Life Cycle Based Risk and Opportunity Mapping: A systematic collaborative procedure to integrate environmental and health aspects in early innovation as possible scoping pre-screening to the safe and sustainable by design (SSbD) assessments – Supplementary Information

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The structured development of LCBROM

Table S1. The structured development of LCBROM divided into three phases, all of which contained a descriptive study and a prescriptive study.

Phase I	
Descriptive study I	
Aim:	Apply a methodological procedure for the evaluation of the most important environmental and human health aspects of material production, application, post-consumer fate, and management in early innovation using a MET matrix or similar eco-design tool to obtain a life cycle-based risk mapping.
Main activities:	Unstructured dialogues were initiated with technology- and problem owners to identify the function of the innovation and the best approach for identifying potential human- and environmental impact of the innovation.
Outcome:	The realization that a structured framework and well-thought-out questions are needed to facilitate communication.
Prescriptive study I	
Aim:	Develop a structured method for mapping human- and/or environmental risks of emerging technologies using a life cycle thinking.
Main activities:	Internal discussions on what aspects to include, how to facilitate communication with non-experts, how to ensure that no aspect is overlooked, and how to formalize the procedure.
Outcome:	The concept of life cycle-based risk mapping (LCBRM) was developed in which the MET matrix was in focus. Questionnaires (Q1 and Q2) to be used as a basis for discussion topics at stakeholder meetings were developed.
Phase II	
Descriptive study II	
Aim:	Test out the first version of the method.
Main activities:	Introduced the MET matrix and questionnaires to the technology- and problem owners.

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Outcome:	The realization that technology owners may not be willing to discuss the risks of their innovation unless also opportunities are presented as a counterpart.
Prescriptive study II	
Aim:	To refine the framework based on the outcome of the feedback received from technology- and problem owners.
Main activities:	Internal discussions on how to improve to method.
Outcome:	By adding focus on opportunities LCBRM method was transformed into LCBROM.
Phase III	
Descriptive study III	
Aim:	Test out the improved method in four case studies and concretize its applicability domain.
Main activities:	Continued meetings with stakeholders in various case studies.
	Structuralized documentation of the method development itself as well as a description of its approach and possible uses.
	Poster presentation of LCBROM at SETAC LCA symposium 2024.
Outcome:	The developed LCBROMs in the case studies were presented to the steering group of the research programme at which feedback was obtained. Hence, the iterative nature of the method could be tested.
	The method was formally described in case study reports.
	Dissemination of the method via the SETAC LCA symposium 2024.
	The realization that the method has great potential to be used in the SSbD framework outlined by the EC.
Planned prescriptive study III	
Aim	Identify further improvement of the method as well as dissemination of the method.
Main activities:	Application of LCBROM in at least three case studies in BioSusTex, an EU funded research programme that will implement the SSbD framework as outlined by the EC. To be initiated during spring 2025.
	Platform presentation of the method at the 35th SETAC Europe Annual Meeting in May 2025.
	Publishing a scientific article describing LCBROM.
Outcome:	Learnings from the application of LCBROM in BioSusTex.
	Further dissemination of the method via this article and SETAC conference 2025.

LCBROM questions

A non-exhaustive list of typical questions to keep in mind when applying the LCBROM methodology is presented in Table S2. These questions were generated via internal discussions with LCA experts during method development. Inspiration has been derived from other published methods such as the Screening level approach developed by Pizzol et al.[20]

Table S2. Suggested questions to discuss during an LCBROM assessment.

