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Integrating Prospective LCA and TEA: Challenges, Proposed Solutions, and Pathways for Sustainable Design and Decision-Making



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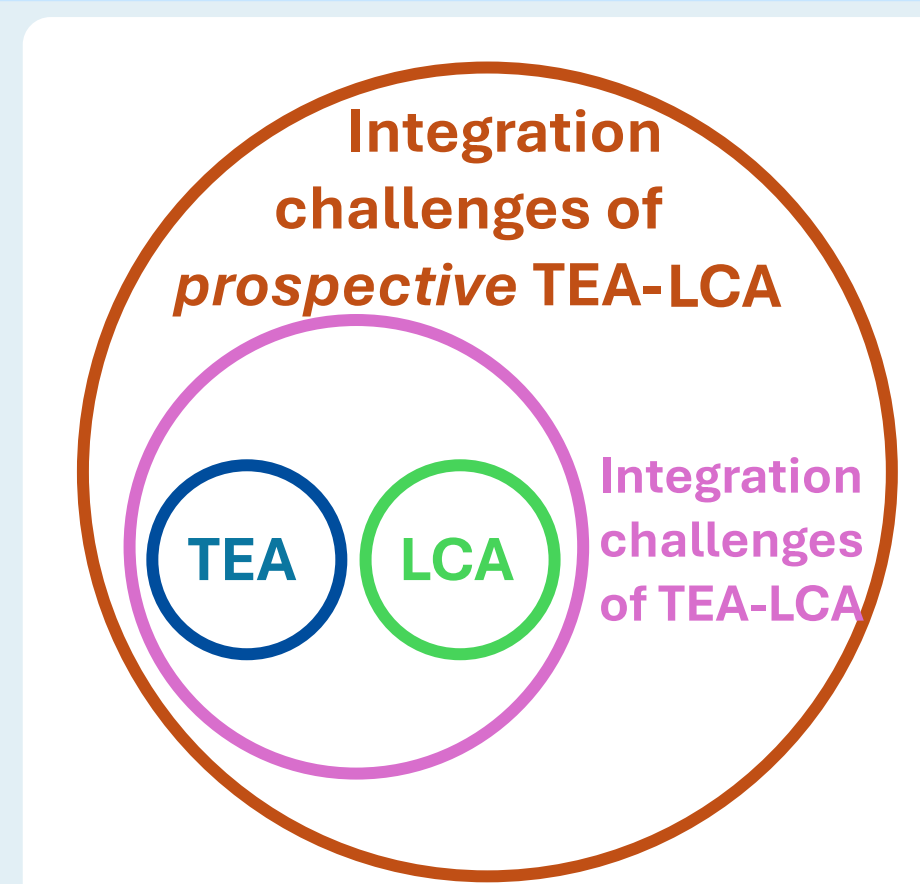
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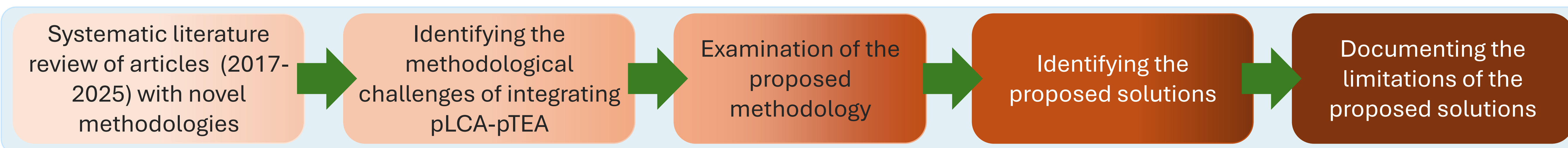
Introduction

Integrating life-cycle analysis (LCA) and techno-economic assessment (TEA) into a single methodology is essential for **emerging technologies**: it enables the *systematic identification of trade-offs* between economic, environmental, and technical performance at an early design stage, and provides *more accurate decision support*.

Therefore, integrated assessment offer a stronger foundation for sustainable policy-making, investment strategies, and innovation roadmaps, compared to the cases in which they are assessed separately. This study addresses the **methodological challenges** of integration of prospective LCA (pLCA) and TEA (pTEA) by *identifying gaps* in the current literature, *proposed potential solutions*, and *evaluating the limitations*.



Methodology



Results

Challenges	Solutions	Limitations	References
Alignment of goal and scope, system boundary, and assumptions	Expand TEA to include indirect costs and validate with stakeholders	Data intensive	Thomassen et al. 2019, Silva et al. 2024
	Simplify LCA for foreground boundaries	Risk of excluding significant impact	Thomassen et al. 2019
Indicator selection	Literature research and expert opinion	Potential bias and reliance on outdated or context-mismatched indicators	Van Schoubroeck et al. 2021
Difference in indicators	Combine the indicators such as 'carbon abatement cost'	Loss of information	Yanjie et al. 2021
	Harmonize in scope to allow decision makers to weigh trade-offs independently	Heavy documentation	Thomassen et al. 2019
	Trade-off and eco-efficiency analysis	Single index	Sauve et al. 2023
The integration of economic and environmental results	Delphi method, MCDA	Subjective weighting, limited applicability, advanced knowledge in modelling is needed	Van Schoubroeck et al. 2021
	MOO		Ferdous et al. 2023, Silva et al. 2024, Thomassen et al. 2019
	ROO		Kern et al. 2017

Challenges	Solutions	Limitations	References
Spatial / Temporal representativeness	Multi-scenario development	Complex and data intensive	Sauve et al. 2023
	IAM scenarios	High impact of chosen scenario's built-in assumptions	Wang et al. 2024
	Geographic information systems	Data availability	Ferdous et al. 2023
	Incorporating time-varying costs and learning curves	Increases uncertainty	Silva et al. 2024
	Dividing planning into strategic and operational periods	Risk of oversimplifying	Silva et al. 2024
Handling of large uncertainties	Global sensitivity analysis	Computationally demanding and method-sensitive	Sauve et al. 2023
	Uncertainty analysis	Neglects interactions	Thomassen et al. 2019
Data gaps at early TRLs	Proxy data and assumptions	Risk of simplification and misleading results	Thomassen et al. 2019
Scale-up issues	Simulation	Model validation is needed	Ferdous et al. 2023
	Process engineering	Data intensive and limited by design constraints	Thomassen et al. 2019

Discussion and Conclusion

The findings present an **up-to-date perspective** on the current state of integrated prospective assessments, **guiding future research** towards the development of more comprehensive and consistent methodologies. In this work, **eight methodological challenges** were identified. For each challenge, potential solutions were proposed, and their limitations were summarized.

The pairing of challenges with solutions and limitations can help researchers and decision makers estimate trade-offs, prioritize methodological improvements, and design assessments that are both reliable and useful for decision making. While most existing integrated assessments provide valuable but sector-specific insights, **the outcomes of this research can support the creation of a framework that can be applied across multiple sectors.**

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