.6.2 Gender Dimensions, Innovations and Risks in the Chemical Industry

With respect to gender dimensions in chemistry, issues of gender equality in research, teaching, the workforce but primarily the chemical sound management should be explored. It is important to consider both biological and social aspects:

- **Biological dimensions** ('sex'): Due to biological differences, chemical substances can affect individuals differently. These differences may arise from hormonal variations, genetic factors or physical characteristics such as body fat percentage, all of which can influence the level of risk when interacting with chemicals. Most strikingly, the development of drugs has been a 'one size fits all' model neglecting pharmacokinetic differences resulting in women suffering significantly more adverse reactions compared to men (Zucker & Prendergast, 2020). However, there is a systematic underrepresentation of sex- and gender-disaggregated data in toxicology and exposure studies as well also for trans and intersex individuals.
- **Societal dimension** ('gender'): Structural inequalities limit women's representation in innovation roles in chemistry and expose certain groups to disadvantages along the chemical's life cycle. For example, women and children often conduct informal plastic sorting in low-income regions, facing disproportionate exposure to hazardous substances (WEFC, 2023). Beyond employment in informal sectors, women are more frequently exposed to indoor pollution and everyday chemicals through cleaning products or personal care items. In contrast, men are more often affected by workplace poisonings, with chemical-related deaths occurring about twice as frequently as among women (IPEN & SAICM, 2021).

Neglecting the gender perspective in innovations can hold significant consequences to the business operations including reputational damage but also business failure. The example of the hypnotic drug Thalidomide produced in the 1950s by Grünenthal resulted in thousands of birth defects due to a lack of testing on pregnant women (Rehman et al., 2011) leading to a massive reputation loss and a settlement of 100 million German Mark (Grünenthal GmbH, 2023). In a similar fashion, the inadequately tested contraceptive 'Dalkon Shield' caused infections and loss of fertility in women. More than 370,000 women linked to infertility and inflammations held claims against the respective A.H. Robins Company and was ultimately unable to remain in business (Roepke & Schaff, 2014).

In the chemical sector, gender dimensions are particularly significant, as chemical innovations may inadvertently lead to unintended exposure across the life cycle. The nematicide dibromochloropropane (DBCP) rendered many exposed workers sterile. Cases of male infertility was found with production workers in the US and also downstream for banana farm workers due to the inappropriate or absence of use for personal protection equipment (PPE) (EEA, 2020; Teitelbaum, 1999). Large scale health impacts can be associated to endocrine-disrupting chemicals, such as polybrominated diphenyl ethers (PBDEs), bisphenol A (BPA) and di(2-ethylhexyl) phthalate (DEHP), used in the plastics sector with adverse impacts documented across their life cycle (Lynn et al., 2017). These leachable additives have been associated with substantial health and economic burdens linked to $920 billion of healthcare expenses and economic losses in the US (Landrigan et al., 2023). These examples demonstrate that overlooking gender considerations in innovations is not only a social and ethical risk but could lead to actual innovation flaws and shortcomings, resulting not only in business failure and financial losses but also large societal implications.

The concept of **Gendered Innovations** directly addresses this gap by employing sex and gender analysis as a strategic resource in the innovation process (Schiebinger & Schraudner, 2011). The idea is to shift the focus from treating gender as a compliance requirement to treating it as a tool for access more competitive innovation. Examples show that this concept encourages the development of novel products and services enhancing inclusivity and societal benefit promoting stakeholder-driven value creation (EC. DG RTD, 2020).

In the context of sustainable innovations, particularly in policy frameworks such as the SSbD, considering gender perspectives must be essential to ensure safe and socially responsible outcomes but could also lead to improved business value through gendered innovations.

1.7. Shifting of Policy Landscapes and Industry Responses in the European Chemicals Sector

Despite growing environmental concerns and with intensifying global competition, the EU has intensified its efforts to strengthen industrial competitiveness. The Draghi Report (EC, 2024) emphasises the need for a resilient and innovative European industrial base capable of addressing global challenges while maintaining its competitiveness. As a result, the EU

Competitiveness Compass (EC, 2025a) has been provided with 'Innovation' as a pillar of competitiveness and hence an area where the SSbD approach can serve as a key instrument.

At the same time, chemical industry representatives have raised significant concerns about the need for a more predictable and supportive regulatory environment as expressed in the Antwerp Declaration (CEFIC, 2024b). It underscores the urgent need for policies that both promote innovation and ensure Europe's industrial competitiveness at the global level. Hence, the Clean Industrial Deal (European Commission, 2025) outlined a framework for aligning industrial policy with the EU's climate objectives and promoting sustainable growth through green technologies and clean manufacturing. Following this, the European Commission published an **Action Plan for the Chemicals Industry** (EC, 2025b) addressing key challenges such as high energy costs and regulatory complexity by promoting innovation and streamlining legislation.

However, most recent European but also global political tendencies and setbacks for sustainable development should be considered in the policy field:

- Simplification of the EU's Green Deal sustainability reporting and due diligence efforts via the 'Omnibus' package with effects on the CSRD, CSDDD, CBAM and potential abandonment of the Green Claims directive (EP, 2025)
- Anti-ESG bills to prohibit considering environmental, social and governance (ESG) investment criteria in public financial investments (Tang et al., 2024)
- Institutional rollback on inclusion frameworks and workplace social norms in particularly in the major economies, notably in the U.S., dismantling public Diversity, Equity and Inclusion (DEI) efforts, followed by the private sector (Ng et al., 2025)

It is noteworthy that on the academic level the Stockholm Declaration on Chemistry for Future (P. Anastas et al., 2025) calls for sustainability within the whole chemical society to follow public movements like Fridays for Future and the Global Youth Climate Movement, which demand systemic change toward environmental responsibility.

The uncertain potential of such topics sends a signal that comprehensive regulation of sustainability is becoming a lower priority for policymakers. Hence, a slight balance between sustainability measures and industrial competitiveness will remain crucial for the future.

1.8. Current State and Relevance of the SSbD framework

Since its initial publication in 2022, the framework and its methods have been regularly updated and open consultation and stakeholder workshops have been held (Figure 12).

Figure 12: Overview of the relevant JRC's publications on the SSbD framework.

At the current stage, the SSbD concept has been tested in various industrial cases (EC. JRC, 2023). Further, ongoing open consultation activities of the JRC (Abbate et al., 2025) and efforts in various EU-funded SSbD projects across all sectors, material types and substances are observed (Figure 13).

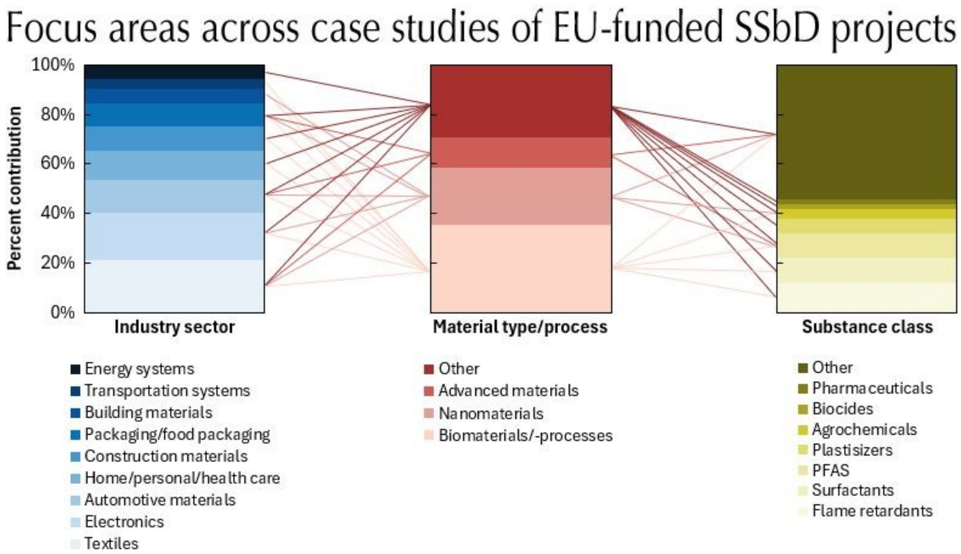

Figure 13: Overview of topics focusing on SSbD horizon projects (Fantke, 2025).

Overall, 284 Mio. € are allocated to such research activities, where the PARC project held an additional 200 Mio. € underpinning the EC's efforts to proceed in this direction. The SSbD framework is anticipated as a key incentive to transform the European chemical sector (Soeteman-Hernández et al., 2025) with its uptake projected to grow as it becomes progressively required in Horizon Europe projects.

1.9. Aim and Scope

The aim of this thesis is to critically analyse the current state of the SSbD framework in the context of sustainability and innovation management, in particular from a gender dimension point of view. Further, the objective is to provide guidance on how to integrate the gender dimensions into the SSbD framework but also sustainability innovation process of companies.

The scope of this thesis covers, analysing the SSbD framework through sustainability strategies and innovation perspectives, by examining stakeholder positions and assessing benefits and risks for corporate innovation. Further, the gender dimensions in the SSbD framework are assessed, followed by mapping of stakeholder positions In addition, the thesis proposes pathways for integrating gender considerations using learnings from the gender and stakeholder analysis by

- Integration of the gender dimension into the scoping process
- Gender-specific toxicological interactions with chemicals
- Societal dimension of chemical innovations from a gender perspective

2. Methods

The methods that are used within this thesis are intended to provide insights into stakeholder positions regarding the SSbD framework and gender dimensions that can be integrated into the SSbD framework. In particular, the integration of social aspects and stakeholder dimensions into sustainability innovation in the chemical industry was investigated.

To propose an implementation of stakeholders, such as gender, within the SSbD framework, the following scientific methods have been used:

- Analysis of interviews, literature survey and positioning statements
- Stakeholder mapping and analysis

2.1. Description of the Literature Review

A literature review of scientific publications, position papers and initiatives has been conducted initially to map existing knowledge and opinions on the SSbD framework and gender dimensions in the chemical sector. Bibliographic search engines such as Scopus, Web of Science and Google Scholar were used, applying keyword combinations including 'safe and sustainable by design', 'gender and chemicals'. In addition, cited and related publications were identified through this approach. However, as various non-scientific sources, such as policies or white paper, dominate the field, these sources were identified through web search. Moreover, lectures from the MBA 'F1: Principles of Sustainability Management', 'F2: Perspectives of Sustainability Management', 'F5: Concepts of Sustainable Chemistry' and 'F7:

Regulations and International Conventions' were drawn upon to frame the theoretical background. The outcome of the literature review in combination with the lectures, served as a guidance for the results and discussion part of the research.

2.2. Overview of Analysed Documents per Stakeholder

As a result of the literature review, the following stakeholders and amount of reports/position papers were identified. They form the basis for the position analyses (Table 1).

Table 1: Overview of considered stakeholder groups and amount of reports considered for the analysis.

Stakeholder	Organisations	Reports
Upstream/Downstream Industry	BASF, Unilever	2
Industry Associations	CEFIC, VCI, ATC, NIA	4
NGOs	WECF/WICF (UNEP), BUND, EEB, IPEN	4
Governmental/Policy	UBA, BfR, EEA, DG RTD	4
RTOs/Academic	TNO, GDCh/EuChemS	2
Networks/Stakeholder initiatives	IRISS, ISC3, PARC, MSP Institute	4
IGOs	ILO, UNEP, OECD	3

2.3. Limitation of the Methodology

The herein described approach is limited to materials that are publicly accessible and limited to the perspective of stakeholders. Hence, positions of relevant stakeholders like consumers, small and medium-sized enterprises (SMEs), financial institutions and other relevant stakeholders, are not represented. Some stakeholder's position might be overrepresented as they are also part of other stakeholder groups, e.g. the chemical company BASF is a member of CEFIC and VCI but also represents the upstream industry. Moreover, the length of a document (position paper vs. full reports) could not be factored into the results. Further, interviews of three companies concerning their experience on the SSbD framework were taken into account, see Annex.