Material	
Question	**Life cycle stage**
1. Are there any non-renewable resources used in production of the innovation?	Production
2. What process chemicals are used?	Production; Use
3. Does the innovation require frequent maintenance?	Use
4. Can the material in the innovation be recycled?	Disposal
5. Any scarce metals used?	Production
Energy	
Question	**Life cycle stage**
6. Is the production and/or usage of the innovation energy intense?	Production; Use
7. What type of transportation is foreseen in the life cycle of the innovation?	Production; Use, Disposal
8. Will the innovation be waste handled via incineration?	Disposal
9. Will energy recovery be possible?	Production; Disposal
10. Where, geographically, may the production take place?	Production
Toxicity	
Question	**Life cycle stage**
11. Will any chemicals classified as hazardous under CLP (EU regulation No 1272/2008) be used?	Production; Use
12. Will the innovation require the use of chemicals that are PBT, vPvB, PMT or vPvM*?	Production; Use
13. Will the innovation require the use of chemicals with endocrine disrupting properties?	Production; Use
14. Does the innovation require use of PFAS?	Production; Use
15. Does the innovation give rise to emissions of particles, such as microplastics?	
16. Will there be a risk of emissions of problematic substances to air, water or soil?	Production; Use
17. Any risk mitigation measures (RMMs) required to keep exposure low? If yes, what type of material resources and energy use may such RMMs consume?	Production
18. Is there a risk for toxic emission during landfill?	Disposal

19. Risk of toxic emissions from incineration?	Disposal

*PBT = Persistent, Bioaccumulative, Toxic; vPvB = very Persistent, very Bioaccumulative; PMT = Persistent, Mobile, Toxic; vPvM = very Persistent, very Mobile

Questionnaire 1 and 2

Questionnaires for early information gathering in the early steps of the LCBROM methodology are listed in Table S3. These questions were generated via internal discussions in an iterative manner based on feedback from technology owners in case study applications.

Table S3. Questions included in the questionnaire 1 and 2. Questions written in italics refer to economic and social aspects, not yet implemented in LCBROM.

Questionnaire 1 (Q1)
1. What is the function of the new material or process? Please be as detailed as possible about emissions, waste streams, material flows, or contaminated sites (if applicable).
2. What stakeholders (e.g., problem owners or beneficiaries) are involved? Could they provide further information for the LCBROM if needed? Please list contact details if possible. Also consider if known possible union representatives, non-governmental organizations (NGOs) etc related to social impacts and stakeholders involved in funding, supply chains, or economic evaluations, if applicable to economic impacts (competitors/supplier of the baseline technology).
3. Do you know of any potential human, environmental, *economic and social* risks if the innovation is not implemented?
4. Are there other state-of-the-art benchmark technologies available? Please, describe them and its TRL level (established, under development etc.).
5. In case there are benchmark technologies available, what are the potential advantages of the innovation? Are there potential advantages in efficiency (quality, speed, or cost) compared to the benchmark?
6. *Could the new material or process address **economic** challenges such as high operational costs, raw material scarcity, or market competitiveness in comparison to a benchmark/state of the art?*
7. *If known, could the new material also bring **social** challenges, such as health and safety risks (during raw material extraction, production, or disposal), unpleasant working conditions (e.g., unfair wages, discrimination), risks for the local community around the production facility, or health issues for children as consumers? Which countries and sectors are foreseen to be used in the supply chain?*
Questionnaire 2 (Q2)
1. Provide a technical description of the new solution/technology, what materials are included (chemical list and other materials used in the process), describe the production process (set up, chemicals involved, temperatures etc.) and other relevant information. Please also prepare a process flowchart describing the process.
2. Are there any toxicity aspects during the life cycle of the product/solution, such as emissions of toxic chemicals (to air, land or water) in production, use phase or waste management? Will you use or avoid any hazardous chemicals or materials? (Work environment exposure related to classification of chemicals?)
3. Describe the energy use during different life cycle stages of the product/solution, such as energy requirement in production, use phase etc. What kind of energy is included, is it electricity, steam or fuels (fossil or biobased)?
4. What would happen if the production of the product/solution would be upscaled and used in reality? Any materials used during eventual maintenance? Any emissions during use phase or waste management? How would the product be handled at end of life?

Where would the origin of raw materials be? Any long- or short-distance transportation?
5. *Do you see any risk in terms of economic and social aspects during any life cycle stage of the product (i.e., production, use and end-of-life)?*
6. *Do you see any opportunity in terms of economic and social aspects during any life cycle stage of the product (i.e., production, use and end-of-life)?*