

Recent advancements in prospective life cycle assessment of emerging technologies

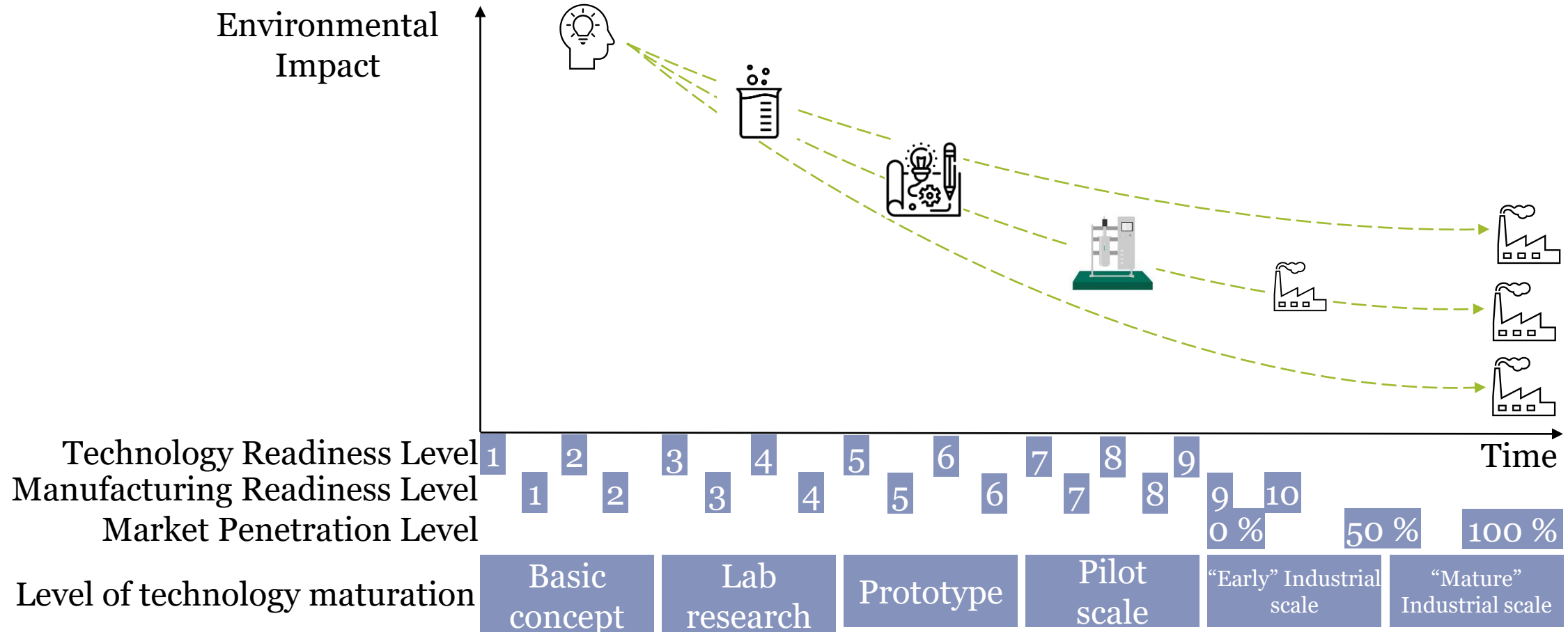
Nils Thonemann
Assistant Professor, CML, Leiden University



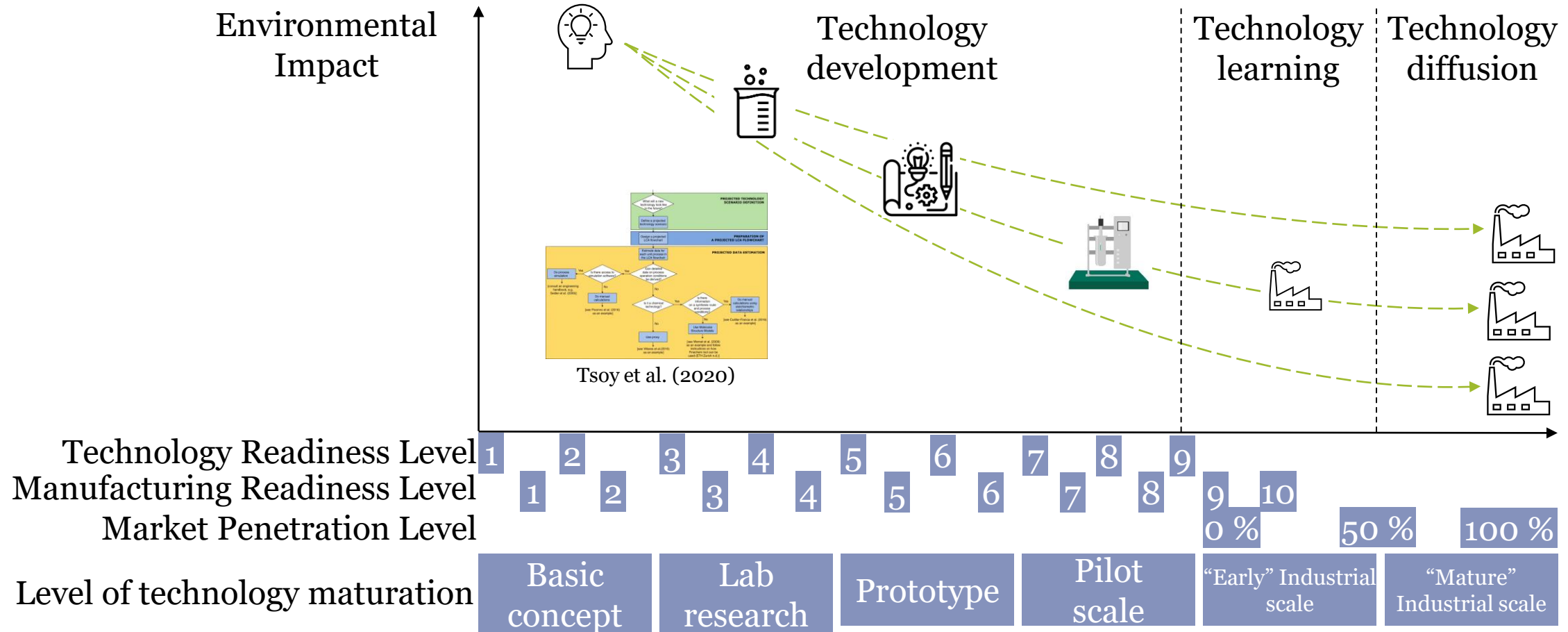
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Why prospective LCA?



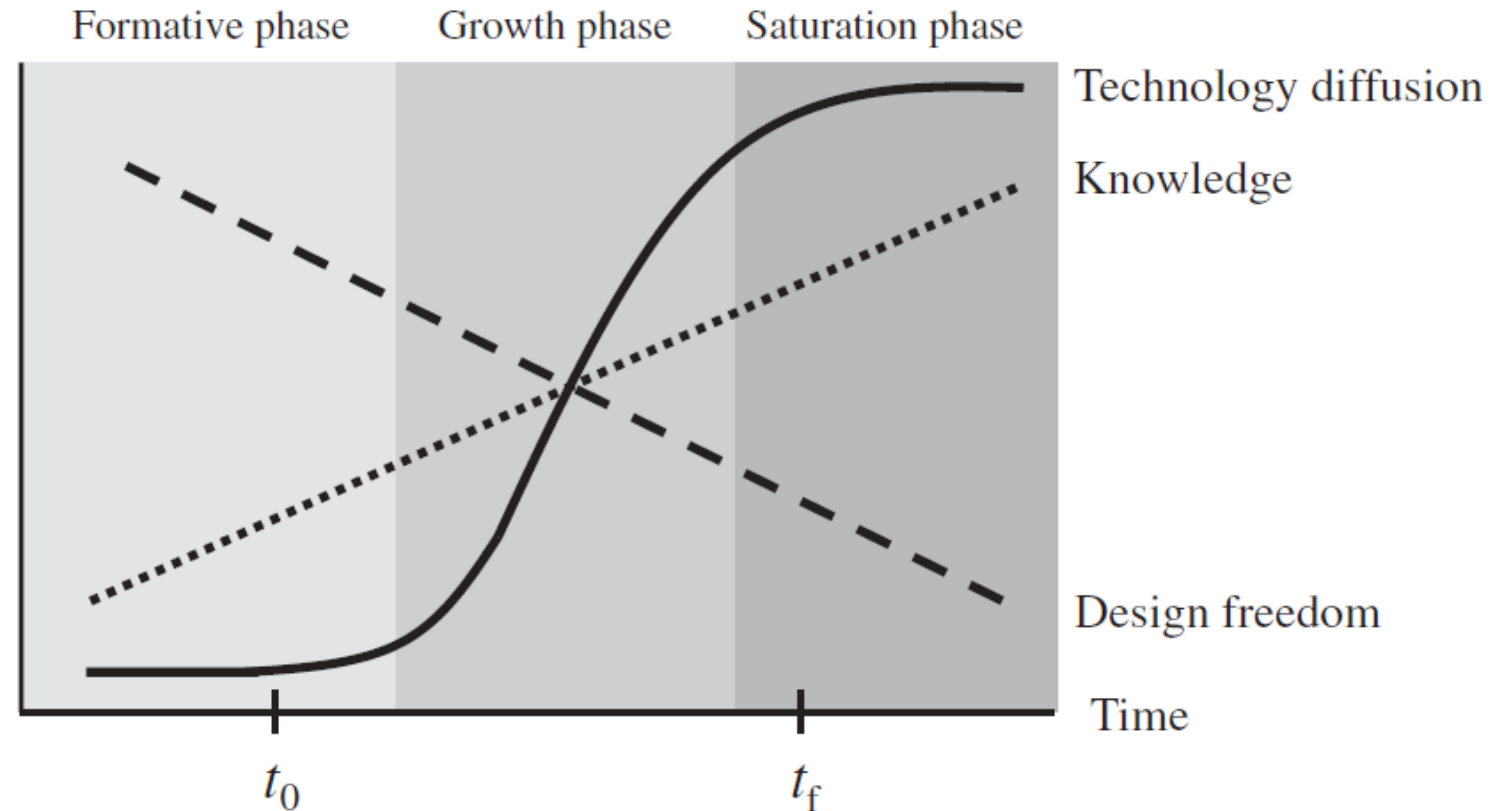
Why prospective LCA?