3. Safe and Sustainable by Design in Corporate Sustainability

In this chapter, the SSbD framework is situated within the field of sustainability and innovation management to facilitate its effective implementation in corporate innovation management. The analysis examines which sustainability strategies it follows, to which perspective of sustainability practice it can be assigned and which perspective of sustainable (innovation) management it can be assigned to. Then, the focus shifts to analysing the positions of various stakeholders on the SSbD framework through a position analysis. The insights gained, in connection with sustainability management strategies, were subsequently examined with regard to the risks and benefits of integrating the SSbD framework into corporate innovation.

3.1. SSbD as Corporate Innovation Instrument

To first understand the scope of the SSbD approach from the perspective of sustainability management, initially the basic sustainability strategies behind the SSbD principles (efficiency, consistency and sufficiency) were analysed (chapter 1.3). The proposed measures from material-focused approaches such as green/circular chemistry outweigh more holistic sustainability concepts such as sustainable chemistry (EC. JRC, 2022a, pp. 25–27).

Table 2: Design principles as proposed by the JRC (EC. JRC, 2022a) and the underlying sustainability strategy.

No.	Principle	Definition	Strategy
SSbD1	Material efficiency	Incorporate all chemicals used in a process into the final product or recover fillers within the process to reduce the use of raw materials and waste generation	Efficiency
SSbD2	Minimise hazardous chemicals or materials	Maintain product functionality and reduce or avoid the use of hazardous chemicals/materials wherever possible	Consistency
SSbD3	Design for energy efficiency	Minimise energy used to produce a chemical in the production process and along the supply chain including recycling or disposal	Efficiency
SSbD4	Use renewable sources	Focusing on integration of renewable raw materials in to the chemical/material or imposing closed loops	Consistency
SSbD5	Prevent and avoid hazardous emissions	Application of technologies to minimize and prevent hazardous emissions or pollutants in the environment	Efficiency
SSbD6	Reduce exposure to hazardous substances	Avoid exposure to chemical hazards in processes as much as possible and do not use substances that require a high level of risk management. Further, best available technology should be used to avoid exposure at all stages of the life cycle	Efficiency, Consistency
SSbD7	Design for the end-of-life	Chemicals should not hamper waste collection/sorting reuse, recycling and after their fulfilled their function and also break down into harmless products	Consistency
SSbD8	Consider the whole life cycle	Design the chemicals for the whole life cycle (cradle to grave)	Consistency

In summary, these principles illustrate that the SSbD framework primarily focuses on efficiency and consistency strategies, while sufficiency plays only a minor role. This emphasis shapes the positioning of the framework in broader debates on sustainability management and forms the basis for its link to approaches to sustainable innovation management (chapter 1.4). Setting the SSbD framework into context of the principles of the **Sustainable Innovation Management** the framework can support:

- **Operational organisation**: In a company applying the SSbD approach, the focus is on optimising chemicals and processes by reducing waste, improving eco-efficiency or redesigning products into safer and more sustainable alternatives without making any organisational changes.
- **Organisational transformation**: Instead of redesigning existing chemicals, companies can design entirely new products by integrating SSbD principles into their core innovation strategy to avoid creating unsafe and unsustainable products. This may involve shifting portfolios toward inherently safer chemicals or circular materials.

To extend the reach of this analysis, also the underlying concepts of the SSbD approach from a Corporate Sustainability Management (CSM) point of view were studied. While the market-oriented CSM is focused on integrating sustainability into market relations and innovations, the cooperative approach is based on partnerships and collaborations with stakeholders and policy-oriented CSM centres on managing stakeholder interests and conflicts through policies (Schaltegger & Cieslewicz, 2022). Applied to the SSbD innovation idea, following results:

- From a **market-oriented** perspective, the SSbD approach integrates safety and sustainability to proactively differentiate in the marketplace, creating value-added products while mitigating long-term risks and addressing the interests of external stakeholders (consumers).
- From the **collaboration-oriented** management perspective, the SSbD framework mainly focuses on the product/innovation level and does not systematically build in cooperation mechanisms at the current stage.
- Implementing the SSbD framework into corporate innovation is **policy-oriented**: Through alignment with the policies like the EU's Green Deal, CSS but also global approaches like SDGs, in detail to SDG 3, 6 and 12 (EC. JRC, 2022a, p. 18), corporations would align with various policies reducing conflicts and enhancing legitimacy with stakeholders. The strong emphasis on the safety dimension within the SSbD framework functions relieves companies from balancing competing dimensions of innovation and ensures coherence with policy goals.

To conclude, from a sustainable management point of view, the SSbD framework is mostly relying on efficiency and consistency strategies aligning mainly with market- and policy-oriented CSM by creating value and ensuring compliance. As it focuses on product-level optimisation, systems building, sufficiency-oriented strategies or approaches for collaborative sustainability management are not within its scope.

3.2. Stakeholders' Positions on the SSbD Framework

The SSbD framework has been developed using various stakeholder workshops and open consultation phases. Data have been published for the 3rd stakeholder workshop, highlighting that mostly industrial associations (30%), large companies (27%) and regulatory bodies (9%) contributed to the respective survey (EC. JRC, 2023, p. 188). The feedback and a review of technical reports were published later by the JRC (Abbate et al., 2025).

With methods of policy-oriented sustainability management, stakeholder views on the SSbD framework that may conflict with sustainability objectives are identified. To explore stakeholder perceptions of the SSbD framework, position papers from diverse groups were systematically analysed. These stakeholder groups included upstream and downstream industries, associations, RTOs, NGOs, government agencies and academia. As the length, details on the position and level of detail varied strongly between the statements, the following leading questions have been applied to sort their positions:

- Do they support the SSbD framework and its ideas?
- Do they favour the proposed risk-based approach (overruling the prevalent hazard-based approach for REACH)?
- Do they propose to (re)use existing solutions from industry? Established metrics?
- Do they propose to integrate stakeholders into the chemical innovation process, e.g. underrepresented groups (women)? Or to pursue co-creation via open innovation?

A summary of these positions and further relevant viewpoints are described below.

Table 3: Positions of various stakeholders commenting on the SSbD framework. Positions can be in alignment with the question (☑), neutral (☐) or opposing (☒).

Stakeholder Group	Name	Support SSbD	Hazard-based	Exist. Solut.	Stakehold. Int.	Specific SSbD-related positions	Source
Upstream Industry	BASF	☑	☑	☑	☐	• Stresses need for practical and science-based approach promoting innovation • Highlights that its portfolio follows already own safety/sustainability criteria	(BASF, 2024)
Downstream Industry	Unilever	☑	☒	☑	☑	• From 'absolute' to 'risk-based' safety in line with OECD' SSIA approach • Focuses strongly on practical safety dimension for consumer products (NAMs) • Emphasises transparency and due diligence with circular economy using tools	(Rajagopal et al., 2025)
Industry Associations	CEFIC	☑	☒	☑	☐	• Published their own SSbD guidance for an integrated and holistic innovation process • Supports pragmatic tools, collab. with policymakers but warns of bureaucratic burden • Puts emphasis on the combination of innovation, trade-offs and competitiveness	(CEFIC, 2022, 2024a)
	VCI	☑	☒	☑	☐	• Warns against restrictions discouraging research freedom and innovation • Concerns about bureaucracy, overregulation and potential loss of competitiveness	(VCI, 2022)
	NIA	☑	☐	☑	☐	• Framework is highly resource, time consuming and remains theoretical for SMEs • High uncertainty for global uptake with potential disadvantage for EU companies	(NIA, 2023)
	ATC	☑	☒	☑	☐	• SSbD concept is vague; holistic sustainability should include circularity & performance • Warns transition to toxic-free not feasible in short term; criteria must be proportionate	(ATC Europe, 2022)
RTO	TNO	☑	☐	☑	☑	• Sees SSbD as driver for innovation in advanced materials from early stage on • Advocates integrating predictive modelling and early assessment tools • Stresses collaboration with industry and regulators to make framework practical	(TNO, 2024)
IGO	OECD	☑	☑	☑	☐	• Promotes international harmonisation of SSbD approaches (OECD vs. JRC) • Realises SSbD as instrument for innovation and achieving SDGs	(OECD, 2024)
NGO	BUND	☑	☑	☐	☐	• Sees SSbD as essential for toxic-free environment and precautionary principle • Warns against voluntary/self-regulatory approaches; calls for a binding standard	(BUND, 2023)
	EEB	☑	☑	☐	☐	• Strongly supports binding SSbD and opposes trade-offs that weaken safety • Pushes for substitution of hazardous substances, transparency and precaution-principle	(EEB, 2024)

Government agency	UBA	☑	☑	☑	☐	• Stresses importance for advanced materials regulation with no safety cut-off • Calls for EU leadership and mandatory application in funding programmes	(UBA, 2023)
	BfR	☑	☑	☑	☐	• Supports SSbD for human health protection based on scientific criteria • Emphasises consumer safety and transparency	(BfR, 2022)
	EEA	☑	☑	☑	☐	• Highlights life cycle perspective, circular economy and eco-design • Supports EU-wide implementation and data-driven policy	(EEA, 2023)
Academia	GDCh/ EuChemS	☑	☒	☑	☑	• Calls to balance safety and scientific freedom; focus on universities' role in innovation • Is against prohibition of whole chemical classes for fundamental research • Highlights role of chemical education, green chemistry and funding for SSbD research	(GDCh & EuChemS, 2024)
Policy	DG RTD	☑	☐	☑	☑	• Current research should focus on interoperable data for coherent SSbD assessments • Advocates for acceptance of SSbD through stakeholder co-creation	(EC. DG RTD, 2022)
Networks	IRISS, PARC	☑	☐	☑	☑	• Aim to promote SSbD through collaborative projects; call for a trusted environment • Bridge academia, industry and regulators for harmonised approaches and understanding	(Apel et al.,2024)

The analysis of stakeholders' positions on the SSbD framework shows broad support across all sectors but also highlights significant differences in priorities and concerns. The most disputed point, particularly among industry associations (CEFIC, VCI, ATC), academia (GDCh/EuChemS) and industry (BASF/Unilever) vs. NGOs (BUND, EEB) and governmental agencies (BfR, UBA, EEA), concerns the exclusion of intrinsically hazardous chemicals without a dedicated risk assessment that may exclude promising substances prematurely. Interestingly, those contrary positions (NGOs/policy vs. industry) follow the narratives on pollution vs. competitiveness in the REACH debate (Hempel et al., 2025) and highlight that the risk topic has been overly addressed regarding the SSbD approach (Cann, Vicky, 2024). Further, NGOs and government agencies supported hazard-based restrictions but emphasised the need to integrate a binding SSbD standard. The consumer safety and transparency perspective is envisioned across all stakeholder groups (Unilever but also BfR and EEA).

Several industrial stakeholders, such as BASF, Unilever and CEFIC, underscored the need to build on existing regulation (REACH, SSIA) or their own established approaches (e.g. Portfolio Sustainability Assessment). The integration of stakeholders in the innovation process was particularly emphasised across all stakeholder groups (DG RTD, Unilever and TNO, SSbD networks). Governmental and research institutions, including UBA, BfR and TNO, advocate strongly for embedding SSbD principles early in product development and that governance mechanisms such as early warning systems and mandatory reporting should be facilitated. Adding to this, the SME representative NIA raises concern about the disadvantages of not implementing SSbD at the global level, which OECD foresees.

3.3. Benefits and Risks of Adopting the SSbD Framework into the Innovation Process

After the various stakeholder positions on a theoretical level have been analysed, empirical experiences of adopting the SSbD framework were drawn from statements of the industrial stakeholders (BASF; Clariant, Novozym) that participated in the first SSbD case studies (EC. JRC, 2023), see Annex.

