Toward robust decision-making in safe and sustainable by design (SSbD) current state and recommendations for MCDA integration

Dulmen, N. van; Cinelli , M.; Corbett, C.J.; Blanco C.F.; Guinée, J.

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Review

Toward robust decision-making in safe and sustainable by design (SSbD): current state and recommendations for MCDA integration

Nina van Dulmen[1], Marco Cinelli[1,2], Charles J Corbett[3], Carlos F Blanco[1,4] and Jeroen Guinée[1]

Designing and evaluating alternative chemicals, materials, processes, or products using a Safe and Sustainable by Design (SSbD) approach can be facilitated by integrating decision support methods like multicriteria decision analysis (MCDA) to evaluate safety, environmental, economic, and social sustainability criteria.

Clear guidance is needed to assess chemical, material, or product life cycles on various criteria, especially when a wide range of options is available, and multiple stakeholders' interests must be accounted for. This study adds to guidance on the implementation of MCDA in SSbD assessments. Reviewing a set of 18 papers addressing MCDA and safety and sustainability assessments, we discuss various decision-making features (MCDA process characteristics) that require development for the application of MCDA in the SSbD framework.

We identify six features for further exploration, including defining the decision-maker and problem statement, justifying the set of alternatives under evaluation, defining whether the system should allow for rank reversal, taking a life cycle perspective and defining the assessment scope, justifying the set of criteria used for the assessment, and managing uncertainties. These issues motivate the call for guidance on defining SSbD-specific issues that influence the selection of a suitable MCDA method for a specific problem, to ensure tailored decision-making recommendations. Addressing the identified features should help clear the path toward methodologically sound studies, useful results, and appropriate decision support.

Addresses
[1] Institute of Environmental Sciences (CML), Faculty of Science, Leiden University, P.O. Box 9518, 2300 RA Leiden, the Netherlands
[2] Decision Engineering for Sustainability and Resilience (DESIRE) Laboratory, Leiden University College, Faculty Governance and Global Affairs, 2595 DG The Hague, the Netherlands
[3] Anderson School of Management, UCLA, 110 Westwood Plaza, Box 951481, Los Angeles, CA 90095-1481, USA
[4] Department Circularity and Sustainability Impact, Netherlands Organization for Applied Scientific Research (TNO), P.O. Box 80015, 3508 TA Utrecht, the Netherlands

Corresponding author: van Dulmen, Nina (n.van.dulmen@cml.leidenuniv.nl)

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Introduction

The European Union (EU) Chemicals Strategy for Sustainability [1] promotes 'Safe and Sustainable by Design' (SSbD) as "*a pre-market approach to chemicals that focuses on providing a function (or service), while avoiding volumes and chemical properties that may be harmful to human health or the environment […]*" (p. 4). Developed as the scientific basis for a European Commission (EC) recommendation [2], the Joint Research Center (JRC) then developed an SSbD framework in 2022. The Recommendation sets a testing period for the framework, resulting in the 2025 revised framework. This framework provides guiding principles on the (re)design of chemicals, materials, processes, along the life cycle, and products through an iterative safety and sustainability assessment [3,4]. As a voluntary and pre-market approach, SSbD is rapidly evolving and attracting increasing attention [3]. The JRC framework is applied and tested in various case studies [5], while a range of EU-funded research initiatives are advancing SSbD [6]. Some of these efforts, though still limited in scope, include elements of decision support [7].

Identifying chemical or material alternatives and quantifying their impacts using methods like risk assessment, life cycle assessment (LCA), life cycle costing, and social LCA (S-LCA) is, in itself, a useful exercise. However, they often identify conflicts between alternatives. As in SSbD such methods come together, this underscores the need for systematic adoption of decision support methods like multicriteria decision analysis (MCDA) [4,8–10].

MCDA is an established decision support method [9,11]. Through structured protocols, MCDA helps identify alternatives and the criteria to evaluate them. Also, it can aggregate information on criteria performances as well as stakeholders' preferences to provide concise decision recommendations, such as tailored information through classification, ranking, choice, or clustering of alternatives [12]. Alternatives are options developed as potential solutions to address a challenge or opportunity. Regarding SSbD, and this paper, the term primarily refers to alternative chemicals, materials, processes, or products.