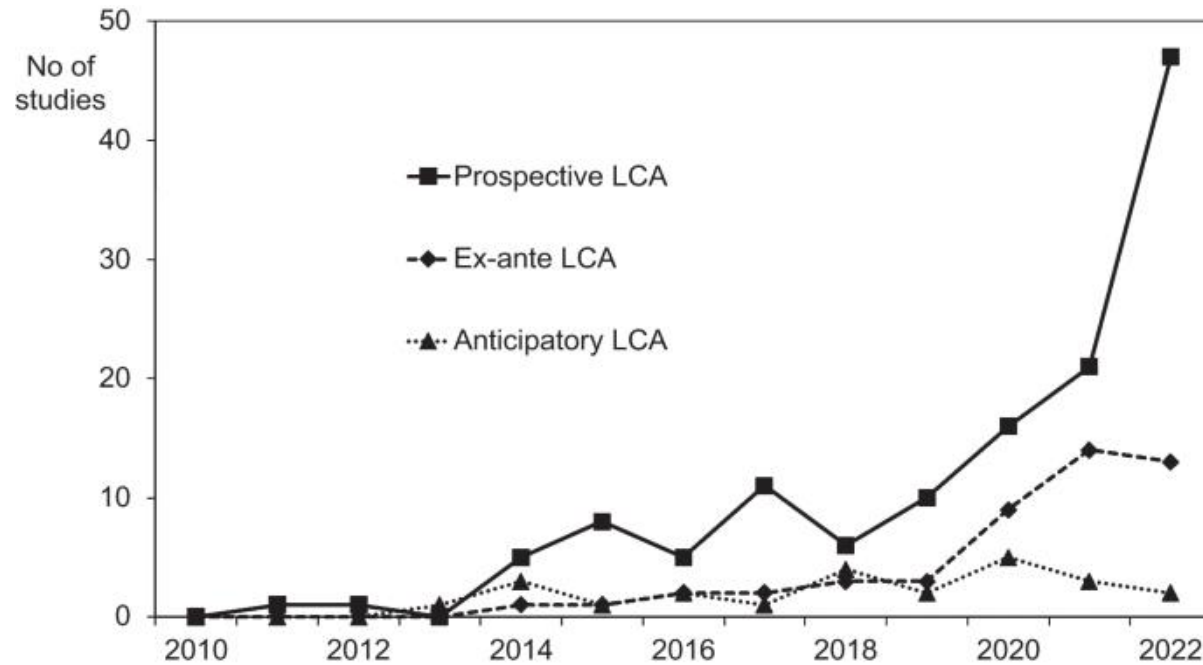
Collingridge dilemma

Optimal development of emerging technology faces a **double-bind problem**:

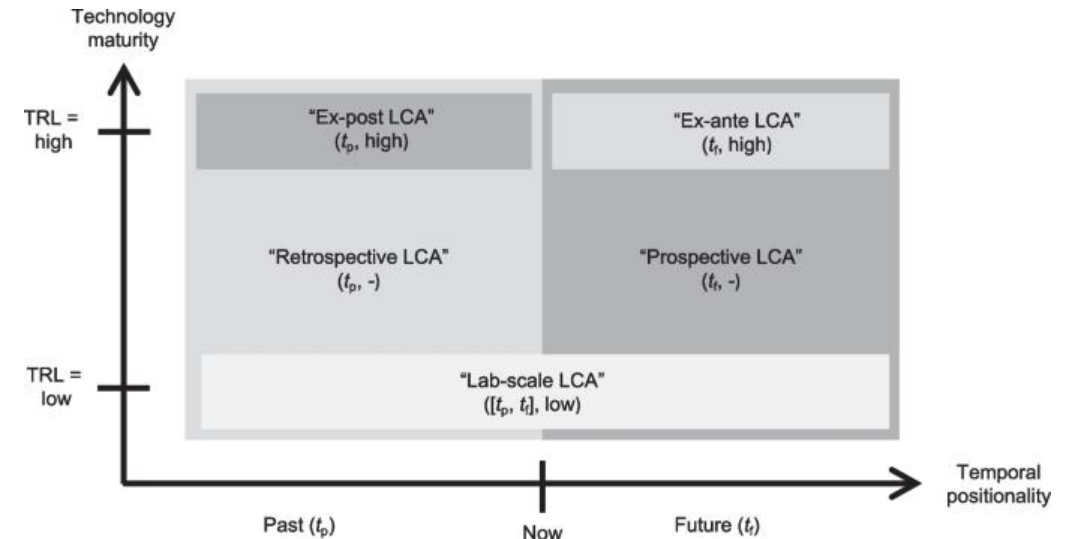
- **Knowledge** vs.
- **Design freedom**



Terminology for future-oriented LCA



Term	Definition	Source
Prospective LCA	"[LCA] studies [...] looking <i>forward</i> at <i>future</i> environmental impact."	Sandén and Karlström (2007)
Prospective (or future-oriented) LCA	"[A] systematic assessment of <i>future</i> events and developments in society, technology, economy and policy that in the <i>long-term</i> could considerably influence the product system (and/or functional unit) and its conditions and hereby the environmentally relevant flows."	Olsen et al. (2018)
Prospective LCA	"[LCA] estimating <i>future</i> life-cycle environmental impacts using scenarios"	Guinée et al. (2018)
Prospective LCA	"An LCA is prospective when the (emerging) technology studied is in an early phase of development (e.g., small-scale production), but the technology is modeled at a future, more-developed phase (e.g., large-scale production)."	Arvidsson et al. (2018)
Ex-ante LCA	"[LCA] studies [...] that: • Scale-up an emerging technology using likely scenarios (e.g., using expert help, extreme views, learning curves for similar technologies) of <i>future</i> performance at full operational scale ; • Compare the emerged technology at scale with the evolved incumbent technology."	Cucurachi et al. (2018)
Ex-ante LCA	"[A]n environmental [LCA] of a new technology <i>before</i> it is commercially implemented in order to guide R&D decisions to make this new technology environmentally competitive as compared to the incumbent technology mix."	van der Giesen et al. (2020)
Anticipatory LCA	"[A] <i>forward-looking</i> , non-predictive [LCA] tool that increases model uncertainty through inclusion of prospective modeling tools and multiple social perspectives."	Wender et al. (2014a)



Definition of prospective LCA:
 “LCA that models the product system at a future point in time relative to the time at which the study is conducted”

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Terminology for future-oriented life cycle assessment: review and recommendations

Richard Arvidsson¹, Magdalena Svensson¹, Olina A. Sandén², Mik Thomsen³, Bernhard Steubler⁴, Stefano Cococcia⁵

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Abstract
 Purpose: This paper introduces the terminology for future-oriented LCA, which is a type of LCA that is used to assess the environmental impact of a product system at a future point in time. The paper aims to provide a common terminology for future-oriented LCA, which is currently used in a variety of ways, and to provide a common terminology for future-oriented LCA. The paper also provides a common terminology for future-oriented LCA, which is currently used in a variety of ways, and to provide a common terminology for future-oriented LCA. The paper also provides a common terminology for future-oriented LCA, which is currently used in a variety of ways, and to provide a common terminology for future-oriented LCA.

Keywords Prospective · Ex-ante · Retrospective · Anticipatory · Emerging technologies

1 Introduction
 One of the major challenges of the assessment of the environmental impact of a product system is the uncertainty associated with the future. This uncertainty is due to the fact that the future is unknown, and the environmental impact of a product system at a future point in time is therefore uncertain. This uncertainty is due to the fact that the future is unknown, and the environmental impact of a product system at a future point in time is therefore uncertain. This uncertainty is due to the fact that the future is unknown, and the environmental impact of a product system at a future point in time is therefore uncertain.