Benefits could be seen as the framework is considered valuable as it enables the early integration of safety and sustainability into invention processes, thereby supporting more targeted and future-oriented innovation (BASF, Novozymes). Moreover, it allows companies to better assess the sustainability performance of their products and identify critical environmental hotspots for improvement (Clariant). Nevertheless, all of the contributing companies stated uncertainty regarding full-scale implementation of the SSbD methodology (BASF, Clariant, Novozymes), see Annex. Further insights of applying the SSbD framework could be derived from a survey performed for the 3rd Stakeholder workshop (EC. JRC, 2023, p. 188). It highlighted that the implementation of the SSbD framework would be accelerated if 'an increase demand for safe and sustainable from the costumer' would arise.

Those empirical insights and stakeholders' positions above contributed to mapping the benefits of integrating the SSbD framework from a corporate perspective (Table 4).

Table 4: Benefits and outcomes of adopting the SSbD framework into corporate innovation strategy.

Approach	Benefit	Outcome
Life Cycle Approach	• Wider view on sustainability • Identification of gaps and trade-offs	• Informed decision making • Improve business value
Risk reduction and compliance	• Anticipates hazards and SoC early • Safer products on the market • Integrates safety and sustainability thinking from innovation stage	• Avoids litigation and potential regulatory penalties • Improves business resilience and consumer acceptance
Innovation and market positioning	• Drives product innovation and growth through scientific concepts • Early elimination of risky innovations	• Gains competitive advantage by delivering products with reduced impacts
Value chain transparency	• Encourages stakeholder collaboration • Identifies hotspots early in life cycle on social topics	• Stronger supplier relations • Regulatory readiness (due diligence) • Enhanced brand reputation
Cost, resource efficiency	• Delivers insights on processes • Identifies inefficiencies early	• Cuts waste, lowers resource use • Prevent lock-ins at early stage • Saves long-term costs
Governance and Reporting	• Builds accountability • Enables monitoring for innovation	• Stronger regulatory trust • Early adaptation benefit

Applying SSbD creates benefits in several strategic dimensions. A life cycle perspective supports a holistic consideration of environmental and socioeconomic aspects and helps identify trade-offs and gaps early on, while strengthening long-term value creation (Larrea-Gallegos et al., 2025). Risk reduction is achieved by anticipating hazards and substances of concern early on in the innovation phase, which reduces the likelihood of accidents, litigation and regulatory sanctions while addressing potential SSbD-driven market demand (Wohlleben, 2025). Embedding green design principles also strengthens innovation and market positioning by enabling ground-breaking products with lower sustainability impacts (Stoycheva et al., 2024). Finally, transparency along the value chain promotes stakeholder collaboration and accountability and improves supplier relationships, regulatory readiness and brand reputation.

Underlining the benefits of adopting SSbD principles, outcomes of such an implementation into innovation approaches from Horizon Europe research project have been published (EC. HaDEA, 2025): Results of the DIAGONAL project indicate that redesigning nanomaterials using the SSbD approach reduced environmental and social impacts by 68% and 87% respectively, as well as costs by 25%. Further, in the SURPASS project, problematic polyvinylchloride (PVC) window frames had been substituted by polyurethane resins, reducing thermal conductance by 70% with optimised recyclability. The ongoing SSbD projects ZeroF and TORNADO report technical success but critical challenges with industrial upscaling and cost competitiveness.

To not only highlight benefits for implementing the SSbD framework into corporate strategy, the actual risks and benefits of implementing this approach in corporate innovation processes were examined. As a suitable method for this strategic decision, a SWOT analysis is conducted. A SWOT analysis is particularly relevant in this context, as it allows companies to systematically overview insights preventing unforeseen trade-offs for decision making. Such SWOT analysis can be later utilised to create a SWOT matrix that compare internal strengths and weaknesses with external opportunities and threats (Petersen & Buhr, 2022a, p. 61).

The implementation of the SSbD approach into innovation strategies of a company is studied with a SWOT analysis (Table 5).

Table 5: SWOT analysis of implementing the SSbD framework in corporate sustainable innovation management.

Strengths	**Weaknesses**
• Supports safer products on the market and anticipates stricter standards, enabling timely compliance; reduces legal and reputational risks • Redefines the innovation process through science-based methods that identify risks early but also follow concepts like Life Cycle Thinking • Opens innovation processes could go beyond compliance by embedding sustainability as a driver of R&D, including also stakeholders • Strengthens consumer trust and brand reputation, attracting talent and promoting cultural change	• High investment costs, data requirements as well as long timelines and need for cross-sectoral knowledge limit adoption, especially for SMEs • Currently, a lack of clear guidance to an abstract and voluntary framework could lead to variability in market uptake; bureaucratic burden • Persistent data gaps and methodological shortcomings undermine credibility and comparability of results • The chemical industry holds established value supply chains; lock-in effects • Collaboration, open innovation and co-value creation in innovation are rarely operationalised in practice; networks are still missing
Opportunities	**Threats**
• Early hazard/sustainability screening through AI and modelling via digitalisation and predictive tools for faster early-stage screening • Early SSbD adoption offers first-mover benefits, opening new market opportunities and positioning firms as leaders in safe innovation • Growing consumer and investor demand for safe and sustainable products can create a market pull. The SSbD approach delivers the tool to innovate • Multi-stakeholder engagement can drive co-creation, new partnerships and systemic innovation and better collaboration with value chain partners • Programs such as Horizon Europe are funding SSbD testing; JRC provides SSbD training but also allow participation in developing the framework	• Lack of industry-wide uptake and consistent application. Moreover, different sector's own interpretations of SSbD can dilute the approach • High economic and market risks persist without regulatory signals (pull), potentially discouraging investment in the SSbD approach • Future shifts in EU policies or methodological approaches (e.g. Green Claims or CSDDD) could undermine current efforts and make early SSbD investments obsolete • If applied too strictly, the SSbD approach could limit flexibility in innovation due to immature methodological approaches

The SSbD framework offers companies a structured approach for integrating safety and sustainability into the entire innovation cycle. A life cycle perspective helps identify trade-offs early on, while science-based assessments uncover risks and hotspots that would otherwise remain unnoticed.

This potentially strengthens resilience, reduces liability and economic risk due to loss of reputation and legitimacy (Petersen & Buhr, 2022b). However, embedding SSbD design principles promotes innovations with lower environmental impacts, while transparency in the value chain improves regulatory readiness, accountability and brand reputation (Larrea-Gallegos et al., 2025; Wohlleben, 2025; Stoycheva et al., 2024) (vide supra).

Despite these strengths, the implementation of SSbD suffers from significant **weaknesses**. High investment costs (Wohlleben, 2025), extensive data requirements and the need for interdisciplinary expertise pose hurdles, see Clariant case study in the Annex, in particularly for SMEs with limited capacities. When profit maximisation dominates, the effectiveness of sustainability initiatives, thus the acceptance of frameworks such as SSbD, tend to decline (Alharbi et al., 2025). Furthermore, infrastructural dependencies in a highly integrated sector like the chemical industry, make transitions costly and risky as systemic inertia has to be overcome due to lock-in effects (EEA, 2023). As the framework is voluntary and abstract with limited operational guidance, uneven adoption and increased bureaucratic burden can occur (ATC Europe, 2022; VCI, 2022). This can hinder its practical application and limit cross-sector comparability (van Dijk et al., 2025). But also persistent data gaps and methodological weaknesses can undermine its credibility, see Novozymes case study Annex. Although many stakeholders call for collaboration (EC. DG RTD, 2022; OECD, 2024), practical participation and the involvement of external stakeholders remain rare.

At the same time, the framework holds significant **opportunities**: Advances in digitalisation, artificial intelligence tools and predictive modelling promise to accelerate early hazard and sustainability screening, reducing costs and time while improving reliability (TNO, 2024). Companies that adopt SSbD early can distinguish themselves as leaders in safe innovations and gain access to new markets (Rajagopal et al., 2025). Rising consumer and investor demand for sustainable products, reinforced by EU initiatives such as the Green Deal and the CSS, is strengthening market demand for SSbD. Furthermore, multi-stakeholder collaboration and systemic innovations, as promoted by initiatives such as IRISS and PARC, can develop common methods and improve value chain collaboration (Apel et al., 2024).

Nevertheless, several **threats** could limit the transformative potential of SSbD. Differing interpretations and own approaches, see CEFIC's SSbD approach (CEFIC, 2024a), across industries pose the risk of inconsistencies and dilution of the overall approach (BASF, 2024). Without strong regulatory signals or consistent demand, economic risks may discourage companies from investing in costly sustainability assessments (case study Clariant). Moreover, similar to other EU sustainability policies such as the Product Environmental Footprint (PEF), which has so far experienced limited adoption by industry, the SSbD framework may also face difficulties in progressing from policy rhetoric to practical implementation. Likewise, future changes in EU policy or methodology, see chapter 1.7, could undermine current efforts and render early investments obsolete. Finally, it has to be mentioned that immature methods, if applied too rigidly, could limit innovation flexibility and prematurely exclude promising solutions, especially for novel materials and technologies (Novozymes case study, (GDCh, 2024)).

In summary, the SWOT analysis presents a twofold perspective. SSbD holds great potential as a strategic driver for safer, more sustainable and more competitive innovations, but is held back by short-term financial and practical constraints. Large-scale implementation in early development phases can be prohibitively expensive, highlighting the need for simplified, industry-specific protocols. Wider adoption will ultimately depend on clearer guidelines, optimised methodologies and stronger political and market incentives.

4. Integrating Gender Dimensions into the SSbD Framework

After considering the methodological and policy-related strengths and weaknesses of SSbD for its implementation into sustainable innovation management, it is relevant to reflect on the framework's capability to integrate inclusive societal dimensions. Hence, this chapter examines the SSbD framework from a gender perspective and highlights the extent to which equality and inclusivity are integrated into the framework. Then, it describes the diverse stakeholders' positions who link gender to chemical safety and sustainable chemistry. The results are integrated into proposed mechanisms that can be used to implement the gender dimension into the SSbD framework. Finally, both the strengths and weaknesses of implementing gender dimensions into innovation processes in the chemical domain are discussed in detail.

4.1. Gender dimensions of the SSbD Framework

A first step in integrating gender aspects into the SSbD framework is to evaluate the extent to which they are already considered within existing approaches. As the SDGs explicitly addresses gender equality in SDG5, these development goals provide a structured reference point for analysing how the SSbD framework addresses gender concerns (Table 6).

Table 6: All sustainable development targets defined under SDG5 (UN, 2015).

Target	Description
5.1	End all forms of discrimination against all women and girls everywhere.
5.2	Eliminate all forms of violence against all women and girls in the public and private spheres, including trafficking and sexual and other types of exploitation.
5.3	Eliminate all harmful practices, such as child, early and forced marriage and female genital mutilation.
5.4	Recognize and value unpaid care and domestic work through the provision of public services, infrastructure, and social protection policies, and the promotion of shared responsibility within the household and the family as nationally appropriate.
5.5	Ensure women's full and effective participation and equal opportunities for leadership at all levels of decision-making in political, economic, and public life.
5.6	Ensure universal access to sexual and reproductive health and reproductive rights as agreed in accordance with the Programme of Action of the International Conference on Population and Development and the Beijing Platform for Action and the outcome documents of their review conferences.
5.a	Undertake reforms to give women equal rights to economic resources, as well as access to ownership and control over land and other forms of property, financial services, inheritance, and natural resources, in accordance with national laws.
5.b	Enhance the use of enabling technology, in particular information and communications technology, to promote the empowerment of women.
5.c	Adopt and strengthen sound policies and enforceable legislation for the promotion of gender equality and the empowerment of all women and girls at all levels.

The JRC notes that the SSbD framework addresses target 5.5 in SDG5 (EC. JRC, 2022a, p. 18), which concerns ensuring women's full and effective participation and equal opportunities for leadership. From a societal and inclusive point of view, it leaves potential to improve in other goals and targets of SDG5 in particular discrimination, reproductive health, and gendered exposure linked to domestic and economic roles(UN, 2015). This can be relevant to access social sustainability but is unfortunately not suitable to assess gender-differentiated impacts of chemical exposure and access to safe and sustainable products.