SSbD balances a wide set of safety, environmental, social, and economic criteria [13]. Considering this broad scope, clear guidance is needed for well-informed decision-making, which MCDA can aid. The latest JRC SSbD framework and methodological guidance provide an initial foundation of MCDA for this purpose [4,14], upon which we elaborate further. We review studies performing safety and sustainability assessments and evaluate their use of MCDA, building on a study by Dias et al. on multi-attribute aggregation in SSbD [9].

The purpose of this short opinion piece is to provide an overview of the application of MCDA in the context of SSbD, rather than to present new empirical results or a comprehensive review. As interest in MCDA for SSbD grows, further research is required to systematically identify and evaluate key decision-making features relevant to MCDA methods [12]. The paper aims to stimulate discussion and to offer preliminary recommendations based on an initial consideration of such features. The intended audience includes stakeholders involved in developing SSbD-related decision support solutions, including policy and regulatory bodies (e.g. EC, European Chemicals Agency), industry and innovators (e.g. chemical manufacturers, product designers), research institutions, and public funding organizations.

We evaluate how six key decision-making features characterizing the MCDA process are addressed in the selected studies. Sections *Literature review on the application of multicriteria decision analysis in safety and sustainability assessments* and *Features analyzed in the selected papers* present this review, with Section *Key insights* discussing its findings. Lastly, in Section *Discussion and recommendations*, we reflect on the main aspects that require attention for the development and application of the SSbD framework and the integration of MCDA.

Literature review on the application of multicriteria decision analysis in safety and sustainability assessments

Dias et al. analyzed MCDA studies addressing safety and sustainability assessment of chemicals and materials [9]. Our focus is on literature from the past five years, so ten of these articles were selected [15–24]. A search up to and including July 2025 added eight more recent papers [25–32]. For this, the query adapted from Dias et al. [9] was applied in Web of Science: *Topic= multicriteria OR multi-criteria OR "multiple criteria" OR mcda OR mcdm OR multiattribute) AND (chemical OR material OR substance) AND (safe* or sustainab*).*

To explore the complete landscape, this query initially includes studies performing either safety or sustainability assessments. Specifically, we review studies combining a safety and sustainability assessment with MCDA, in line with SSbD and the work by Dias et al. Further filtering of these records to studies performing safety and sustainability assessment, as well as MCDA, finalized our sample of 18 papers (See Appendix A and Supplementary Material 1). The review reveals the scant attention paid to the 'by Design' aspect. This, however, should be addressed throughout chemical, material, and product life cycles where product design strategies play an important role in addressing substances of concern across (subsequent) product life cycles [33].

Features analyzed in the selected papers

In an MCDA, characteristics of a decision-making problem must be identified, such as a problem formulation and the model that the decision-maker will use. These characteristics can be defined as 'decision-making features' [12] and are crucial to ensure the selection of an appropriate MCDA method.

We briefly present six features, mainly informed by the framework presented by Cinelli et al. [12,34] to support complex decision-making, and recent research on this topic [4,9,35–38] (See Appendix B). A focus is put on important features that are recurrent in SSbD assessments and prominent in EU projects[1] aligned with SSbD principles.

Feature A: defining the decision-maker and the problem statement. The decision-maker is the person or group tasked with making a decision, and a key reason for performing the assessment. The problem statement includes the type of decision recommendation required. In MCDA, this can be a ranking, sorting, choice, or clustering[2] of alternatives [12].

[1] Such as Horizon Europe projects IRISS (http://iriss-ssbd.eu), PARC (https://www.eu-parc.eu/), and PROSUITE (https://cordis.europa.eu/project/id/227078/reporting) or Horizon 2020 projects ORIENTING (https://orienting.eu/), SUNSHINE (https://www.h2020sunshine.eu/), HARMLESS (https://www.harmless-project.eu/) or DIAGONAL (https://www.diagonalproject.eu/).

[2] Ranking: ordering the alternatives from most to least preferred; Sorting: Assigning alternatives to pre-defined preference-ordered decision-classes; Clustering: dividing alternatives into groups according to a similarity measure or preference relation; Choice: selecting the most preferred sub-set of alternatives [12].

Feature B: justifying the set of alternatives under evaluation. Important for SSbD-driven assessments, this defines the expected scope of the work, ranging from a single to a multitude of alternatives.