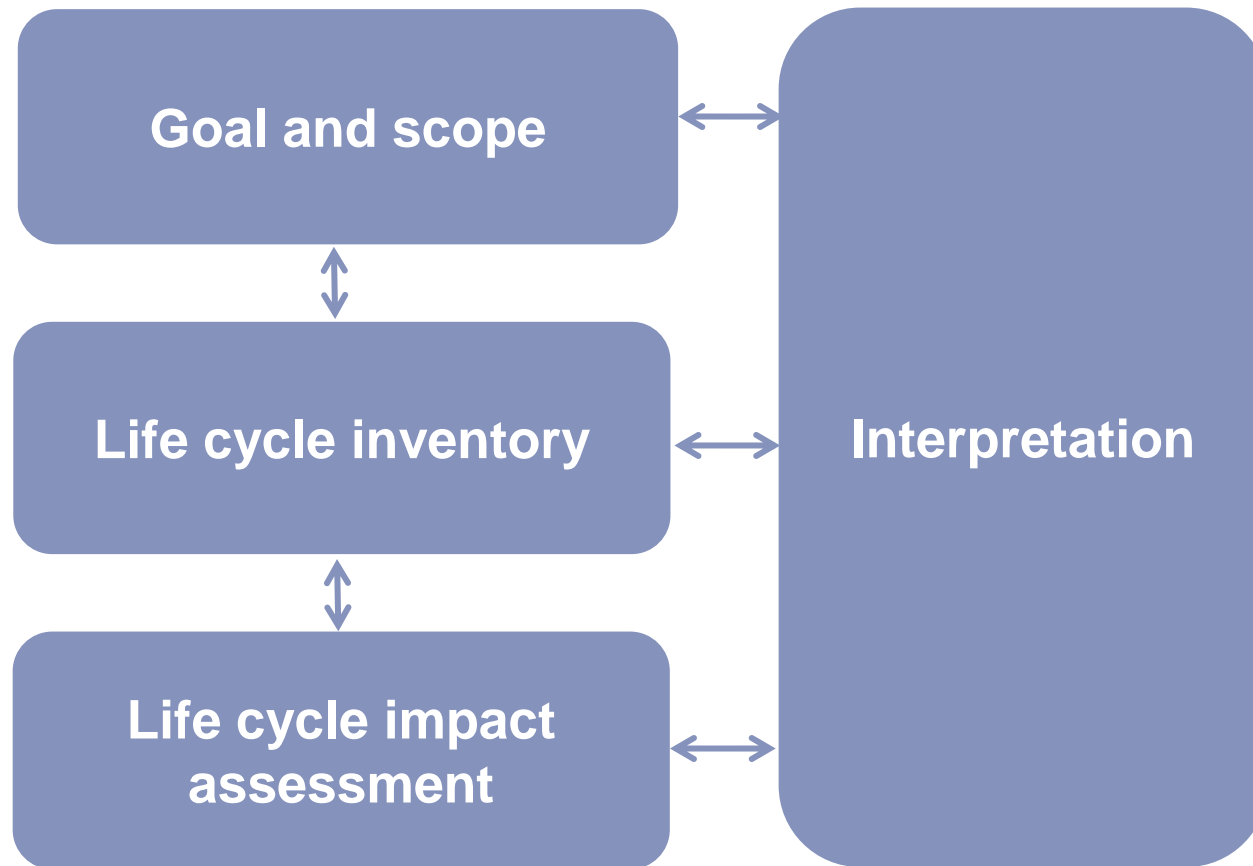
Challenges for prospective LCA



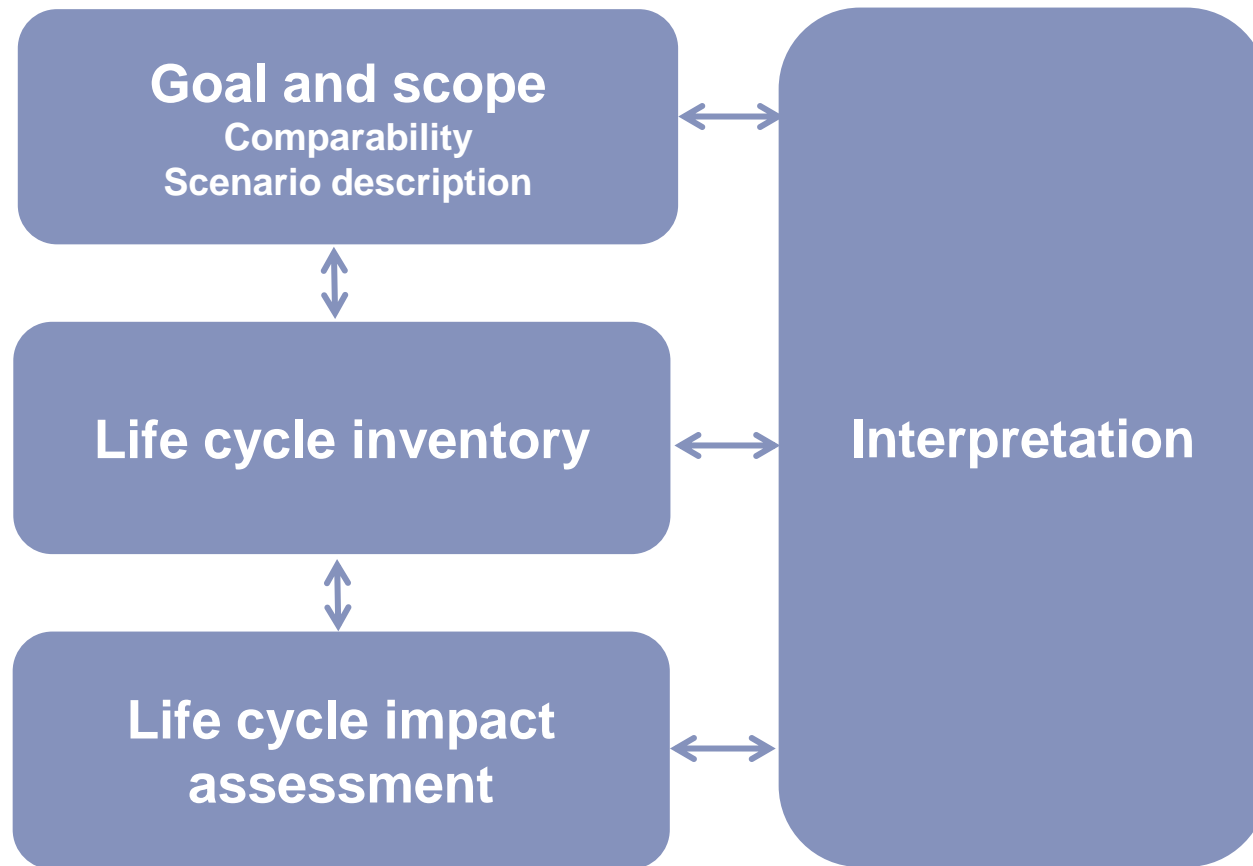
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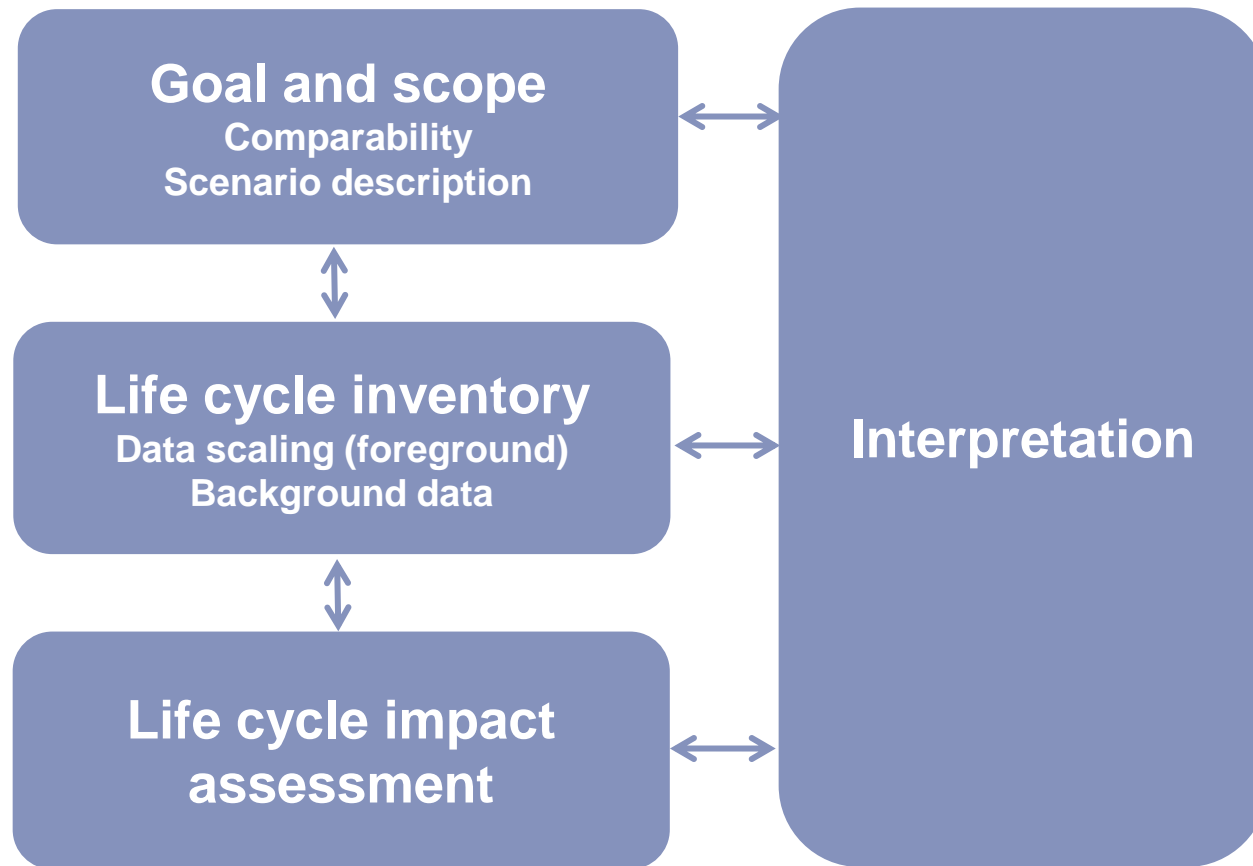
Challenges for prospective LCA