However, it became apparent that most SDG5 targets are inadequately addressed in the SSbD framework and gender dimensions are not explicitly mentioned. Still, a closer look at the individual steps of the framework reveals partial overlaps where gender aspects are already directly or indirectly considered below (Table 7).

Table 7: Potential gender dimensions of the individual SSbD steps.

SSbD Step	Gender dimension
Scoping	The scoping step does not consider the sex or gender specifically. However, while a 'target population' refers to the group exposed to or affected by the novel chemicals, its definition is left to the discretion of the SSbD practitioner (EC. JRC, 2025, p. 18).
Step 1 (Hazard)	This step identifies hazardous properties, including reproductive toxicity, fertility impacts and developmental effects. Hence, these endpoints inherently consider potential sex-specific vulnerabilities.
Step 2 (Process Safety)	Process exposure assessment commonly includes occupational safety that could be linked to worker-specific vulnerabilities (sex-based threshold limit values). However, the SSbD framework does not account for uncontrolled exposure of materials/substances throughout the life cycle as affected by gender.
Step 3 (Consumer Safety)	Exposure risks to human health and the environment during the use phase, which potentially could cover sensitive consumer groups. Nevertheless, a gender dimension is not considered herein.
Step 4 (Environmental sustainability)	Does not account for gender dimensions at the moment. Environmental impacts can affect gender (water usage) but are then covered in sLCA.
Step 5 (Socioeconomic sustainability)	In social LCA, the gender dimensions could be incorporated through indicators such as gender equality measures (e.g., wage gap) or due to gender norms (e.g., female genital mutilation, child marriage by sex) as defined in the materiality analysis.

It is evident that, regarding the gender dimension, the current SSbD framework does not address toxicological vulnerabilities linked to biological sex or gender norms. However, the details of the current strategy are assessed.

From a toxicological point of view ('safe by design'), the SSbD framework should provide guidance to prevent the innovation of harmful substances as stated in the SSbD design criteria 2, 5, 6 during the redesign/scoping phase. Moreover, the safety considerations during the assessment phase of the SSbD strongly rely on the REACH and CLP regulations which do not require detailed reproductive toxicity or fertility testing for a substance with production < 100 t/year (third tonnage stage), unless earlier assessments indicate so (EP and Council, 2006). Hence, it is very likely that during the SSbD innovation process this gender dimension is neglected as it is not specifically mentioned.

From a societal perspective, the gender dimension is addressed during performing the social LCA of the innovation at a more mature point. While the JRC does not give guidance on which stakeholders and social indicators should be mandatorily addressed in sLCA, all sex/gender-relevant subcategories of the UNEP sLCA (C. Norris et al., 2020) have been extracted:

Table 8: Example of stakeholder and subcategories within the UNEP sLCA framework that adress gender or sex.

Stakeholder	Subcategories	Sex	Gender
Worker	Equal opportunities/discrimination		☑
	Fair salary		☑
	Health and safety	☑	☑
	Sexual harassment		☑
Local community	Safe and healthy living	☑	☑
Consumers	Health and safety	☑	☑
Children	Health issues for children as consumers	☑	☑

The table depicts to what extent a subcategories from the UNEP sLCA guideline is sex, gender or both relatable. sLCA is suitable as a method to cover gender dimensions such as fair salary and equal opportunities. However, also sex/gender-related subcategories such as health and safety for consumers or workers are described. As social LCA data is depending on existing social data from sectors, countries and IGOs, social LCA is well suitable for providing detailed information on gender-related social impacts and foremostly absolute safety for a chemical.

From a sustainability perspective, using social LCA as method to prevent interdimensional trade-offs, in particular in regard to gender aspects is not sufficient as this step in SSbD remains optional. Taking this into account, this omission of gender dimensions is remarkable given that the framework is a significant element of the EC's innovation policy and its vision for competitiveness. Furthermore, from a sustainable innovation perspective, carrying down this path leads the framework to miss the opportunity to provide guidance on integrating diverse stakeholders into the innovation process, as described above.

The WHO has established a Gender Assessment Scale (WHO, 2011) to analyse to what extent a programme or policy integrates the gender dimension, see Table 16 in the Annex. Taking the above analysis into account, the SSbD framework as a EU policy could be considered as '**gender blind**' on the gender assessment scale thereby indicating a critical shortcoming in its policy approach.

4.2. Stakeholders' Positions with Gender Relevance in the Chemical Sector

As the SSbD framework is lacking gender dimension not only from a safety but social sustainability and equity (gender) perspective, positions of relevant stakeholders on gender dimensions in relation to sound chemicals management were analysed. In contrast to the assessment above, which was dominated by industry, regulatory and policy actors, the stakeholders weighted toward gender dimensions are mostly NGOs, intergovernmental bodies and networks, see Figure 14.

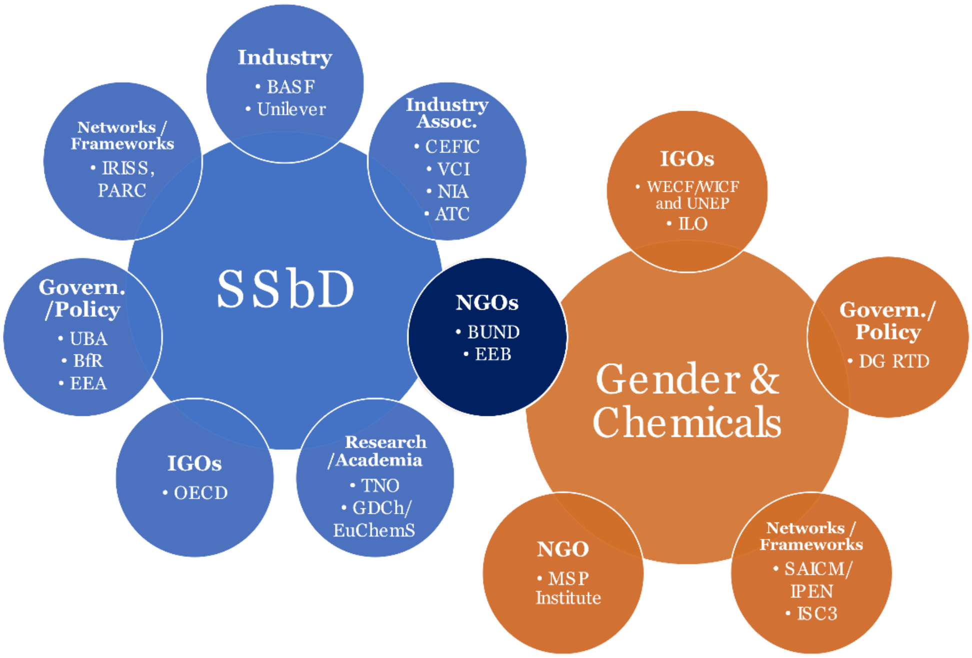

Figure 14: Adapted Venn diagram for the mapping of the stakeholders per topic and stakeholder group.

As visualised, the only overlapping stakeholder group between the topics 'SSbD' and 'Gender & Chemicals' is the NGO which is represented by BUND and EEB. This suggests two aspects. Firstly, the gender and inclusion discourse is being driven more by civil society and policy networks. Secondly, the SSbD topic and the gender dimension of chemicals are evolving in a parallel pattern in the policy sphere with limited overlaps for now.

However, details on the 'Gender & Chemicals' stakeholder positions were collected. Due to the overlap on some positions, their opinions were sorted by leading questions:

- Do they explicitly address gendered impacts of chemicals (e.g. exposure, health, occupational risks)?
- Do they propose actionable inclusion mechanisms?
- Do they recommend (re)using existing gender equity solutions or frameworks?
- Are there calls for stakeholder integration in the innovation process in particular for gender-related topics?

- *Table 9: Position of various stakeholder with regard to gender dimension in the chemical sector.*

Stakeholder Group	Name	Gendered Impacts	Inclus. Mechan.	Exist. Framw.	Inteh. in Innovat.	Specific gender-related positions	Source
IGO	WECF/WICF and UNEP	☑	☑	☑	☐	• Highlights women's imbalanced exposure (informal sector, reproductive health) • Collection of sex-disaggregated data for exposures and health impacts • Advocates mainstreaming gender into chemicals/waste policies (see SAICM)	(WECF & WICF, 2016)
	ILO	☑	☑	☑	☐	• Addresses gendered division of labour and risks in chemical-intensive sectors by identifying women as vulnerable groups in global value chains • Encourages gender-responsive occupational standards and worker participation	(ILO, 2022)
NGO	EEB	☑	☐	☐	☐	• Promoted inclusion of gender equality consideration into the chemical labelling and packaging (CLP) regulation and gender-related issues in chemical hazard assessment	(EEB, 2024)
	MSP Institute	☑	☑	☑	☐	• Develops indicators and guidance for mainstreaming gender in chemicals policy • Strong focus on monitoring, evaluation and governance using GIA • Stresses training both chemicals experts on gender and gender experts on chemicals	(MSP Institute, 2021)
	BUND	☑	☐	☐	☐	• Calls attention to sex and gender differences in human health and the environment • Highlights the possibility to perform Gender Impact Assessments (on policies)	(BUND, 2023, p. 55)
Policy / Governmental	DG RTD	☑	☑	☑	☑	• Embeds gender dimension into Horizon Europe research and funding criteria • Positions gender as factor improving innovation quality and relevance	(EC. DG RTD, 2020)
Policy (framework) and Network	SAICM and IPEN	☑	☑	☑	☑	• Favours gender-disaggregated data, women participation and gender mainstreaming • Lack of gender-disaggregated data hinders effective policies ('gender data gap') • Both gender equality and chemical safety are both essential to achieving the SDGs	(IPEN & SAICM, 2021; SAICM, 2020)
Network	ISC3	☑	☐	☐	☐	• Connects gender with sustainable chemistry and entrepreneurship at the global level • Calls for mainstreaming gender in policy and education as well as industry practices • Highlights diversity as a driver of safer, more innovative chemical solutions	(ISC3, 2025b)

Across the stakeholder scope, the gendered impacts of chemicals are recognised, particularly in terms of health risks and occupational exposure to women. NGOs such as the EEB and BUND explicitly link gender equity to chemical safety (BUND, 2023, p. 55; EEB, 2024). Further, BUND emphasises the greater burden on women in the home and the environment and calls for mandatory gender impact assessments to close persistent ‘gender data gaps’ (BUND, 2023, p. 55; EEB, 2024). The gender-advocacy MSP Institute is advancing this agenda by developing indicators and governance mechanisms to incorporate gender aspects into chemicals policy and further calls for specific training (MSP Institute, 2021). Most stakeholders emphasise the need for gender-disaggregated data and women's participation as essential for precautionary approaches (IPEN & SAICM, 2021).

International organisations are strengthening this narrative by embedding gender in global frameworks. The International Labour Organisation (ILO) emphasises the gendered division of labour in chemical-intensive sectors and advocates for gender-equitable occupational safety standards (ILO, 2022). Likewise, UNEP and WECF/WICF emphasise the disproportionate burden on women in the informal sector and in the area of reproductive health and promote Gender Mainstreaming in chemicals and waste policy with explicit references to the SDGs (WECF & WICF, 2016).

Several stakeholders explicitly link gender to stakeholder integration and co-creation. Participatory governance should ensure that women and vulnerable groups are included in decision-making, arguing that integrating sex/gender analysis into R&D improves the validity of results and expands market reach (EC. DG RTD, 2020; IPEN & SAICM, 2021; ISC3, 2025a; MSP Institute, 2021). Global platforms such as ISC3 and the Research and Innovation Directorate of the European Commission’s gendered innovation approach, connect gender to innovation by promoting co-creation and stakeholder participation. Both emphasise that diversity and gender-responsive approaches promote more socially relevant and innovative chemical solutions (EC. DG RTD, 2020; ISC3, 2025a).