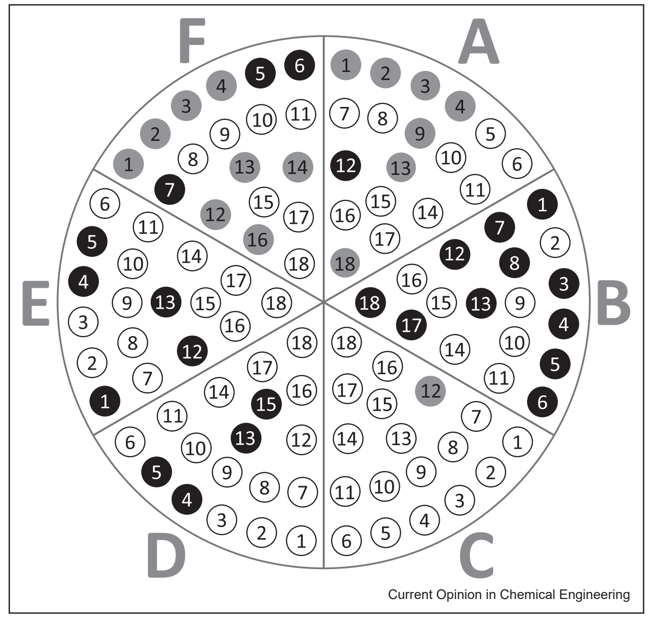
Feature C: defining whether the system should allow for rank reversal. In MCDA, 'rank reversal' relates to the order of alternatives being changed by adding or removing alternatives in the set of interest [39]. We argue for no preference, but in SSbD, an assessor must be aware of the dependency of the decision recommendation on the set of alternatives.

Feature D: addressing life cycle coverage and scope. Accounting for multiple life cycle stages is a prerequisite of SSbD's approach [4]. Similar reasoning applies to the development stage of alternatives: assessments at low technology readiness level (TRL) will likely require a different approach than those at high TRL.

Feature E: justifying the set of criteria used for the assessment. Criteria are variables used to assess the impacts and benefits of alternatives. As this set is the technical basis upon which a decision recommendation is made, a justification is of paramount importance in SSbD.

Feature F: managing uncertainties. In SSbD, decisions are made in conditions of uncertainty, such as those related to inventories or impact assessment models. Studying how uncertainties are accounted for is important in MCDA to aid better decision support.

Figure 1



Selected six decision-making features: **(a)** defining the decision-maker and the problem statement; **(b)** justifying the set of alternatives under evaluation; **(c)** defining whether the system should allow for rank reversal; **(d)** taking a life cycle perspective and defining the assessment scope; **(e)** justifying the set of criteria used for the assessment; **(f)** managing uncertainties. Feature addressed (black), partially addressed (gray), or not addressed (white) in the reviewed 18 studies (numbered 1–18).

Key insights

The features and how they are addressed in the literature are examined schematically in Figure 1, indicating a limited application. The reviewed studies often lack justification of these features, and are fragmented in their application. A detailed breakdown is included in Supplementary Material 2.

Defining the decision-maker and the problem statement

17 out of 18 studies do not, or are unclear about, who the decision-maker is or who will use the MCDA results. This makes results potentially not tailored to an intended audience. Five studies partially address the type of MCDA method they are using, and justify the weighting method and aggregation function.

Naturally, different decision-makers have different needs. An innovator, regulator, or investor faces specific problems and uses MCDA results differently. At low TRL, innovators may work with dynamic sets of alternative designs with tiered criteria: first requiring sorting to narrow the options (tier 1), after which the performance of alternatives may be scored and ranked (tier 2). In contrast, regulators typically face a static set of alternatives, such as a company's product dossier, and are tasked with a choice problem, deciding whether risks fall beneath a given threshold or providing a pass/fail evaluation. This shows how decision-makers shape a problem statement, directly influencing the type of MCDA method.

The review reveals that the rationale for the problem statement or purpose of the study often remains unaddressed. While MCDA can aid ranking, sorting, clustering, and choice problem statements [12], 16 out of the 18 studies apply a ranking method. However, SSbD challenges often require different types of problem statements, for example, when subsets of alternatives should be allocated to different levels of sustainability and business potential (sorting).

Justifying the set of alternatives under evaluation

Of the 18 papers, 11 define and clearly justify the inclusion of specific alternatives in the set. In total, 17 evaluate a static, pre-defined set of alternatives, and 1 evaluates a dynamic set through in silico modeling [24].