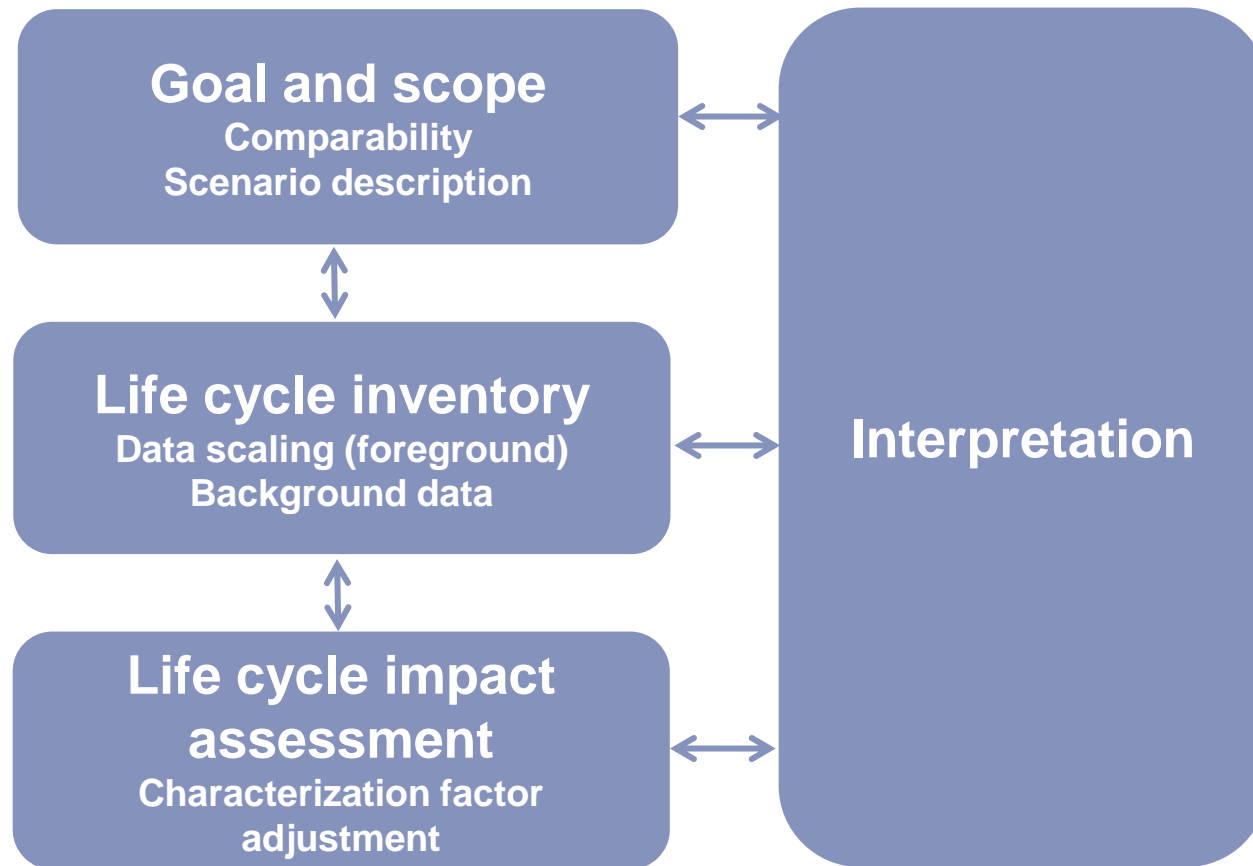
Challenges for prospective LCA



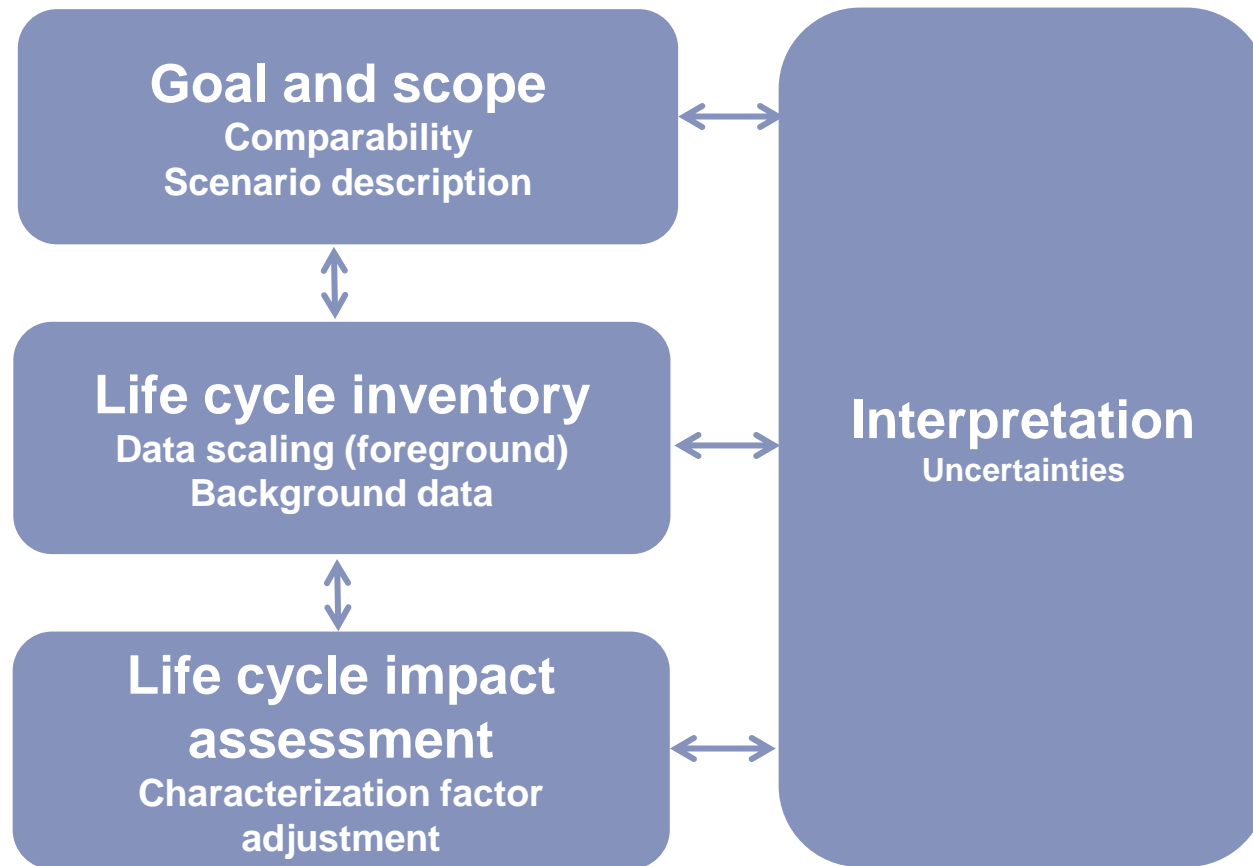
Challenges for prospective LCA



Challenges for prospective LCA



Challenges for prospective LCA



Key challenges for prospective LCA

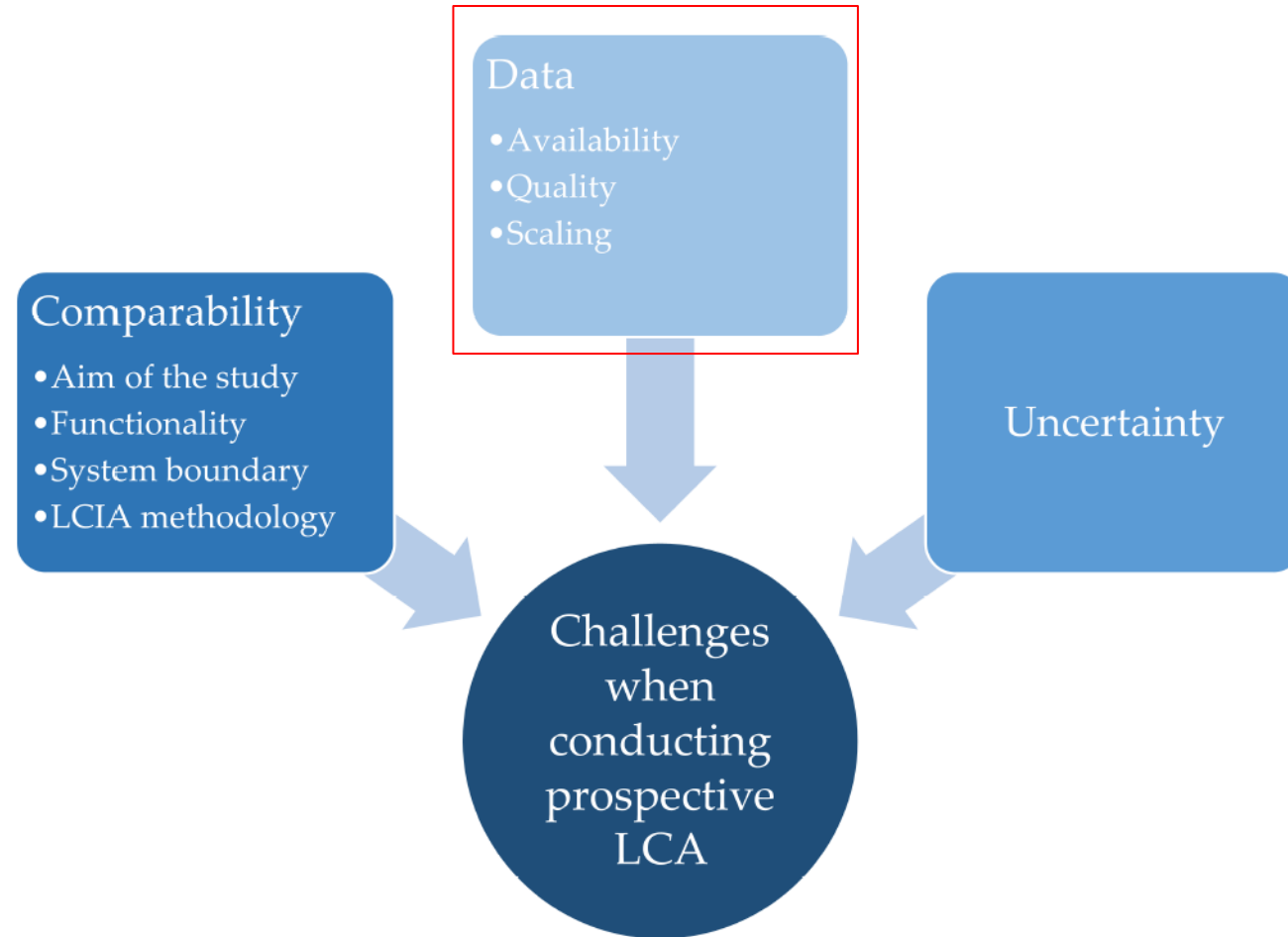


Figure 4. Schematic overview of the challenges for the application of prospective LCAs.