4.3. Proposed Integration of Gender Dimensions in the SSbD Framework

Having first discussed the positions on the SSbD framework and subsequently the stakeholders' position on gender in relation to chemicals, the following section will examine how the SSbD framework can be strengthened to support sustainable innovation and how gender dimensions can be integrated into the framework. Three major improvements to the SSbD approach have been identified with regard to the gender dimension. All three bullet points are results of the previous analyses:

- Safety: Apply sex-disaggregated data and gender-specific exposure patterns to hazard, occupational and product safety assessments addressing physiological/societal differences.
- Sustainability: Assess environmental and social lifecycle impacts using gender-sensitive indicators and hotspot analysis. Conduct a Gender Impact Assessment to anticipate risks.
- Innovation Approach: Ensure inclusive decision-making and embed equity as a principle in the design process and promote collaboration and stakeholder co-generation.

To provide a detailed procedure to implement these measures in aspects and phases of the SSbD framework (Table 10).

Table 10: Overview of the proposed gender-integrated SSbD steps.

SSbD Step	• Improved gender dimension
(Re-)Design Principles	• Integrate relevant stakeholders for inclusive innovation • Ensure life cycle safety equity and deliver equitable social value • Design for transparency along the supply chain

Scoping	• Define metrics for gender equity in innovation processes
	    • Inclusive stakeholder engagement; training on gender
	    • Promote open innovation, gender-balanced stakeholder
	• Apply Gender Impact Assessments (GIA) early in design
	    • Define sex- and gender-differentiated target populations
	• Ensure gender-balanced innovation teams and participatory design

Hazard Assessment	• Include sex-disaggregated testing and data if present (gender data gap) • Screen on fertility, reproductive toxicity, endocrine disruption early on
Occupational Safety	• Add gendered division of labour and exposure risks due to gender norm • Ensure PPE and safety measures fit all body types and gender norms • Apply gender-sensitive health policies for the whole life cycle
Use Safety	• Consider gendered product use patterns and cultural norms in exposure • Product safety tests accounting for physiological differences • Confirm gendered PPE and safety measures for users
Environmental LCA	• Apply gender-sensitive impact assessment (disaggregate health impacts) • Assess potential for emissions or waste streams to gendered impacts • Integrate gender dimensions to endpoints (climate affected groups)
Socioeconomic Analysis	• Investigate gender-relevancy during materiality assessment • Give relevance to UNEP social LCA gender indicators • Perform and report gender impact assessment

4.3.1 Design Principles

The SSbD design criteria predominantly emphasise material-oriented concepts improving efficiency and safety of innovation originated from green and circular chemistry principles (P. T. Anastas et al., 2000; Keijer et al., 2019). However, they largely overlook societal dimensions which are more integrated in complementary academic approaches. The societal dimensions are embedded in the principles of sustainable chemistry, including social responsibility, transparency and responsible innovation (UBA, 2024, p. 16). Further, the Triple E approach (Environmental, Economic and Equity) dimensions for chemicals has been proposed (Mitchell et al., 2024). In herein, additional criteria include promoting fair governance, supporting equitable development and embracing corporate sustainability falling under the objective of maximising social well-being.

Unfortunately, at the current stage, explicit criteria and examples for social design remain scarce and those that can be intended in a broader sense are still underdeveloped. For concepts such as 'Design for Social Impact', 'Design for Social Change', 'Design for Social Good' and 'Design for Public Good' only isolated references can be found (Veiga & Almendra, 2014). Emerging concepts including 'Social by Design' are developed and comply with relevant frameworks such as the Global Reporting Initiative, ISO 26000, the Portuguese Social Responsibility Standard and the United Nations Global Compact (Vicente et al., 2010). These social design criteria are not strongly developed or prevalent in the chemical sector.

Based on the above provided input and the stakeholder analysis with regards to, additional 'Equity by Design (EbD)' criteria are proposed that should cover social and gender dimensions:

Table 11: Overview of ‚Equity by Design' criteria developed within this thesis.

No.	Principle	Definition	Related to
EbD1	Integrate stakeholders for inclusive innovation	Integrate diverse stakeholders through co-creation and design thinking, ensuring gender equity and participation of underrepresented groups	(EC. DG RTD, 2020; MSP Institute, 2021)
EbD2	Ensure life cycle safety equity	Ensure protection across the life cycle by applying gender-specific data, exposure patterns and occupational differences, adapting safety measures to diverse vulnerabilities	(ILO, 2022; WECF & WICF, 2016)
EbD3	Deliver equitable social value	Deliver fair and inclusive outcomes across the value chain using gender-sensitive and social LCA indicators. Promote equity in wages, opportunities, health and safety, while reducing disparities. Support with gender impact assessments	(IPEN & SAICM, 2021)
EbD4	Design for transparency and traceability	Design products with transparency and traceability (e.g., digital product passports), reporting hazards, social/environmental impacts	(BUND, 2023; EEB, 2024)

Together, these four criteria address important levers of social sustainability: Inclusion, health equity, social value and fairness as well as transparency. They are aligned with established frameworks such SDGs, UNEP's sLCA guideline and ISO 26000, yet are precise enough to support practical implementation in industry and policy without compromising clarity.

With these design criteria, the SSbD framework could readily expand its scope to not only on material focused safety and environmental aspects but also include social dimensions and foremostly inclusive design criteria also covering gender considerations. The combination of such criteria with the existing SSbD design principles would guide users to a more holistic understanding of sustainability in the context of chemical innovations, see Table 15.

4.3.2 Scoping Phase

The scoping phase provides a crucial opportunity to embed gender dimensions early in the innovation process. A gender-responsive scoping should define metrics for gender equity in innovation processes to guide subsequent assessments and design decisions. A useful method here would be to additionally conduct a Gender Impact Assessment (GIA) to anticipate differentiated risks, benefits and unintended consequences for women, men and gender-diverse groups in respect to the innovation (BUND, 2023; EC. DG EMPL, 1998; EC. DG RTD, 2020). Optionally, the GIA may also be carried out through participatory processes in collaboration with external stakeholders. At the same time, implementing training modules to raise awareness of gender and equality in innovation teams and promotion female leadership should be established at the scoping stage (EIGE, 2016).

Nevertheless, the scoping phase should identify relevant stakeholders along the value chain focusing on diversity and representation aspects. Here, established concepts from innovation and sustainable management such as value chain engagement and co-creation of shared value with suppliers, customers, NGOs, regulators and affected communities can be built on (EC. DG RTD, 2020; MSP Institute, 2021). In this regard, approaches like design thinking (Baldassarre et al., 2024), open innovation (Konstari & Valkokari, 2024), co-creation and participatory design (EC. DG RTD, 2020, pp. 189–191) and norm-critical innovation (EC. DG RTD, 2020, pp. 236–239) are remarkable instruments to integrate stakeholders. A concrete example can be even found in the chemical industry: The Clariant Innovation Center aims to expand the company’s innovation process by involving stakeholders from academia and related industries to expand their collaboration-oriented management measure (Kottmann, 2016).

4.3.3 Safety Assessment

The safety dimensions within the context of SSbD must exceed general hazard and risk assessments and consciously consider gender differences as described throughout this thesis. Hence, systematic data gaps have to be adressed to reflect on inequities affecting of women, trans and intersex individuals. Thus, during hazard assessments testing initially, sex-disaggregated data for various end points should be considered and explicit strategies must be developed to adress potential gaps (BUND, 2023, p. 55; EC. DG RTD, 2020, p. 63; EEB, 2024). It further ensures that novel innovation and chemicals do not disproportionately affect populations with different physiological conditions. Moreover, protocols that consider endocrine disruption and reproductive health should be performed early in development to assess the gender dimension of the innovation throughout the life cycle.

Occupational safety requires the recognition that the division of labor is often gender-specific and leads to different exposure scenarios (Gender Norms, chapter 1.6.1). Thus, gender-sensitive PPE and workplace health guidelines that consider pregnancy and hormonal cycles but also gender-related safety behavior must be consistently applied throughout the entire life cycle of chemicals (ILO, 2022; WECF & WICF, 2016). This also applies in particular to the informal sector, where women are often overrepresented and less protected by regulations.

The consumer or use safety is shaped in particular by cultural norms and gender-specific consumption patterns. Products such as cosmetics, cleaning or childcare items are used more frequently by women, while other products, like engine oils or tools, are predominantly used by men. Hence, risk assessments should therefore consider physiological differences and cultural usage contexts to avoid hidden risks when handling chemical end products (pesticides, detergents) (WECF & WICF, 2016). Moreover, this approach should go beyond classic binary approaches (King, 2022) but also should include risk assessment for transgender (Tassinari et al., 2023).

4.3.4 Sustainability Assessment

From an environmental perspective, life cycle impacts can to some extent be analysed from a gender perspective. Foremost, midpoint impact categories like ecotoxicology and human health (near-field, far-field) could be sex-disaggregated building on learnings from the safety dimensions (vide supra). Hence, charaterisation factors, measures for the potential impact, should provide potential harm based on sex-dissagrregated data. However, the implementation might be rather complex as the data stock for such assessments, often ECHA's database, does not provided details on the species' sex. Taking the uncertainty of those impact categories into account, it might be more reliable to assess the sex/gender-disaggregated impacts within the safety dimension of the SSbD framework.

Still, environmental LCA can integrate gender considerations on another level. Endpoint categories, representing the damage to ecosystems or human health, such as susceptibilities to heat/cold stress through climate change, but also work environment impacts could be indeed sex/gender-disaggregated. Policy documents acknowledge already gendered effects such as changes in well-being resulting by climate change (EC. DG RTD, 2020, p. 46). Hence, there is potential for improvement in the future which should be supported by research and might be more certain than implementation in human health or ecotoxicology impact categories of LCA.

Nevertheless, those secondary environmental impacts are often covered by social LCA addressing gendered effects. Easily, subcategories such as GHG footprints, water use and environmental footprints (Stakeholder: Local Communities, Subcategory: GHG Footprints and Environmental Footprints) (Hamed et al., 2025) could be disaggregated by gender to show how climate change, water consumption and environmental impacts affect women and men differently. The advantage would be that those are better investigated (WECF & WICF, 2016).

As the JRC recommends, social impacts on product level should be assessed using social LCA. It is the only method in the current SSbD framework where the gender dimensions are intrinsically included as social LCA can hold large number of sex/gender-specific indicators. To ensure that these aspects are adequately addressed, an initial Materiality Analysis should also consider gender dimension into sLCA assessments. Although sLCA is currently optional within the SSbD framework of, mandatory incorporating UNEP's gender indicators into the assessment process would improve constistency across SSbD applications. These have to be proposed by the JRC but relevant gendered indicators could include equal opportunities, non-discrimination, equal pay, occupational health and safety and participation (EC. DG RTD, 2020; ILO, 2022). However, further research into this topic has to be deployed from the policy side.

Finally, the socioecnomic dimension should also include a structured Gender Impact Assessment (GIA) that assesses the distribution of risks and benefits of a chemical innovation across gender groups (BUND, 2023, p. 55; MSP Institute, 2021). This assessment should not remain qualitative as during the scoping phase but translated into quantitative results. The outcomes should be reported transparently and ideally summarised by a predefined KPIs from the scoping phase.

4.4. Benefits and Risks of Integrating Gender dimensions into the innovation process via SSbD

Building on the need to rethink innovation in the chemical industry, SSbD provides a strategic entry point for incorporating not only safety/environmental but also societal aspects into research and development. This creates opportunities for the meaningful inclusion of gender dimensions in the policy and highlights how gender-responsive approaches can significantly influence innovation outcomes and regulatory adaptation (Table 12).

Table 12: Advantages of implementing gender dimensions into the SSbD framework from a policy perspective.