This highlights a current misalignment with the rationale of the SSbD framework, which is to support the (re-)design of chemicals, materials, processes along the life cycle, and products [4]. This inherently creates dynamic decision-making with multiple alternatives available on an ongoing basis. It is important to define and justify the set of alternatives under evaluation, which in SSbD will typically be dynamic, to consider suitable MCDA methods.

Defining whether the system should allow for rank reversal

Underpinning the objective of the SSbD framework to move from relative (safer and more sustainable) to absolute (safe and sustainable) [4], Dias et al. [9] state that MCDA in SSbD should be absolute and evaluate a chemical or material on its own merits, with decision recommendations not being affected by other alternatives assessed.

In MCDA literature [39,40], the term 'absolute assessment' is not commonly used. Instead, the relevant issue is referred to as 'rank reversal', which describes the phenomenon whereby, through using specific MCDA methods, the relative ranking of alternatives changes when alternatives are added or removed from the set, or when the criteria are modified. This occurs when MCDA methods generate their recommendations in relation to the specific set of available alternatives [39]. Dias et al. [9] relate the concept of absolute sustainability assessment[3] as reflected in the JRC SSbD framework [4] to this concept of rank reversal in MCDA. In our opinion, this relationship is flawed: both absolute and relative sustainability assessments can be combined with MCDA methods, regardless of rank reversal. In some settings, rank reversal is acceptable, while in others it is not; the MCDA method should be chosen with that in mind. Moreover, absolute frameworks based on LCA have also been contested as misleading [41].

Our review shows that 4 papers perform a non-rank-reversal prone assessment, whereas 14 do perform rank-reversal prone assessments, though none justify or define the choice of this set-up, and might not be aware of their implications. We argue that for SSbD no preference for rank reversal or not exists, as there is no correlation between rank reversal and absolute or relative sustainability assessment. It is, however, important to be aware of how final recommendations may (or may not) depend on the set of alternatives considered.

Taking a life cycle perspective and defining the assessment scope

SSbD addresses the (re)design of chemicals, materials, processes, and products from a life cycle perspective, so the life cycle must be clearly defined [35]. Our review reveals variation in the scope of assessments (12 processes, 2 chemicals, 3 materials, and 1 product) and life cycle stages: only 4 out of 18 studies include more than one stage. The technologies evaluated cover a broad range of applications and TRL (Supplementary Material 2).

Whether to tailor SSbD assessments to the TRL of the technology should be considered. Given that more design freedom and uncertainty exist at low TRL, the assessment strategy should entail dedicated tools, such as simplified prospective LCA, that can manage early stages of development [36]. Once the TRL increases, more data will become available for more detailed assessments, justifying a variety of tools for SSbD in the development stage of the alternatives, which may be offered through the SSbD Toolbox currently being developed by the PARC project [42].

Justifying the set of criteria used for the assessment

All studies evaluated performed safety and sustainability assessment with diffuse criteria sets, leading to fragmented assessments and input data to support decision-making. For example, safety is assessed in a variety of ways, from a single indicator of 'influence on public health' [15,16] or 'safety of passengers' [29], to extensive safety and health hazards [24–26]. Although criteria are critical to the decision recommendations, only five studies elaborate on the set of criteria and justify why these are used for the assessment.

Given the focus on different types of alternatives (e.g. materials, production processes, or products) and application sectors (e.g. construction, packaging, or energy production), a normative list of criteria for SSbD, open to adaptation according to the types of alternative and sector, seems appropriate.

Managing uncertainties

The studies reviewed often lack analysis of the most influential factors (10 out of 18 conduct *sensitivity analysis*) and the impact of uncertainty on model outcomes (4 out of 18 conduct *uncertainty analysis*). Studies that performed these analyses approached it in various ways. This can be an issue as comprehensive uncertainty and sensitivity analysis can highlight key sources of uncertainty and enhance the robustness of the assessment's conclusions.

Data and models for SSbD assessments are prone to numerous, large, and heterogeneous uncertainties. These have been well discussed, for example, for LCA on higher-TRL technologies [43]. In SSbD, however, chemical, material, or products in development undergo many changes until they reach the market. Anticipating these changes, which can significantly affect safety and sustainability, introduces a new dimension of

[3] Absolute sustainability is referred to in terms of a chemical complying with planetary boundaries, with moving from comparative (A better than B) to absolute (A is absolutely sustainable) considerations [4].

uncertainty [36]. Thus, decision-makers must consider the associated likelihood of each outcome. Hence, without implementing MCDA approaches that incorporate uncertainty, the decision-making is prone to bias [40,44].