What does prospective LCA require?

Scenarios (i.e., quantified LCI data for):

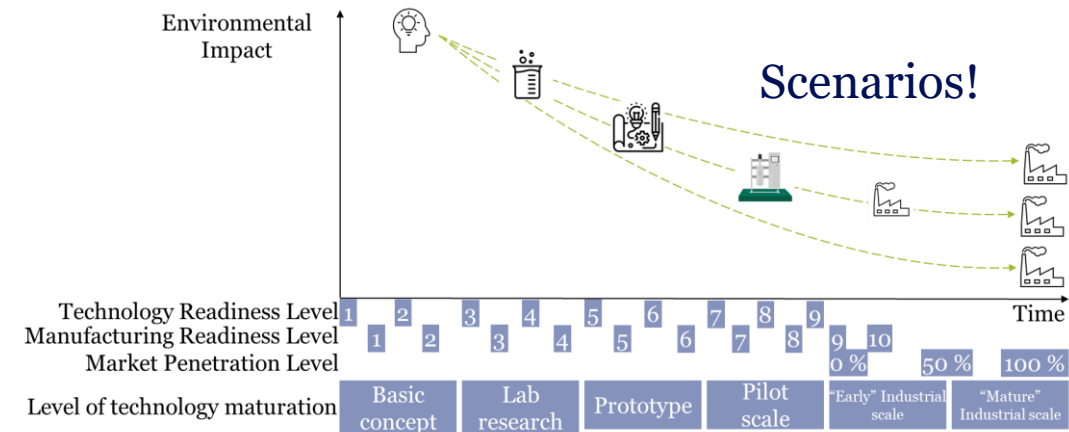
1. The technologies under investigation
(foreground system)

How will new technologies develop?
(technology scenarios, upscaling, ...)

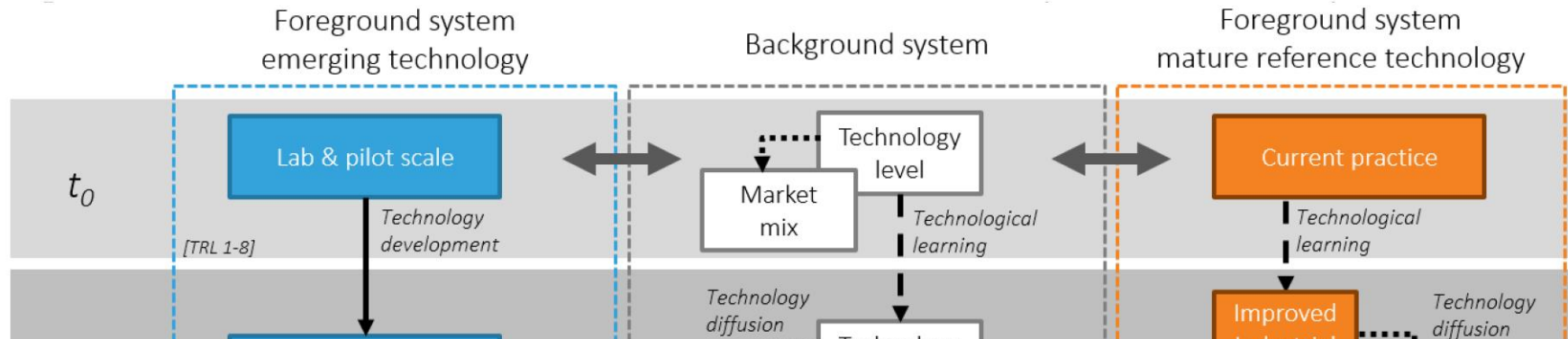
How will respective markets develop?

2. The surrounding technological system
(background system)

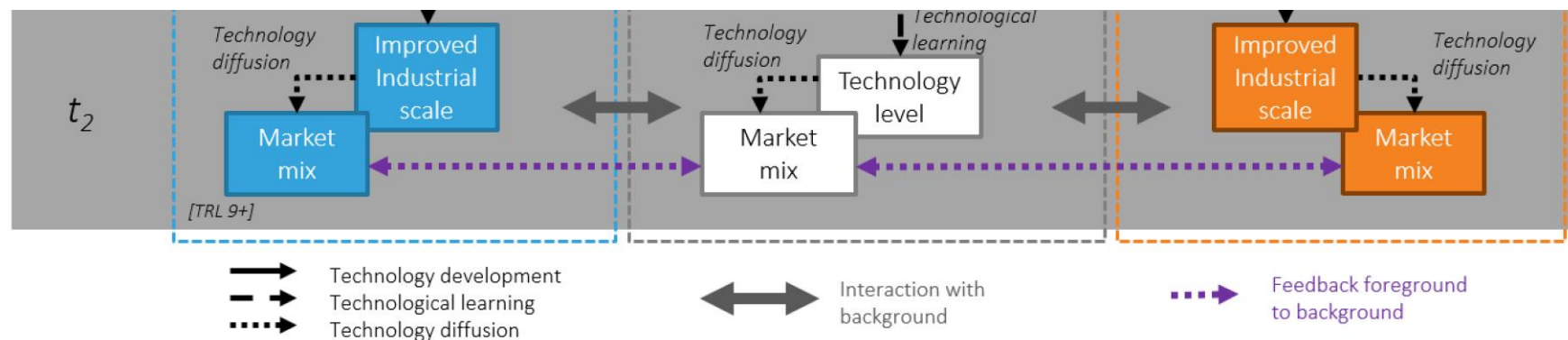
How will the wider economy develop?
(e.g., the energy transition)



Life cycle inventory | Technology scaling

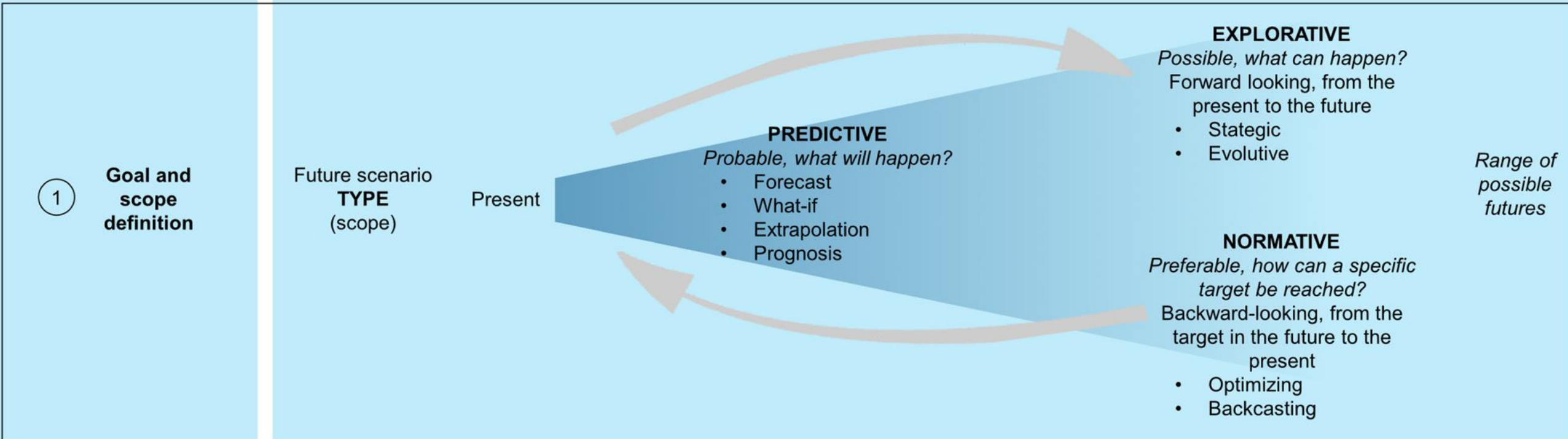
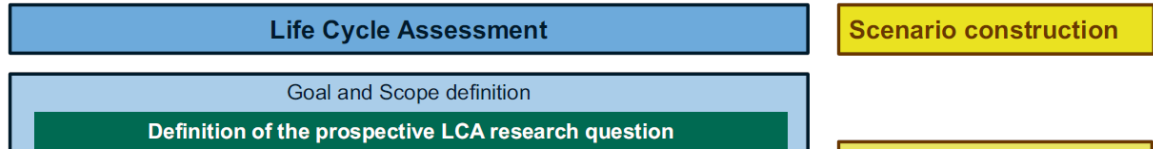


Consistency is key for a fair comparison!