Approach	Benefit	Outcome
Gender Mainstreaming	• Promotes balanced representation and participation in research • Integrates gender analysis across all stages of research	• Results in an inclusive 'safe and sustainable' framework • Strengthened alignment with EU research policy (Gendered Innovation)
Sex- and gender-sensitive safety	• Identifies vulnerabilities earlier (reproductive toxicity, endocrine disruption, PPE fit) • Closes 'gender data gaps' in safety	• Reduced occupational and consumer risks for vulnerable groups • Aligns SSbD with global incentives (ILO, WHO, SAICM)
Inclusive innovation, co-creation	• Broadens stakeholder base, ensures participation and co-creation with understated groups • Integrates diverse knowledge	• Novel products with competitive and commercial appeal • Strengthened legitimacy and trust in SSbD and innovation outcomes
Governance, transparency	• Ensures accountability of the framework through GIA and traceability (e.g. DPP)	• Stronger compliance with EU innovation criteria • Better monitoring of social performance and capacity for reporting

The benefits of considering gender aspects in the SSbD framework can be described as:

- **Gender Mainstreaming** guarantees that underrepresented groups are not only included but also actively engaged in innovation processes, leading to more balanced representation and knowledge integration (EC. DG RTD, 2020; Holthaus & Hemmati, 2022). Moreover, addressing these issues is directly aligned with the EC's own policies, e.g. Gender Equality Strategy (EC, 2020a) or RRI programme (EC. DG RTD, 2013) giving the SSbD framework a 'flagship policy' status for implementing gender dimensions.
- By embedding **gender-sensitive safety assessments**, vulnerabilities such as reproductive toxicity, endocrine disruptors and unsuitable occupational safety can be addressed early on. This reduces occupational but also consumer risks while lowering liability risks for regulators and industry (UNEP, 2019).
- **Inclusive innovation** strengthen the legitimacy of SSbD framework by incorporating diverse perspectives into design processes (MSP Institute, 2021) by improving quality and market relevant of the chemical innovations.
- **Governance mechanisms** such as GIA and gender-sensitive matrices enable accountability (EC. DG RTD, 2020) of the SSbD approach. Moreover, these mechanisms induce stakeholders to explicitly integrate gender-related dimensions into SSbD assessments.

Whilst the benefits of implementing gender dimensions exist in policy, they can only be effectively implemented if it is also embedded in corporate level. To shed light on the business perspective of integrating gender-sensitive SSbD approaches into **Corporate Innovation** processes, both opportunities and risks of this approach will be analysed through a SWOT analysis, see Table 13.

Table 13: SWOT analysis of integrating the gender dimensions into the SSbD framework and implementing it in the corporate innovation process.

Strengths	Weaknesses
• Improves safety and risk assessments by using sex- and gender-sensitive data across hazard assmt., occupational and consumer exposure to reduce liability • Innovation within gendered sound management of chemicals and innovation can elevate innovation quality and legitimacy through inclusive co-creation • Strengthens governance and accountability via GIAs, gender metrics and social LCA, aligning with EU innovation policy but also within the SDGs • Through inclusive products, market situation and reputation can lead to strengthening of the brand and market position	• Requires additional cost, time and data collection plus cross-disciplinary expertise, creating barriers for SMEs • Lack of gender expertise awareness in many companies (training required) and limited data and experience available • Absence of harmonised methods, datasets and clear KPIs makes gender outcomes hard to quantify across innovation stages • Co-creation is challenging where procurement, R&D processes are not set up for inclusive participation (intellectual property)
Opportunities	**Threats**
• Competitive differentiation through socially responsible and inclusive products • Partnerships with NGOs, IGOs and value-chain actors enable systemic co-innovation and social licence to operate • Talent attraction by appealing to younger, diversity-oriented workforce • Deeper partnerships with NGOs/IGOs and value-chain actors enable co-innovation • Financing for gendered research under publicly funded projects	• Lack off uptake and interest by the market and partners ('soft science') • Insufficient guidance, fragmented standards and data protection constraints can hinder implementation • Resistance from stakeholders perceiving gender integration as non-priority • Potential delays in innovation cycles if gender integration adds assessment steps without streamlined processes • Perceived 'pink/green-washing' if implementation is insignificant • Data protection and ethics risks in collecting/processing gender data

Although **benefits** for the implementation of the gender dimension for policymakers had been discussed above, a main point from a corporate perspective is the improvement of safety and risk assessments through the use of gender-sensitive data on hazards, occupational and consumer exposure. This not only reduces liability but is also consistent with the precautionary principle underlying the responsible use of chemicals (UNEP, 2019; Vahter et al., 2007). Moreover, there is potential for gender- responsive innovation that can increase the quality and legitimacy of innovation through co-creation with diverse stakeholders (NGOs, workers and affected communities) across the life cycle stages. Hence, the creation of inclusive products and transparent innovation practices could strengthen brand reputation, improve market position and benefit companies differentiate themselves in increasingly sustainability-conscious markets (Holthaus & Hemmati, 2022).

Despite these strengths, implementation encounters **practical barriers**. On the one hand, many companies lack the respective gender expertise, leading to training and capacity building before effective implementation is possible. Also, resistant attitudes that frame gender science as lacking scientific legitimacy (Mergaert & Lombardo, 2014) can pose another barrier. Nevertheless, those hurdles and capacity building are linked to additional costs and time which is need to implement the gender dimension into innovation although practical guidelines (Government of Canada, 2018) exist. Nevertheless, at the current state of data availability for sex-disaggregated data and limited gender-sensitive indicators, the implementation and quantification of such approach are hard to realise. On the other hand, co-creation with stakeholders and open innovation seem legitimate ideas, R&D structures and information about safety/sustainability can be essential to business operation and limit such approaches. Though, this idea has been already implemented in the OECD's SSIA approach facilitating dialogues between innovators and regulators for regulatory preparedness (OECD, 2024).

Nevertheless, integration of gender dimensions into SSbD approaches offers also **opportunities**. By integrating gender-responsive innovations, corporations can differentiate themselves in a sustainability-oriented market regime. This also accounts for integrating the perspective of gender advocates into the innovation process leading to partnerships that allow co-creation and potentially momentum for diversity-oriented talent pools. Whilst cost and risk are potentially high, public funding schemes, like Horizon Europe, allow businesses to investigate and familiarise with gender dimensions in the innovation process in a more protected way. That said, the largest opportunity in implementing gender dimension into chemical innovation processes remains incorporating gender considerations into risk assessments increasing business resilience in changing regulatory environments.

At present, the absence of harmonised gender methodologies at scale creates significant uncertainty regarding the comparability of results and poses a **risk** of limited market uptake. In particular, in industries where gender issues currently hold limited priority, resistance from the market and ethical concerns related to the collection of gender-sensitive data, both indicators for 'institutional inertia' (Mergaert & Lombardo, 2014), further hinders the introduction of gender-sensitive innovations. Incorporating external stakeholders, such as gender advocates, into innovation processes can also be challenging, although potentially beneficial, as it risks delaying the overall process substantially. Moreover, if gender-sensitive approaches are implemented only superficially, they may be perceived as 'pink washing' (Lanzalonga et al., 2023) thereby undermining the trust of key external stakeholders such as NGOs or consumers.

5. Discussion

The following section provides a discussion of the findings presented on integrating the gender dimension into the SSbD framework, as well as incorporating both SSbD and gender dimensions into corporate innovation activities.

5.1. Gender as a Missing Dimension in SSbD and Implications for Policymakers

Although the SSbD framework was developed through stakeholder workshops and open consultations, the absence of key stakeholders in the chemical domain meant that important aspects were not respected. In particular, regarding the gender perspective, the framework's safety and sustainability dimension does not sufficiently consider gendered aspects. It overlooks not only gender-specific toxicological differences but also exposure pathways shaped by gender norms, although this topic has been raised at the global level by UNEP, ILO and SAICM. A detailed analysis showed that the only gender-responsive element in the SSbD framework is found in the socioeconomic assessment, and it is non-binding for the SSbD evaluation. According to the Gender Responsive Assessment Scale by WHO, it was found that the SSbD framework is effectively '**gender blind**' in its current form. This absence is critical, as both European and international stakeholders were strongly committed to considering gender aspects in the responsible use of chemicals. Failure to address these gender aspects may result in negative impacts on human health and social well-being.

The current 'gender blindness' of the SSbD framework is explicitly serious, given that it is part of the Green Deal's vision of a 'toxic-free environment' by 2050, which aims to promote safe and sustainable innovation. In particular, if we consider the scope of the 'toxic-free environment', it should also include the gender dimension. The social sustainability dimension in the SSbD is still treated as an optional final step of the assessment phase. The herein proposed Equity by Design (EbD) principles could implement inclusive safety and sustainability already in the design phase.

While industry and European policy actors did not prioritise implementing the gender dimension in this policy tool, civil society, represented by NGOs (BUND, MSP Institute), IGOs (ILO) and frameworks (SAICM), has already promoted Gender Mainstreaming in chemicals management. As a result, **stakeholder pressure** to integrate gender dimensions into the SSbD framework is likely to increase in the future and a more inclusive policy could proactively address such criticism. Nevertheless, this also offers the opportunity to build on previous work in integrating gender dimensions into the field of sound chemicals management and to embed these insights into the SSbD framework as one of the EU's key innovation policies.

Gender dimensions should be understood not only as protecting vulnerable groups from toxins but also as opportunities to improve policies by involving underrepresented groups in chemical innovation processes. Embedding requirements for gender-sensitive data collection, stakeholder participation and co-creation into SSbD guidance could transform gender considerations from optional add-ons into integral elements of both safety and sustainability. Moreover, the potential for stakeholder co-creation processes like gendered innovation in EU policies already exemplified (EC. DG RTD, 2020). Multi-stakeholder platforms aligned with the EU's RRI framework could strengthen the uptake by open innovation practices. Although sex- and gender-disaggregated data remain limited, raising awareness is an important first step.

The SSbD framework therefore holds a strong opportunity for Gender Mainstreaming, with the JRC positioned to provide guidance on methodologies such as gendered safety assessments, Gender Impact Assessments and indicators that capture both biological and social vulnerabilities. In similar fashion to the Gender Equality Plan, also the Gender Impact Assessments could be made mandatory in research projects but remain optionally in the SSbD framework.

Nevertheless, it is important to acknowledge that distinct resistance to implementing gender dimensions into EU policies, in particular in the DG RTD, had already been reported and discussed a decade ago (Mergaert & Lombardo, 2014). It underlines that Gender Mainstreaming should not be forced onto policies without building sufficient capacities, otherwise it risks superficial uptake rather than meaningful change. Priority should be given to addressing the current gap by first integrating gender dimensions into the toxicology regime, as this represents the most robust scientific entry point and is already emphasised by stakeholders engaged in the sound management of chemicals (SAICM, UNEP).

For the sake of completeness in the field of sustainability management, it has to be stated that the current approach of the SSbD framework is directed at improving sustainability on product level (**Operational Optimisation** or **Organisation Transformation**, see chapter 1.4). As sustainability challenges are often systemic in nature and cannot be addressed through isolated technical solutions alone, achieving sustainable innovation therefore requires integrated approaches. Those should connect business strategies with policies and actively involve a wide range of stakeholders and external issues to achieve significant impact (Florida, 1996). Hence, the JRC's framework should also explore the dimensions of **Systems Building** through methods like Systems Thinking that could hold a giant potential to overcome the industries inertia and historically grown structures implemented holistic sustainability.

5.2. SSbD and Gender Dimension as a Tool for Innovation

From a corporate sustainability perspective, the SSbD framework offers an opportunity to align regulatory requirements with market opportunities while integrating sustainability into core business strategies on product level. A SWOT matrix was prepared to support strategic decision making (SO, ST, WO, and WT strategies) on the implementation of SSbD principles and/or gender dimension into innovation processes (Petersen & Buhr, 2022a, p. 61)(Table 14).

Table 14: SWOT matrix supporting decision making based on SWOT analysis (Table 13).