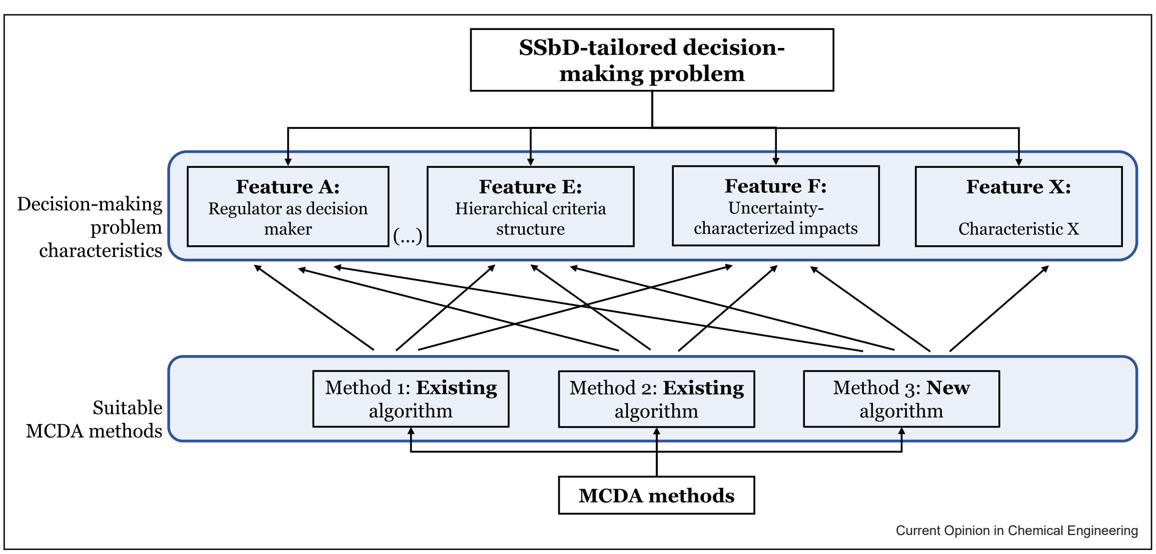
Discussion and recommendations

Based on the number of papers in our set, incorporating MCDA into SSbD-related studies is not yet common, and how MCDA is used and described is highly fragmented. Current SSbD-related studies barely address the presented decision-making features, highlighting the need for guidance on SSbD-specific problem characteristics to support the selection of suitable MCDA methods for tailored decision-making. This mismatch between features and MCDA methods is problematic as it could lead to unsound decision recommendations. For example, combining MCDA methods that are mathematically incompatible leads to biased results and decisions [45]. There should be a greater focus on formulating the specific decision-making challenge that SSbD assessments address. In this regard, the presented six decision-making features call for further exploration, as addressing those supports the selection of a suitable MCDA method. While out of scope here, we acknowledge related approaches to SSbD such as Alternatives Assessment [46] with studies focusing on MCDA [47,48], showing larger community efforts to outline and develop MCDA in chemical alternatives assessment.

To start with, SSbD practitioners should understand the decision-making features of their specific problem, which should be used to identify a suitable MCDA method (Figure 2). Here, we present a conceptual example, whereas for further practical illustration on MCDA method selection based on feature-based problem formulation, we refer to the work by Cinelli et al. [12]. This latter work introduces a decision support system allowing users to select which of a collection of over 200 MCDA methods best fits the user's specific needs, based on a set of 156 decision-making features. Among all available MCDA methods, one or more may be suitable for a specific SSbD problem under evaluation, and it might even be of value to address a problem using multiple MCDA methods. In this conceptual example, existing MCDA methods 1 and 2 can be used for a decision-making problem with its specifics in features A, E, and F. A new MCDA method might be created when a new feature (X) is included in the set, as the previous methods are not capable of dealing with this request. This highlights the need to link the structure of SSbD assessments with MCDA methods that can support such features.

Better integration of SSbD with MCDA means that SSbD problems should be formulated clearly from the start, to understand what matters for structuring the MCDA problem. This reflection shows how important it is to know the capabilities of MCDA methods for a specific problem so that the most suitable one is chosen for mathematically sound decision recommendations.

Figure 2



Conceptual match between some key SSbD-tailored decision-making problem characteristics and the MCDA methods.
Adapted from Cinelli et al. [12].