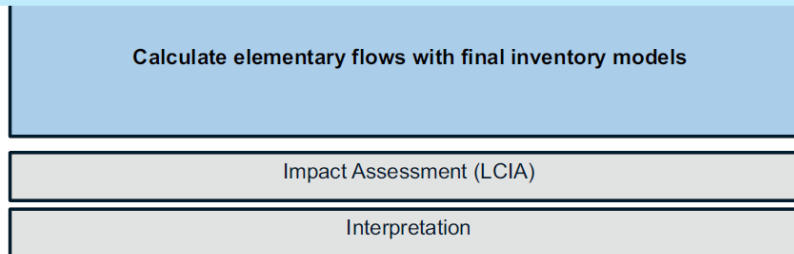


Developing foreground scenarios

- Should be based on a good understanding of the investigated

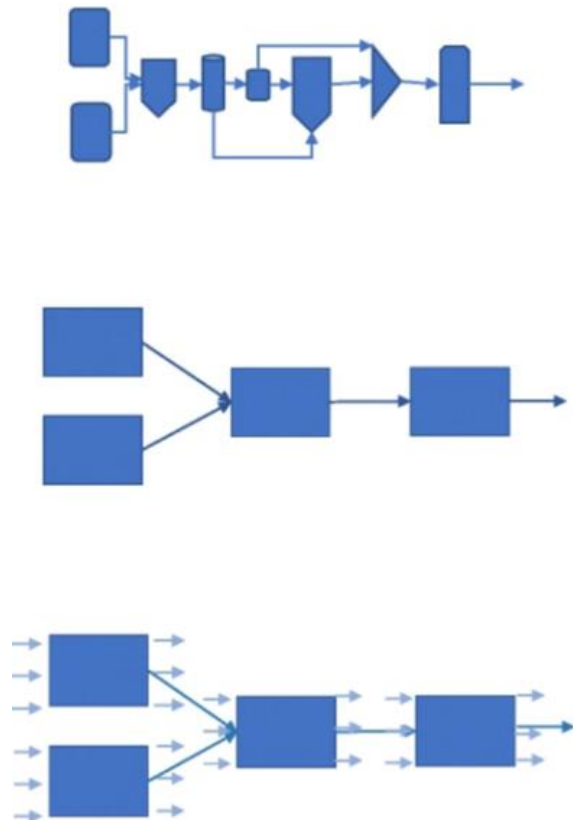


LCA): structured and practical guidance to constructing scenarios for prospective LCA



Life cycle inventory | Technology scaling

Upscaling steps



1. Projected technology scenario definition

2. Preparation of a projected LCA flowchart

3. Projected data estimation

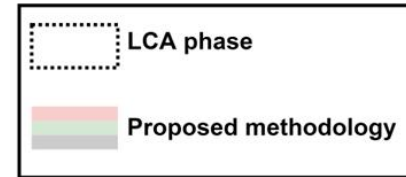
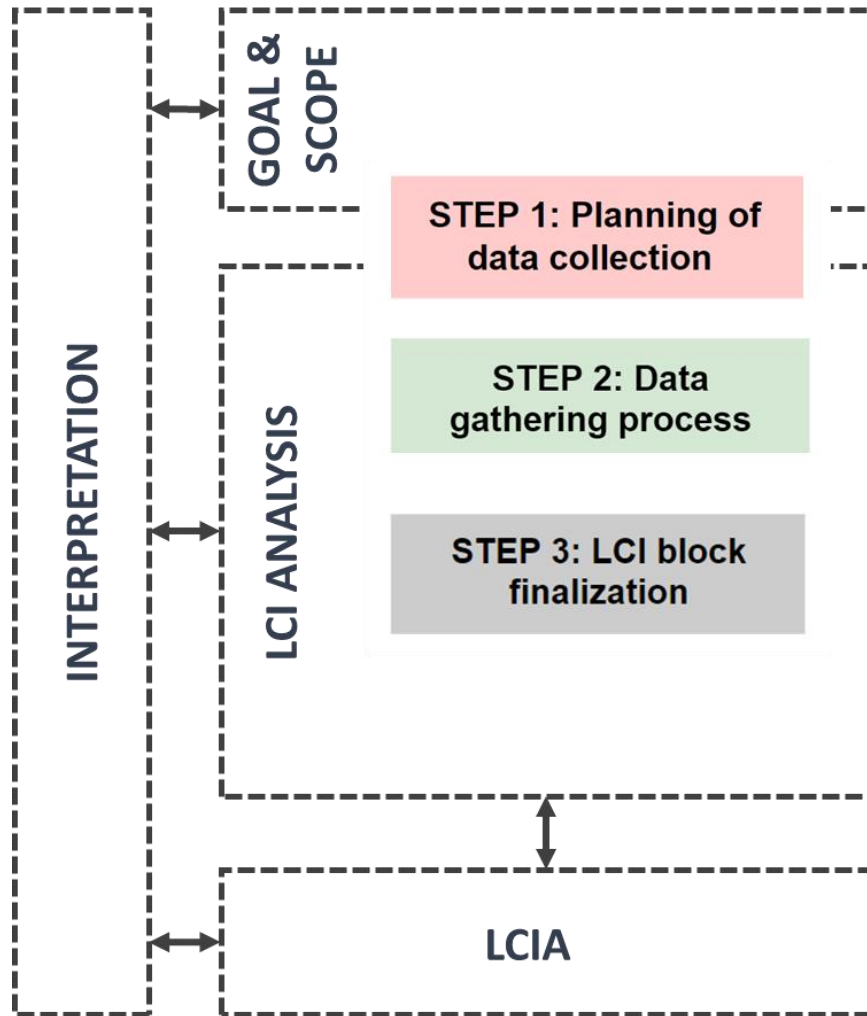
Technology expertise



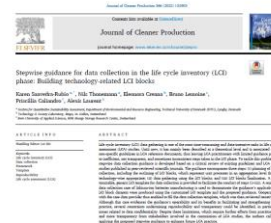
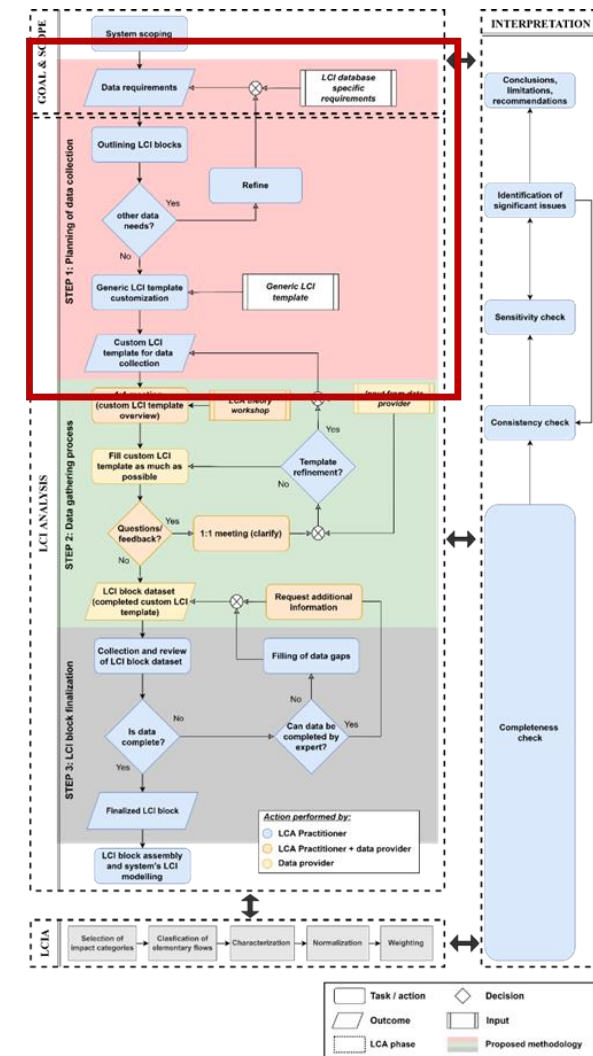
LCA expertise