		External factors	
Internal factors		Opportunities	Threat
	Strengths	• Increase potential sales through inclusive products • Build partnerships using governance and accountability • Attract diverse talents for through co-creation and value alignment • Secure public-funded SSbD projects by exploring gender-responsive safety • Advance co-innovation with NGOs/IGOs from gender chemicals	• Counter sceptics of SSbD by generation of value through inclusive product/brand • Manage data protection risk by governance and external verification • Reduce stakeholder resistance by focusing on safety improvement through gender-response • Overcome fragmented SSbD approaches by contributing to the development of the framework and its methods
	Weaknesses	• Co-creation might be limited if procurement systems are not set up for external stakeholders and the gender dimension • Without gender expertise, such partnerships might be missed out • Differentiation of novel products might be limited by high resource demand	• High cost and lack of expertise can increase risk of market resistance and slow uptake • Lack of gender expertise potentially leads to higher stakeholder resistance • Lack of open innovation structures in R&D will limit the stakeholder co-creation • Data gaps risk delays in innovation cycles

The SWOT matrix analysis shows that opportunities can only be successfully exploited if internal strengths already exist, such as inclusive product design, governance or gender-responsive safety expertise. By identifying critical points along the value chain and considering stakeholder perspectives, including gender dimensions, reputation and innovation strength can be enhanced. Still, the economic benefit of implementing the SSbD approach at the moment is still very uncertain. Potential regulatory pressure, specifically for companies working with hazardous substances, suggests that SSbD could become indispensable and early adoption could reduce liabilities.

Nonetheless, at the moment, the framework's voluntary and resource-intensive nature presents challenges. Pilot implementation through initiatives such as Horizon Europe projects could balance risks and opportunities, and strengthen long-term innovation. To guarantee a market uptake, the SSbD approach requires a regulatory pull (Alharbi et al., 2025). Initial movements in the fine chemical market suggest that companies are beginning to align their sustainability strategies with the anticipated future mandatory status of the SSbD approach.

Weaknesses such as a lack of gender expertise or open innovation structures could limit the exploitation of opportunities and increase vulnerability to risks, such as stakeholder resistance or market scepticism. This is particularly relevant where co-creation is needed but procurement systems are not adapted to include external stakeholders, limiting the potential to attract diverse talents or integrate gender-sensitive perspectives.

Although sex- and gender-disaggregated data remain limited, integrating this dimension into the SSbD framework and corporate practices could raise awareness and foster capacity building. Opportunities to further align with other European and global policies should follow. At the same time, it should be acknowledged that adding complexity to the SSbD framework by introducing a dimension that is yet not well established, like gender considerations, could hinder industrial uptake of this key innovation policy. Consequently, there is a risk that companies may perceive gender integration as an additional burden rather than a value-creating strategy. Hence, alignment with existing corporate frameworks will be essential.

Finally, the power of integrating gender dimensions into a pre-market innovation process lies not only in identifying hotspots of marginalised groups but also in leveraging collaboration and stakeholder co-creation to gain competitive advantages. A feature that SSbD, sustainable innovation and gendered innovation have in common is the openness to integrating stakeholders in the innovation process as a way to offer insider insight, preventing overlooking stakeholder positions, offering new market opportunities and reputational damage or long-term liabilities. As a recent McKinsey study found, collaboration to innovate (Cao et al., 2024), as opposed to traditional innovation processes, allows organisations to become more open and disruptive (Accenture Chemical Industry Vision, 2016). In fact, collaboration-oriented management measures have already been strongly emphasised by CEFIC's SSbD approach (CEFIC, 2025). Existing and analysed case studies exemplify how gendered innovation can be successful (EC. DG RTD, 2020), while also stressing the potential risks of such integration, as have been clearly mapped out above.

6. Conclusion

This thesis has highlighted the urgent need to minimise emissions of ‘chemical novelties’ to remain within the safe operating space of the planetary boundaries. To achieve this, the chemical sector must redesign its innovation processes so that safety and sustainability are embedded from the earliest stages. As part of the Green Deal, its ‘zero pollution’ vision, the European Commission developed the SSbD framework to provide guidance to companies for integrating safety and sustainability into innovation processes.

Initially, the thesis analysed the SSbD framework and its principles from a sustainability management point of view. It was found that the basic strategies underlying the approach focus strongly on improving sustainability by efficiency rather than by systemic changes. Moreover, this study analysed the various positions of industry actors, NGOs, regulators and networks towards the SSbD approach to investigate benefits and risks of adopting the framework into corporate innovation processes. To further develop this framework, a key contribution of this thesis was the investigation of the integration of gender dimensions into the SSbD approach. In the chemical field, the exposure of chemicals affects humans based on their biology (sex) or societal role (gender). Various examples, such as the nematicide DBCP or endocrine-disrupting plasticiser, highlighted the relevance of assessing gender dimensions for chemical innovations. After detailed analysis of all steps of the SSbD framework, it was found that little to no assessment method take the gender dimension neither on sex nor on gender level into account. Hence, the gender-responsiveness of the SSbD framework was rated according to WHO Gender Assessment to find the policy framework to be considered ‘gender blind’.

Whilst the gender dimensions are well understood on the global level (UNEP, SAICM), it was found that it is less integrated into the safety and sustainability consideration on European policy frameworks. Hence, a stakeholder position analysis of actors involved in the gender considerations from chemical sound management were conducted. Interestingly it was found that actors from this field and actors from the SSbD framework were not overlapping and the gender dimension is mostly occupied by NGOs and IGOs. Nevertheless, it was found that the integration of gender dimensions into the SSbD framework offers significant benefits not only at policy and corporate levels but also for gender-relevant stakeholders. Hence, major improvements to the SSbD approach have been identified with regard to the gender dimension:

- Design criteria: To embed gender dimension into chemical innovation processes, this thesis proposes ‘Equity by Design’ criteria that are based on SDGs, sustainable chemistry principles and key learning from gender dimensions in chemicals management. These include (1) stakeholder integration for inclusive innovation, (2) life cycle safety equity, (3) equitable social value and (4) design for transparency and traceability, which should steer sustainability in chemical innovations.

- Scoping: The integration of gender dimensions by into the innovation early is relevant to prevent gender biases. For this equity metrics, Gender Impact Assessments (GIA), training and stakeholder engagement should be applied early on.
- Safety: To be compliant with an inclusive 'toxin-free' environment, the implementation of gender-specific data into toxicological testing and risk assessments is essential. Further societal aspects such as occupation position through gender roles and respective exposure pathways need to be respected.
- Sustainability: Whilst the gender-responsiveness of differentiated environmental impacts between genders are limited, strengthening the focus on social sustainability by sex/gender-sensitive indicators in sLCA and emphasising Gender Impact Assessments key as methodology has to be envisioned.
- Innovation: Opening up new opportunities for collaborative and disruptive research and development by considering diverse gender perspectives. This will ensure diverse participation along the value chain to anticipate differentiated risks and benefits.

Although the **policies** of the European Commission, namely 'Gender Equality Strategy 2020-2025' and its adaptation in research (EC, 2020a; EC. DG RTD, 2021), strongly encourage Gender Mainstreaming in all EC policies, the SSbD framework does not directly address gender related concerns. The current SSbD framework only addresses gender in the optional socioeconomic assessment, leaving significant gaps in both the safety and sustainability dimensions. To correct this 'gender blindness', the integration of gender-sensitive assessments into the overall SSbD methodology should be envisioned. This includes requirements for sex-disaggregated data in toxicological studies, gender-sensitive exposure and risk assessments, the adoption of Equity by Design (EbD) principles and expansion of the social Life Cycle Assessment (sLCA). This will require practical guidelines, trainings and supporting tools to assist SSbD practitioner who currently often lack the necessary expertise.

Even with recent setbacks in diversity and sustainability, see chapter 1.7, integrating gender dimensions into safety policy remains both feasible and adaptable. A key learning is that embedding gender-relevant stakeholders in the SSbD approach makes gender aspects integral, recognising vulnerable groups not only as protected but also as co-creators within the framework. In this way, policymakers can ensure that SSbD not only promotes a gender-responsive toxic-free environment but also meets the EU's commitments to gender equality and inclusive innovation and the respective SDG5 'Achieve gender equality and empower all women and girls'.

Nevertheless, the SSbD framework presents an unprecedented opportunity to integrate the gender dimension into a policy framework aiming at an innovation process. The inclusion of gender equality is not only a normative correction but also a strategic necessity in order to bring the SSbD framework into line with both EU's own policy guidelines and international frameworks for chemicals policy. It further represents a shift toward a more holistic understanding of 'safe and sustainable by design' to one that acknowledges inclusivity as inseparable from safety and sustainability. Policymakers must provide the necessary tools and funding to support potential users and prevent the adoption of gendered innovation approaches from becoming burdensome.

For corporations, the challenges and benefits of integrating the SSbD framework and gender aspects into corporate innovation have been discussed in detail. Due to limitations in expertise and additional resources, the implementation of gendered SSbD into innovation might be hampered. However, for gender-responsive SSbD to create long-term added value, gender aspects must be deeply integrated into companies' innovation processes and not treated as optional or compliance-driven. This includes the adoption of gender-sensitive assessment methods and the involvement of diverse stakeholders in co-creation processes. If the SSbD framework is improved in this direction and guidance is provided, its adaptation seems feasible. Failure to consider the gender dimension in chemical innovations can not only harm human health and the environment but also create liability risks and potential business failure, as demonstrated by several empirical cases.

By reshaping the business environment through stakeholder relationships and company practices, it is possible to drive sustainability transformations. In these collaborative environments, the gender perspective can be used not only to identify areas of exposure for marginalised groups but also to access the potential of co-creation and stakeholder collaboration. Embedding gender considerations in corporate innovation processes thus offers both protection against inequalities and the opportunity to achieve competitive advantages. As recent studies show, collaboration and open innovation remain key drivers of innovation in the chemical sector. However, challenges such as a lack of expertise, data availability and potential market resistance must be addressed to ensure meaningful and credible implementation and avoid superficial approaches. As safety considerations are the highest priority in the SSbD framework, toxicology was identified as an enabler for the uptake of gender dimension, rather than societal dimensions lacking maturity at the moment.

In the future, research building on the herein presented approach should include detailed guidance on the implementation of sex- and gender-disaggregated data for the safety considerations and gap filling methods. Further, clearance on methods like Gender Impact Assessment and stakeholder co-creation in innovation processes, in relation to SSbD should be central to the research. Moreover, actively inviting the stakeholders from the gender chemicals field to stakeholder workshops concerning the SSbD framework should be pursuit.

This thesis concludes that incorporating gender dimensions into sustainable development offers benefits beyond risk reduction. It can promote innovation, improve regulatory compliance and enhance corporate competitiveness. Future research should further explore the use of sex-disaggregated data in toxicology, expand stakeholder consultations and develop robust policy instruments to ensure that gender considerations become an integral part of the SSbD framework but also of sustainable innovation management in the chemicals field.