The integration of MCDA with SSbD could aid in tackling some challenges in the operationalization of the SSbD framework as well, such as uncertainty and trade-off management [10]. Uncertainty can be handled in multiple forms with MCDA methods, from ranges to probability distributions. Trade-off management is at the core of MCDA as its methods have been conceived to help decision-makers find the most suitable alternative(s) according to conflicting criteria.

Of the six features considered, four are characteristics of any well-executed project, that is, defining a decision-maker, setting the scope, and identifying alternatives and criteria, rather than technical aspects unique to SSbD. Consequently, any SSbD effort must already address these elements, irrespective of whether MCDA is applied. Thus, if handled rigorously, the additional effort required to incorporate MCDA is relatively small. From this perspective, MCDA's main benefit is the discipline it introduces: structuring decision-making to support high-quality SSbD without significant additional burden.

Toward implementing multicriteria decision analysis in safe and sustainable by design

We propose a three-stage process for implementing MCDA in SSbD frameworks, elaborating on the concise foundation in the SSbD framework documentation [4]. First, the list of decision-making features should be tested in ongoing projects with an SSbD focus, including MCDA. Second, the set should be refined through further research, and possibly extended to account for additional features improving SSbD-focused decision-making. This could mean, for example, including comparison thresholds (e.g. a preference, veto, or indifference threshold [49] for a hazard indicator such as PNEC (predicted no-effect level) of the alternative substances) or working toward a normative list of more precisely-defined criteria which can be product/sector-specific (e.g. climate change impact indicators for bio-based products that account for biogenic carbon uptake; adverse outcome pathways for microplastics that account for synergistic effects). Lastly, best practice guidance on how to apply MCDA methods in SSbD should be developed. This can be offered, for example, as templates or elaborate suggested workflows included in forthcoming methodological guidance documents from the EU JRC.

Given the active SSbD community, we encourage testing our proposed strategy of feature-based guidance in ongoing projects. This could aid the wider and streamlined development of powerful decision support systems that truly materialize the benefits of applying SSbD principles along the value chain of chemicals and materials. A first step to overcoming implementation barriers is understanding why MCDA, and the presented features, have seen limited application in safety and sustainability studies to date, whether this could be related to a lack of knowledge, perceived complexity, resource demands, or other factors. We conclude by strongly advocating for an enhanced focus from the SSbD community on removing these barriers and using best practices available to make SSbD a truly actionable endeavor.

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Author contributions

Nina van Dulmen: Conceptualization, Methodology, Investigation, Data analysis, Writing – original draft, Visualization. **Marco Cinelli:** Conceptualization, Methodology, Data analysis, Writing – review & editing, Visualization. **Charles Corbett:** Conceptualization, Writing – review & editing. **Carlos Felipe Blanco:** Conceptualization, Writing – review & editing, Supervision. **Jeroen Guinée:** Conceptualization, Writing – review & editing, Supervision.

Data Availability

All data that have been used for the research are enclosed as Supplementary Material.

Declaration of Competing Interest

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

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the author(s) used ChatGPT (OpenAI) in order to assist with language refinement. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the published article.