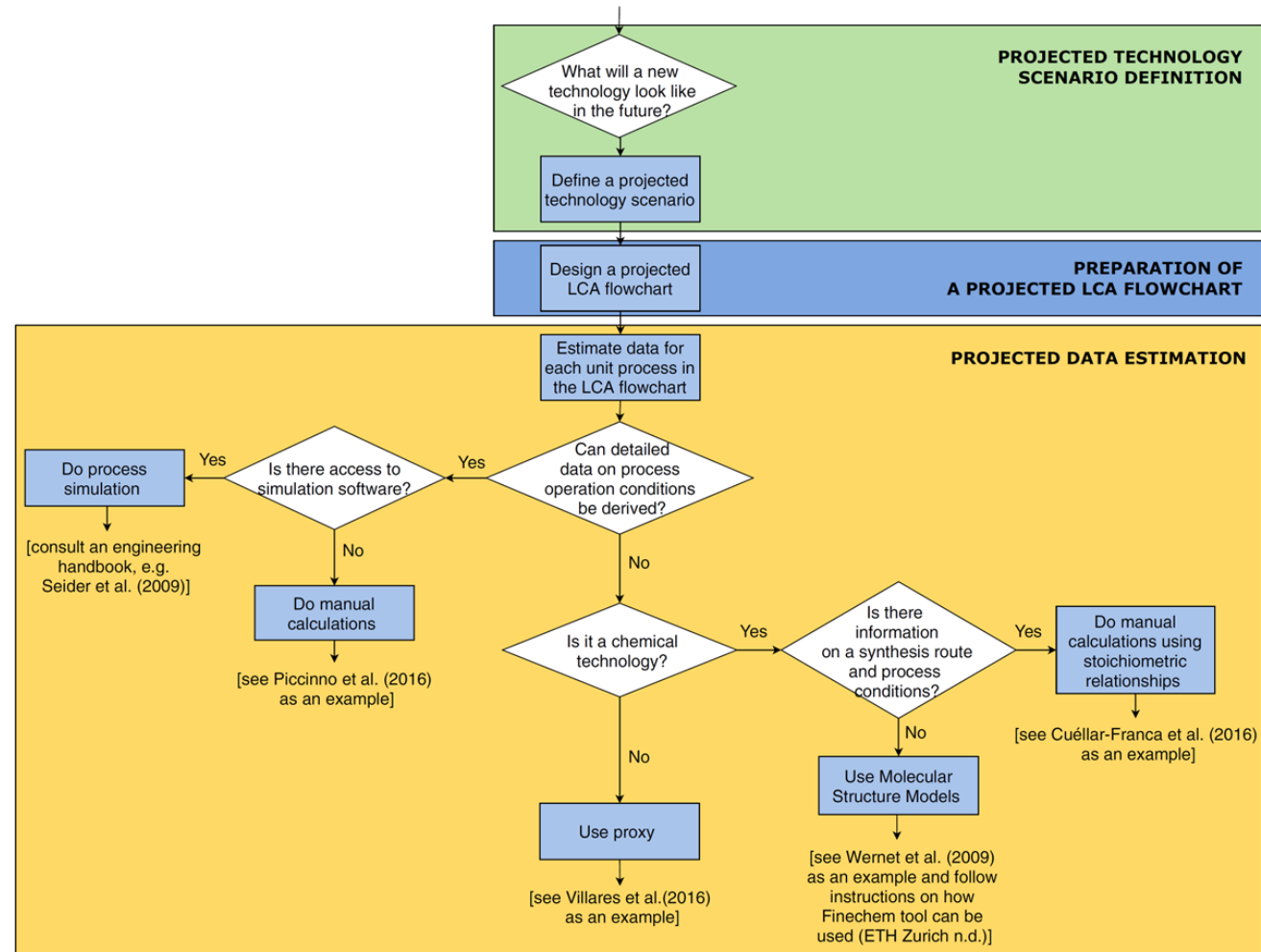
Guidance in pLCI data collection



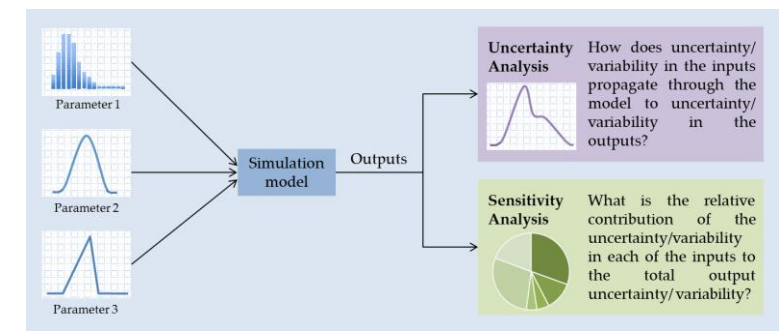
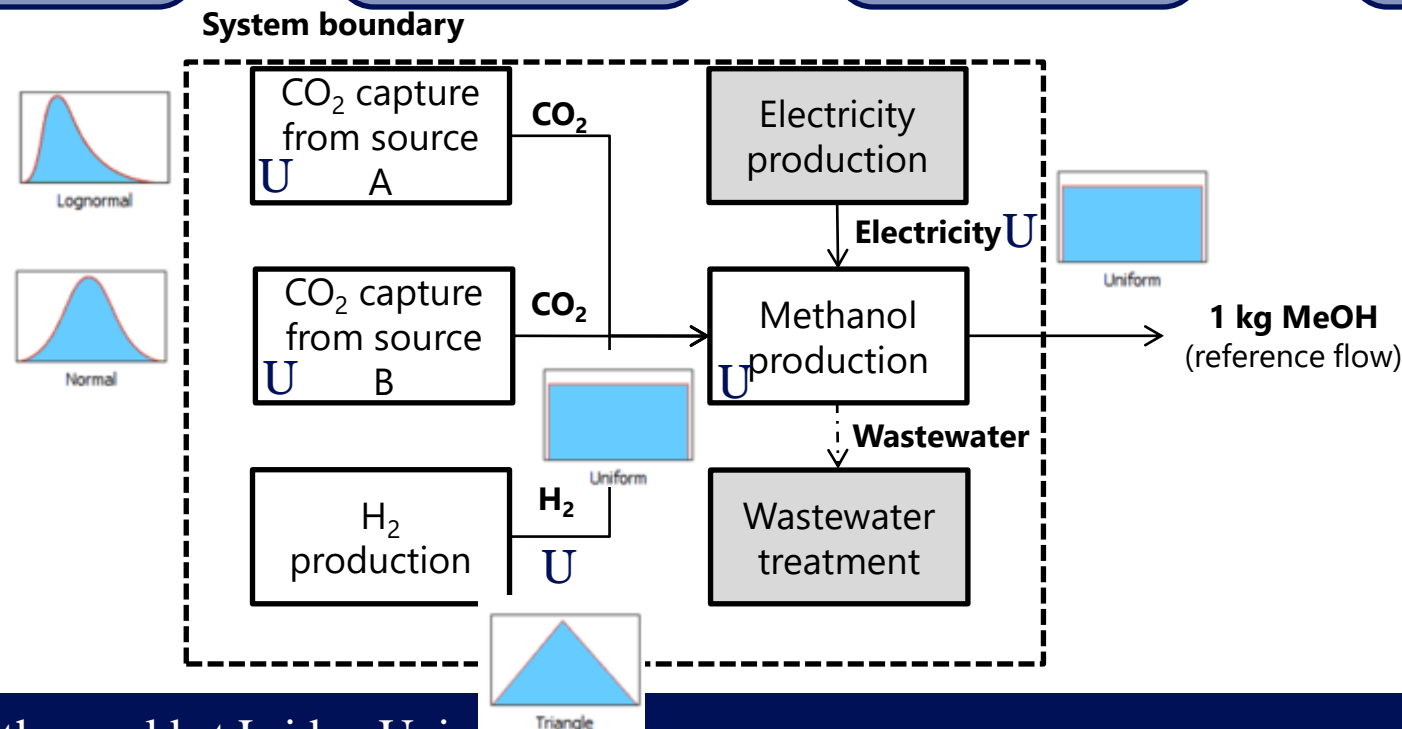
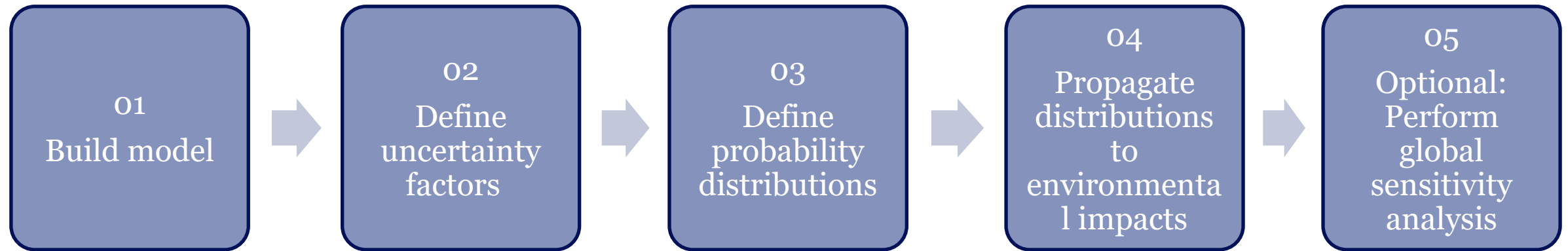
To learn more...



Life cycle inventory | Technology scaling

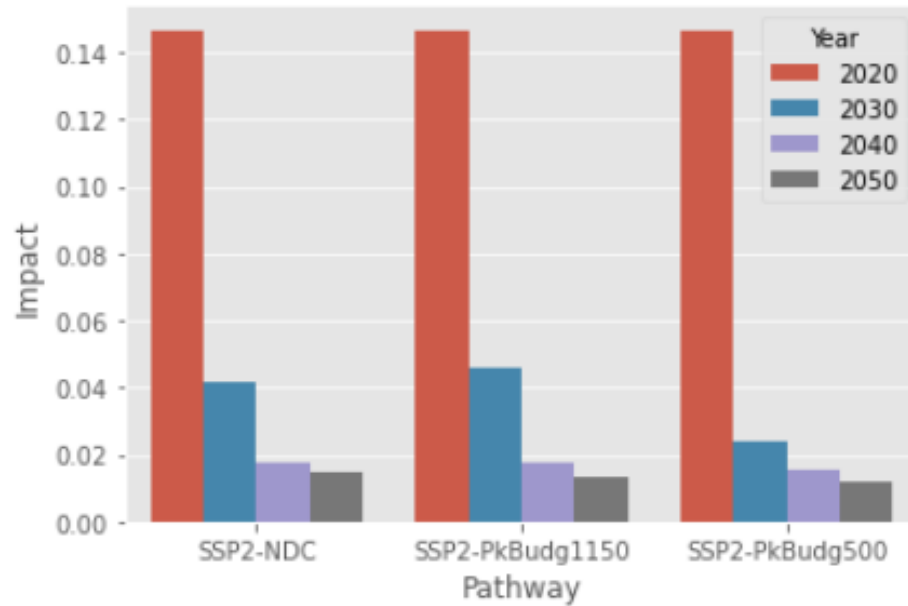


Stochastic or probabilistic LCA under deep uncertainty

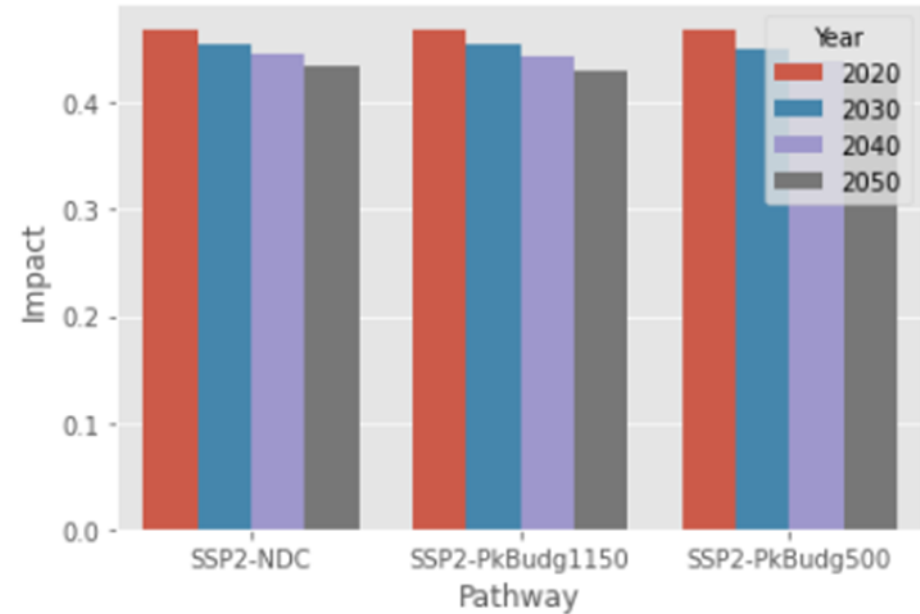


Life cycle inventory | premise in use

Electricity (NL mix)