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I. Annex

I.a List of further Policies Targeting the EU's Chemical Industry

Upcoming policies initiatives impacting the EU's chemical industry Twin Transition:

- The Eco-design for Sustainable Products Regulation (ESPR)
- Revision of REACH
- Revision of Classification, Labelling and Packaging (CLP)
- Green Claims initiative
- Implementation of EU ETS - Phase 4
- Definition of sectorial targets for GHG emissions reduction by 2030 and by 2050 (vs. 1990 levels)
- Bioeconomy Strategy and Bioeconomy Action Plan
- Circular Economy Action Plan
- EU Methane Strategy
- Corporate Sustainability reporting directive

Additional policies with an proposed impact on the chemical industry:

- European Critical Raw Materials Act
- Corporate Sustainability Due Diligence
- EU Advanced Materials manifesto and the critical raw material strategy
- Review of EU strategic dependencies and capacities
- EU's Trade strategy
- Industrial Emissions Directive 2.0 (IED 2.0)
- Revision of the Environmental Crime Directive
- Carbon Border Adjustment Mechanism (CBAM)

I.b SSbD Framework with Design Criteria

The SSbD framework has been analysed according to their sustainability strategy (efficiency, consistency, sufficiency)(Oertwig et al., 2017) and own considerations:

Table 15: SSbD design principles as proposed by the JRC (EC. JRC, 2022a) and their sustainability strategy

No.	Principle	Definition	Strategy
SSbD Framework (EC, 2022)			
SSbD 1	Material efficiency	Incorporate all chemicals used in a process into the final product or recover fillers within the process to reduce the use of raw materials and waste generation	Efficiency
SSbD 2	Minimise hazardous chemicals or materials	Maintain product functionality and reduce or avoid the use of hazardous chemicals/materials wherever possible	Consistency
SSbD 3	Design for energy efficiency	Minimise energy used to produce a chemical in the production process and along the supply chain including recycling or disposal	Efficiency
SSbD 4	Use renewable sources	Focusing on integration of renewable raw materials in to the chemical/material or imposing closed loops	Consistency
SSbD 5	Prevent and avoid hazardous emissions	Application of technologies to minimize and prevent hazardous emissions or pollutants in the environment	Efficiency
SSbD 6	Reduce exposure to hazardous substances	Avoid exposure to chemical hazards in processes as much as possible and do not use substances that require a high level of risk management. Further, best available technology should be used to avoid exposure at all stages of the life cycle	Efficiency, Consistency
SSbD 7	Design for the end-of-life	Chemicals should not hamper waste collection/sorting reuse, recycling and after their fulfilled their function and also break down into harmless products	Consistency
SSbD 8	Consider the whole life cycle	Design the chemicals for the whole life cycle (cradle to grave)	Consistency
Proposed in this thesis			
EbD1	Integrate stakeholders for inclusive innovation	Integrate diverse stakeholders through co-creation and design thinking, ensuring gender equity and participation of underrepresented groups	Sufficiency
EbD2	Ensure life cycle safety equity	Ensure protection across the life cycle by applying gender-specific data, exposure patterns and occupational differences, adapting safety measures to diverse vulnerabilities	Consistency
EbD3	Deliver equitable social value	Deliver fair and inclusive outcomes across the value chain using gender-sensitive and social LCA indicators. Promote equity in wages, opportunities, health and safety, while reducing disparities. Support with gender impact assessments	Sufficiency
EbD4	Design for transparency and traceability	Design products with transparency and traceability (e.g., digital product passports), reporting hazards, social/environmental impacts	Consistency

I.c JRC Questionnaire from the SSbD Case Studies

The following quotes are directly from the JRC report (EC. JRC, 2023, pp. 83–86) and are depicted here to ease companies perspective of SSbD. The original structure of the having all answers of companies per question and not resolved per company was changed:

BASF

What were your main reasons to participate in the JRC SSbD case study?	"Most industrial ecosystems depend on chemistry for delivering on the Sustainable Development Goals globally and enabling the Green and Digital transition in Europe. One of the major contributions of the chemical industry to achieve these goals is to innovate towards chemicals that are safe and sustainable. To evaluate how a company's current portfolio contributes to the purpose of a more sustainable future, BASF developed the Sustainable Solution Steering method in 2012. The objective of Sustainable Solution Steering is to provide a fully transparent and consistent evaluation of the sustainability performance of BASF's solutions. BASF constantly optimizes this sustainability portfolio assessment method, aiming at a solid and up-dated risks and opportunities evaluation. This has proven to be a valuable source for strategic steering of our portfolio. Hence, applying the JRC SSbD framework may support to further develop the early warning-function of our Sustainable Solution Steering approach. With the proposed SSbD framework an alternative approach is available, that holistically looks at safety and sustainability along the value chain and may act as a useful supplement for the innovation community developing the solutions for the future. By participating in the SSbD case study it is possible to test and thus conduct a reality check for each step of the framework. This in turn will also help us to check against our currently established portfolio assessment method, but also to develop improvements helping to broadly apply the SSbD framework. A practical and thus successful framework is at the core to support meaningful R&D steering towards the industry transition."
What are the main challenges you encountered during the development of the case study?	"Defining the case study and the system boundaries needs to be very explicit – guidance on how to practically do this may be helpful: The outcome of the assessment could vary, weather the evaluation is conducted on chemicals or the material where the chemical is present. Identifying and maintain value chain partners, who's input is of great impact for the SSbD assessment (e.g., raw material suppliers): Value chain partners can differ throughout a whole commercial product life cycle, so that initial assumptions may not be applicable in future anymore

	and the SSbD assessment would not be valid anymore – every assessment is a time-limited snapshot. Identifying and collecting (generating) the data/information needed for the assessment Step 1: Difficulty to address all endpoint w/o animal tests – here validated screening tests / alternative testing methods need to be agreed to run early-stage assessment for active R&D steering. Step 2/ Step 3: Accurate data only available for own production steps in the value chain – a limitation of those steps to the in-house production would significantly increase accuracy assessment results. Furthermore, data for the human health and safety assessment in the production/use phase are not available for all substances. Hence, there needs to be a joint understanding about the goal of steps 2 and 3 to prevent usage of industry average values, which in turn will not allow for solid comparison scenarios. Step 4: It is extremely time consuming to gather all necessary data, for certain data points only certain assumptions are readily available. Data accuracy is difficult to maintain throughout a product's commercial lifetime, as certain subcategories may vary. For the PEF method there are only limited sets of product category rules available. Limitations in time and resources: Expertise from different fields required as well as dedicated project management effort is needed to bring together a broad set of expertise to facilitate a single assessment, which will drive time and cost for R&D conducted under this framework."
What benefits you/your company see after having participated in the SSbD case study?	"As BASF is highly interested in a commonly applicable SSbD methodology to develop safe and sustainable product portfolios, a test was very helpful to give feedback in the light of applicability for industrial chemical research and innovation. As SSbD is proposed to be a voluntary initiative it is critical to contribute to its applicability to prevent a lack of acceptance in the markets. The proposed assessment methodology provided various different methods, which BASF is currently evaluating how it could match with the companies Sustainable Solution Steering method."
How do you intend to implement the SSbD (These learnings) in your company/ R&D strategies?	"BASF constantly revises the sustainability portfolio assessment method (Sustainable Solution Steering method) and some aspects of the framework are of high interest to be evaluated to be adopted within our assessment scheme. The framework also offers ideas and fruit for thoughts how to integrate quantitative methodologies into an innovation process."

Clariant

What were your main reasons to participate in the JRC SSbD case study?	"We wanted to understand the SSbD methodology in depth, by applying it to a known product and application Clariant has been using its own portfolio assessment scheme since 2012 (the Portfolio Value Program). We want to continuously improve and update it. Learnings from SSbD could be included. We welcome the opportunity to provide qualified feedback to the SSbD framework to make it a practical tool for the chemical industry."
What are the main challenges you encountered during the development of the case study?	"Defining the case study and the system boundaries: this was not so difficult. Identifying value chain partners: more difficult the farther "away" the value chain partners are, but manageable Identifying and collecting (generating) the data/information needed for the assessment: a very big hurdle: data needs to be collected from (not only direct) suppliers and customers, some of the data is not readily available, but needs to be generated Limitations in time and resources: clearly a limiting factor. The PEF assessment was commissioned to a third party at a cost of several 10 k€. Internal resources require expertise from different departments and many person-hours. Therefore, we strongly advocate to consider a tiered approach with simple screening methods in the early product development stages"
What benefits you/your company see after having participated in the SSbD case study?	"We will be able to better understand the sustainability profile and impacts for a key product line. This is also useful in responding to increasing number of customer enquiries for PEF data. Sustainability "hotspots" were identified and will be addressed in future developments."
How do you intend to implement the SSbD (These learnings) in your company/ R&D strategies?	"We currently do not foresee the feasibility of doing a full SSbD study on every new development. This can only be done for "flagship" products or major central technology platforms. A comprehensive study as being done now can serve to identify sustainability "hotspots" and aim for specific improvements."

Novozymes

What were your main reasons to participate in the JRC SSbD case study?	"Enzymes have been used as sustainable solutions in various industries such as textile, paper, animal feed, detergents and food. Novozymes wanted to learn the JRC SSbD framework by joining the case study."
What are the main challenges you	"As we presented during the workshop, we encountered the limitation of a hazard-based cut-off for safe and sustainable chemicals and products.

encountered during the development of the case study?	EU has been in the good position for biobased technologies with enzymes. Given our industry long-standing experience in ensuring enzymes' safety, their positive environmental impact and their biological profiles, we believe that enzymes are SSbD ensuring innovation in EU keeping its strong competitive edge. In Step 2, our company has generated a lot of data in the past 50+ years, so it was relatively straight forward for our case study. On the other hand, a new innovative use would require new exposure assessment – in our case, new actual measurements of enzyme exposures through collaboration with downstream users. A large company can adsorb such resources, but it would be difficult for SMEs to collect all data. One of the questions raised during the workshop was who is going to make SSbD – is it a manufacturer/importer or downstream users. Thinking about innovations, it can be either or both. Our company is a raw material supplier in B2B business. For us it is difficult to find value chain partners especially when a project is in its early phase Defining the case study and the system boundaries: in Step 4 we compared two processes (conventional and enzymatic scouring) and since PEF is rather product oriented, we had some doubts when defining the life cycle stages. Limitations in PEF method (step 4): - EF 3.0 impact assessment method lacks factors for direct emissions of pectate lyase (or any other enzyme) to environment, which meant we could not account for impact of enzyme emissions on toxicity; - The underlying toxicity model – USEtox – in current version may not be suitable to derive factors for enzymes, as it does not capture their characteristics; - Lack of a procedure or parameterised dataset for modelling treatment of specific composition of wastewater, which led to simplified end-of-life modeling, not reflecting high degradation rate of enzymes."
What benefits you/your company see after having participated in the SSbD case study?	"Overall: We could identify some limitations i.e. the cut-off criteria and issues about USEtox (please see also the below bullet). (step 4) Better understanding of PEF methodology and its practical application"
How do you intend to implement the SSbD (These learnings) in your company/ R&D strategies?	"Our company has implemented 'safety first' policy for R&D strategy, so safety assessment has already been a gate in R&D pipelines in our company. With that said, the learning through case study is that substantiation of sustainability through LCA/PEF is equally critical to safety/risk assessment. Also, EU Transition Pathway describes EU innovation and growth based on amongst others SSbD. The most

	important learning with the case study is how important it is to assess sustainability through LCA/PEF in an early phase of R&D activities. This learning would be reflected to our company's R&D strategy."

I.d WHO Definition for Gender Responsive Assessment Scale

Table 16: WHO definition for Gender Responsive Assessment Scale for assessing programs and policies (Gough & Novikova, 2020, p. 8; WHO, 2011).

Level	Criteria
1. Gender unequal	• Perpetuates gender inequality by reinforcing unbalanced norms, roles and relations • Privileges men over women (or vice versa) • Often leads to one sex enjoying more rights or opportunities than the other
2. Gender blind	• Ignores gender norms, roles and relations • Very often reinforces gender-based discrimination • Ignores differences in opportunities and resource allocation for women and men • Often constructed based on the principle of being 'fair' by treating everyone the same
3. Gender sensitive	• Considers gender norms, roles and relations • Does not address inequality generated by unequal norms, roles or relations • Indicates gender awareness, although often no remedial action is developed
4. Gender specific	• Considers gender norms, roles and relations for women and men and how they affect access to and control over resources • Considers women's and men's specific needs • Intentionally targets and benefits a specific group of women or men to achieve certain policy or programme goals or meet certain needs • Makes it easier for women and men to fulfil duties that are ascribed to them based on their gender roles
5. Gender transformative	• Considers gender norms, roles and relations for women and men and that these affect access to and control over resources • Considers women's and men's specific needs • Addresses the causes of gender-based health inequities • Includes ways to transform harmful gender norms, roles and relations • Objective is often to promote gender equality • Includes strategies to foster progressive changes in power relationships • between women and men