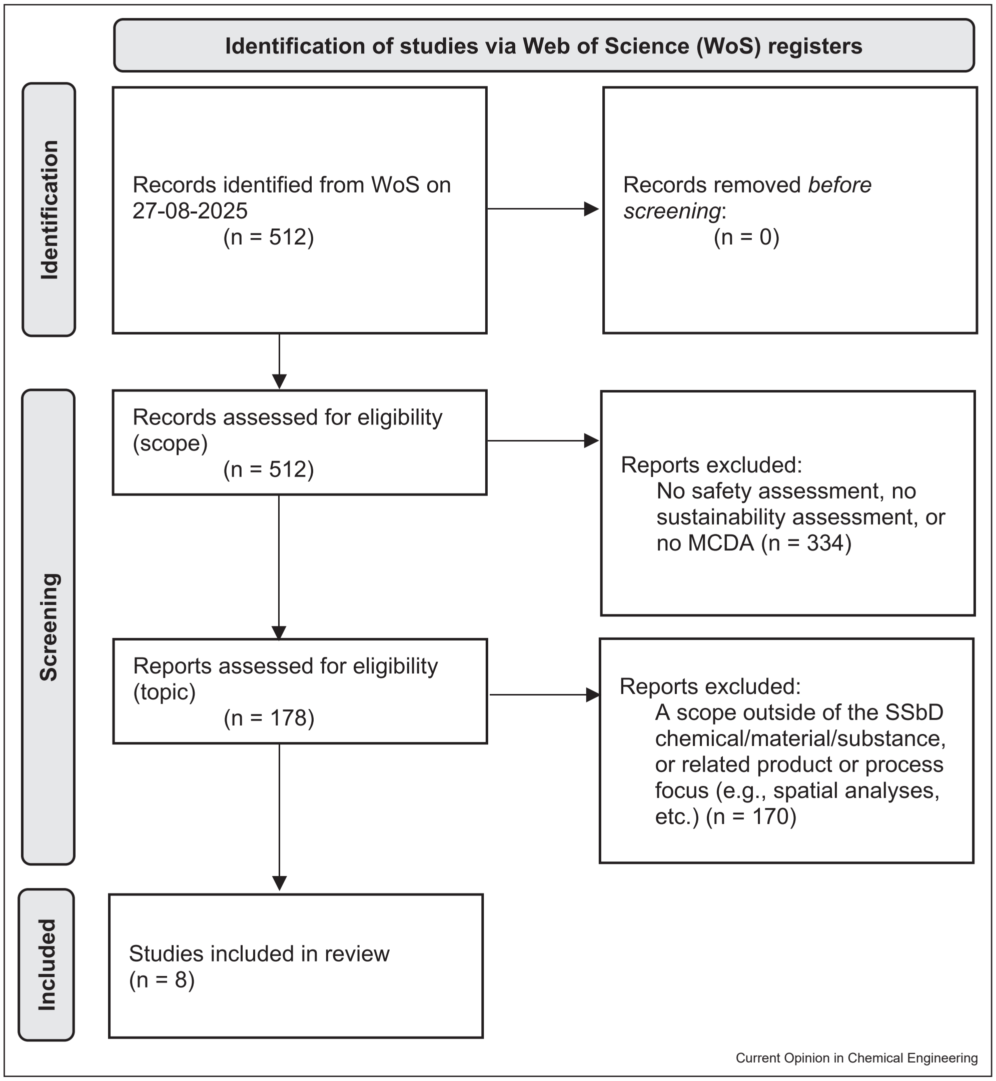
Appendix A

During the process of identifying the literature to evaluate, we followed the following procedure (Figure A.1.):

- Our initial set of papers is based on a review by Dias et al. [9]. As we focus on literature of the last 5 years, this includes a set of 11 papers. We exclude the study from Alkathib et al. [50] from this, as no MCDA method has been applied and no aggregation takes place: this is outside the scope of our review. Therefore, *10 papers from the set of Dias et al. are reviewed in this paper as well.*
- An additional literature review was carried out, following the query of Dias et al. [9] for the following reasons:
  - To stay consistent to this research we are building upon;
  - To focus on an SSbD-related scope, regarding chemicals, materials, or substances, through *(chemical OR material OR substance)*. This limits us to the scope of SSbD, without excluding elements like products, processes, or "by Design".
  - To include "safety", "safer" and "safe", as well as "sustainable" and "sustainability", through *(safe* or sustainab*)*.

    The additional literature search led to the following:
  - The search was performed through Web of Science, on 27-08-2025.
  - *Validation*: as a validation of the search string performed through Web of Science, we also searched for the same string, over the period that Dias et al. [9] performed theirs, though in Scopus. This search, through Web of Science, included *10/11* articles from the papers we included from the set of articles from Dias et al. [9]. (*Janosovski 2022b* is not available in Web of Science).
  - Searching for results from 17-07-2023 (the search done by Dias et al. [9]), to 31-07-2025 (the last full month up to date of the search) returned 512 results.
  - We further filter these 512 articles on *exclusion criteria (scope)*
    - Papers that did not perform a safety, sustainability assessment, or MCDA were excluded. Please refer to SM1 for this record.
    - This excluded an initial 334 papers from the set.
  - This narrowed the search to 178 studies closer to an SSbD focus. We filtered further on a second round of exclusion criteria (topic)
    - No chemical/material/process assessment
    - A completely different scope than SSbD, as spatial studies, or supply chain management. Please refer to SM1 for this record.
  - Of these 178 papers, 8 papers (excluding the paper from Dias et al. itself) were identified that conduct both safety and (environmental) sustainability assessment, and use MCDA, and fit within the scope of the search.
  - These 8 were added to the set of 10 papers taken from the same batch as Dias et al. [9].