Kerosene



Prospective LCA Network



GOALS OF THE NETWORK

			
Open Knowledge Exchange	Develop Global Networks	Advance Prospective Methodology	Facilitate Harmonisation Discussions

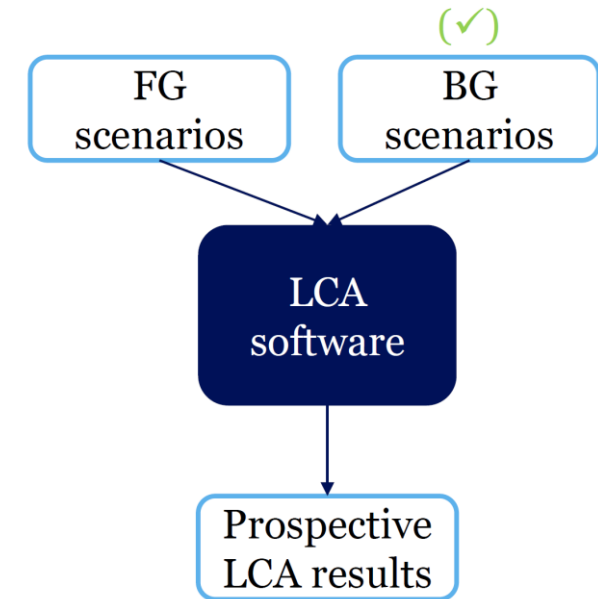
Upcoming events:

- 28.02.2024 → Workshop on Water Use CF
- 23.04.2024 → Webinar on Market Modeling in pLCA
- 05.-09.05.2024 → SETAC 2024 | Seville, Spain | pLCA Session and Social Event
- 21.-23.10.2024 → SETAC Case Study Symposium | pLCA Session and Social Event



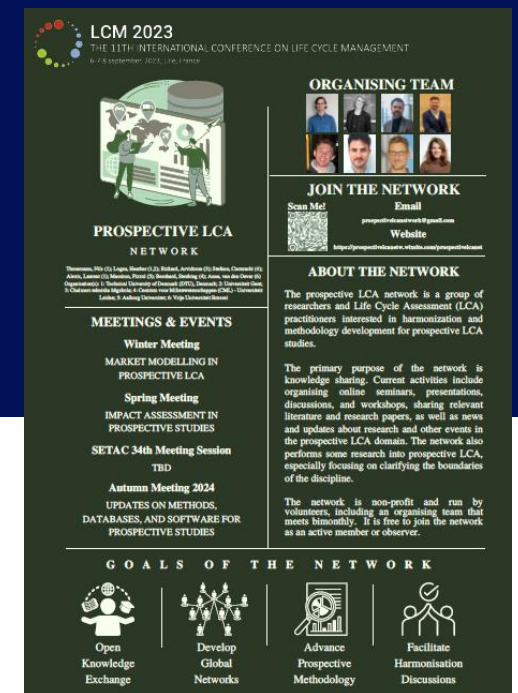
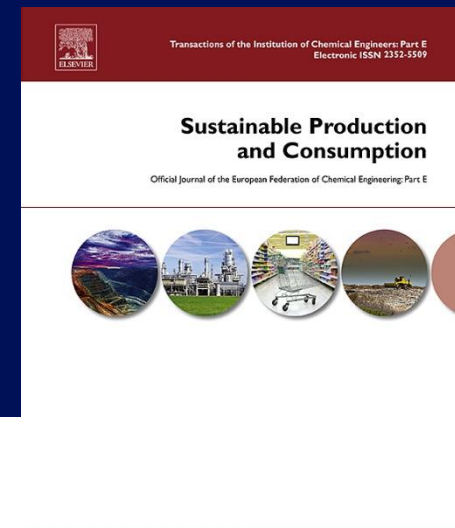
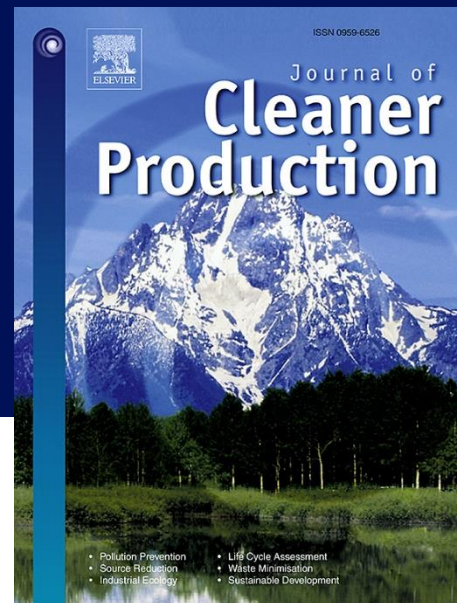
Key take aways

1. Different TRLs need different methodological toolboxes
2. Deriving foreground data must rely on scenarios (e.g., explorative)
3. Background scenarios exist and should be used BUT might need adaptation to your case + limitations(!)
4. Foreground and background scenarios should (at least roughly) align



Interested? Get in touch!

n.thonemann@cml.leidenuniv.nl



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Preprint pLCI paper and data:

https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4537185

<https://zenodo.org/records/8155003>

Code and LCI data:

https://github.com/niltho/pLCA_RegAC

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References

- Arvidsson, R., Tillman, M., Sandén, B. A., Janssen, M., Nordelöf, A., Kushnir, D., & Molander, S. (2018). Environmental Assessment of Emerging Technologies: Recommendations for Prospective LCA. *Journal of Industrial Ecology*, 22(6), 1286-1294. <https://doi.org/10.1111/jieec.12690>
- Arvidsson, R., Svanström, M., Sandén, B.A. et al. Terminology for future-oriented life cycle assessment: review and recommendations. *Int J Life Cycle Assess* (2023). <https://doi.org/10.1007/s11367-023-02265-8> Titel anhand dieser DOI in Citavi-Projekt übernehmen
- Bisinella V, Christensen TH, Astrup TF (2021) Future scenarios and life cycle assessment: systematic review and recommendations *Int J Life Cycle Assess*
- Buyle, M.; Audenaert, A.; Billen, P.; Boonen, K.; Van Passel, S, 2019. The Future of Ex-Ante LCA? Lessons Learned and Practical Recommendations. *Sustainability*, 11, 5456.
- Jouannais, P., Blanco, C. F., & Pizzol, M. (2024). ENvironmental Success under Uncertainty and Risk (ENSURE): A procedure for probability evaluation in ex-ante LCA. *Technological Forecasting and Social Change*, 201, 123265. <https://doi.org/10.1016/j.techfore.2024.123265>
- Langkau S, Steubing B, Mutel C, Ajie MP, Erdmann L, Voglhuber-Slavinsky A, Janssen M (2023) A stepwise approach for Scenario-based Inventor Modelling for Prospective LCA (SIMPL) *Int J Life Cycle Assess*
- Mendoza Beltran A et al. (2018) When the Background Matters: Using Scenarios from Integrated Assessment Models in Prospective Life Cycle Assessment *J Ind Ecol*
- Moni, S. M., Mahmud, R., High, K., & Carbajales-Dale, M. (2020). Life cycle assessment of emerging technologies: A review. *Journal of Industrial Ecology*, 24(1), 52-63. <https://doi.org/10.1111/jieec.12965>
- Piccinno F, Hischier R, Seeger S, Som C (2016) From laboratory to industrial scale: a scale-up framework for chemical processes in life cycle assessment studies *J Cleaner Prod* 135:1085-1097
- Sacchi R et al. (2022) PRospective EnvironMental Impact asSEment (premise): A streamlined approach to producing databases for prospective life cycle assessment using integrated assessment models *Renewable Sustainable Energy Rev* 160:112311
- Saavedra-Rubio, K., Thonemann, N., Crenna, E., Lemoine, B., Caliandro, P., & Laurent, A. (2022). Stepwise guidance for data collection in the life cycle inventory (LCI) phase: Building technology-related LCI blocks. *Journal of Cleaner Production*, 366, 132903. <https://doi.org/10.1016/j.jclepro.2022.132903>
- Steubing B, Mendoza Beltran A, Sacchi R (2023) Conditions for the broad application of prospective life cycle inventory databases *Int J Life Cycle Assess*
- Thonemann, N., Schulte, A., Maga, D., 2020. How to conduct prospective life cycle assessment for emerging technologies? A systematic review and methodological guidance. *Sustainability* 12, 1192–1215.
- Tsoy N, Steubing B, van der Giesen C, Guinée J (2020) Upscaling methods used in ex ante life cycle assessment of emerging technologies: a review *Int J Life Cycle Assess* 25:1680-1692
- van der Hulst MK, Huijbregts MAJ, van Loon N, Theelen M, Kootstra L, Bergesen JD, Hauck M (2020) A systematic approach to assess the environmental impact of emerging technologies: A case study for the GHG footprint of CIGS solar photovoltaic laminate *J Ind Ecol* 24:1234-1249
- Villares, M., Işildar, A., van der Giesen, C., Guinée, J.B., 2017. Does ex ante application enhance the usefulness of LCA? A case study on an emerging technology for metal recovery from e-waste. *Int. J. Life Cycle Assess.* 22, 1618–1633.