Analyzing and adding these 8 papers to the original set of 10 adds up to a total of 18 papers.. Please, see Supplementary Material 1 *on the full review results.*



Literature identification procedure followed.

Appendix B

We focus on the six features presented below, as a selection from a wide repository of decision-support frameworks applicable to several domains. The six features presented in the paper (A-F) are used to evaluate the 18 papers selected. Per feature, we looked at one, or more sub-features, that are presented in Table B.1. The frequency analysis (i.e. counting of literature on each feature) with a description of each feature and identification of the study is shown in Table B.2.

Table B.1

Features analyzed in the selected papers. Set of six features (A-F) and their sub-features including description.

Domain	Related feature	Sub-features evaluated	Description	Reference
Problem structure	A	Assessment performer	Who is performing the study (academics, innovators, etc.)	N/A
	A	Decision-maker	Who is the decision-maker? Investor/regulator/product developer/ etc.	N/A
	A	Problem statement	Type of decision recommendation (if applicable): ranking, sorting, clustering, choice.	[12]
	B	Type of alternatives	What is the chemical, material, process, or product under assessment	N/A

Table B.1 (*continued*)

	B	Static or dynamic set of alternatives	Looks at whether more alternatives are coming in on a regular basis, for example via process engineering) vs static (a regulator that wants to assess a new product at TRL 9)	[12]
	C	(Non) rank reversal system set-up	Allowing assessment results to be (in)dependent from alternatives. Justification for set-up provided.	[9]
	D	Decision scope	What is the focus/scope of the assessment? (chemical, material, product, process, etc.)	N/A
	D	Life cycle perspective	What life cycle stages are covered in the assessment?	[35]
	D	Temporal aspect of performing the assessment	What is the scale (established/pilot/lab) of the technology under assessment? High, medium, low TRL?	[36]
	E	Set of criteria	What criteria are used to evaluate the alternatives (for environmental, socio-economic, and safety assessment)? Is this set justified?	[4]
	E	Environmental assessment criteria	What environmental assessment criteria are used?	N/A
	E	Socio-economic assessment criteria	What socio-economic assessment criteria are used?	N/A
	E	Safety assessment criteria	What safety assessment criteria are used?	N/A
	E	Criteria structure	Flat: The criteria are all at the same level. Or hierarchical: The criteria are organized in levels, hierarchically, from general to detailed ones	[12]
Preference model	A	Type of aggregation of multiple criteria evaluations	Scoring function, binary relations or rules, and MCDA method used	[12]
	A	Justification for the selected aggregation function	Provision of explanation of why the aggregation function has been selected	[37]
	A	Weights of criteria	Include preference information among the criteria. If yes, what type of weights?	[12]
	A	Justification for the selected weighting method	Provision of explanation of why the weighting method has been selected	[37]
Output variability	F	Sensitivity analysis	On input data (weights or performance evaluations) or on preference model (type of aggregation, normalization)	[34,36]
	F	Uncertainty	On input data (weights or performance evaluations): single preference model or preference model (aggregation functions, decision rules, type of preference function): multiple preference models	[34,36,38]

Table B.2

Frequency analysis per feature (A-F), displaying what is counted exactly and identifying the studies that are included in this count.

Feature	Description	Frequency count	Count	Paper #
A	Defining the decision-maker and the problem statement	Defining who the decision-maker is and what the problem statement is. The latter by justifying the selection of relevant weighting and aggregation method, based on problem formulation.	4 partially 1 fully	Partially: 1,2,4,9 (none define the decision-maker) Fully: 12
B	Set of alternatives	Defining and justifying set of alternatives.	11	1,3-8,12,13,17,18
C	Allowing for rank reversal	Justification for the type of assessment.	1 (partially)	12
D	Life cycle perspective and assessment scope	A life cycle approach taken, including 2 or more stages.	4	4,5,13,15
E	Set of criteria	Defining and justifying set of criteria, and criteria structure considered.	5	1,4,5,12,13
F	Managing uncertainties	Performing some sort of sensitivity and uncertainty analysis.	8 partially 3 fully	Partially: 1-4,12-14,16 Fully: 5-7

Please see Supplementary Material 2 on the full analysis of these features on the 18 studies.

Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.coche.2026.101243.

References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

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