PROSPECTIVE ASSESSMENT AND UNCERTAINTY IN LCA FOR TECHNOLOGY DEVELOPMENT

MASSIMO PIZZOL, 08 February 2023

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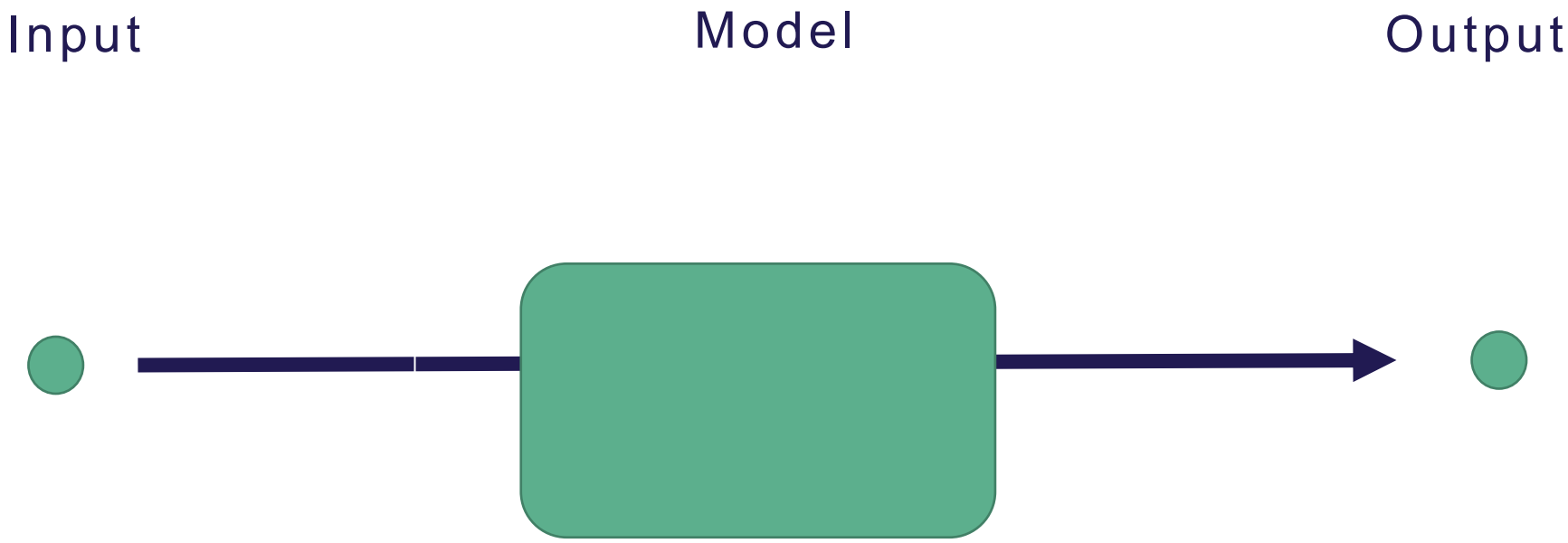
Today

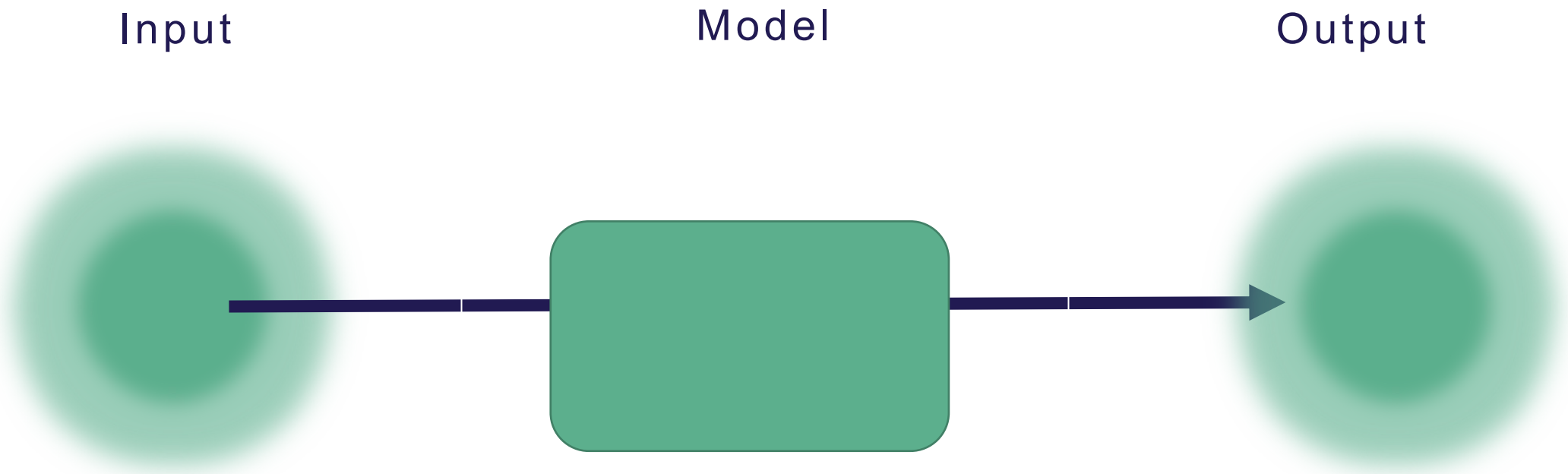
- Uncertainty in LCA, theory and practice
- What is special about LCA of new technologies
- The “uncertainty first” paradigm
- Examples from practice at AAU
- The new vision, skills and mindset

LCA AND UNCERTAINTY

LCA



Uncertainty analysis



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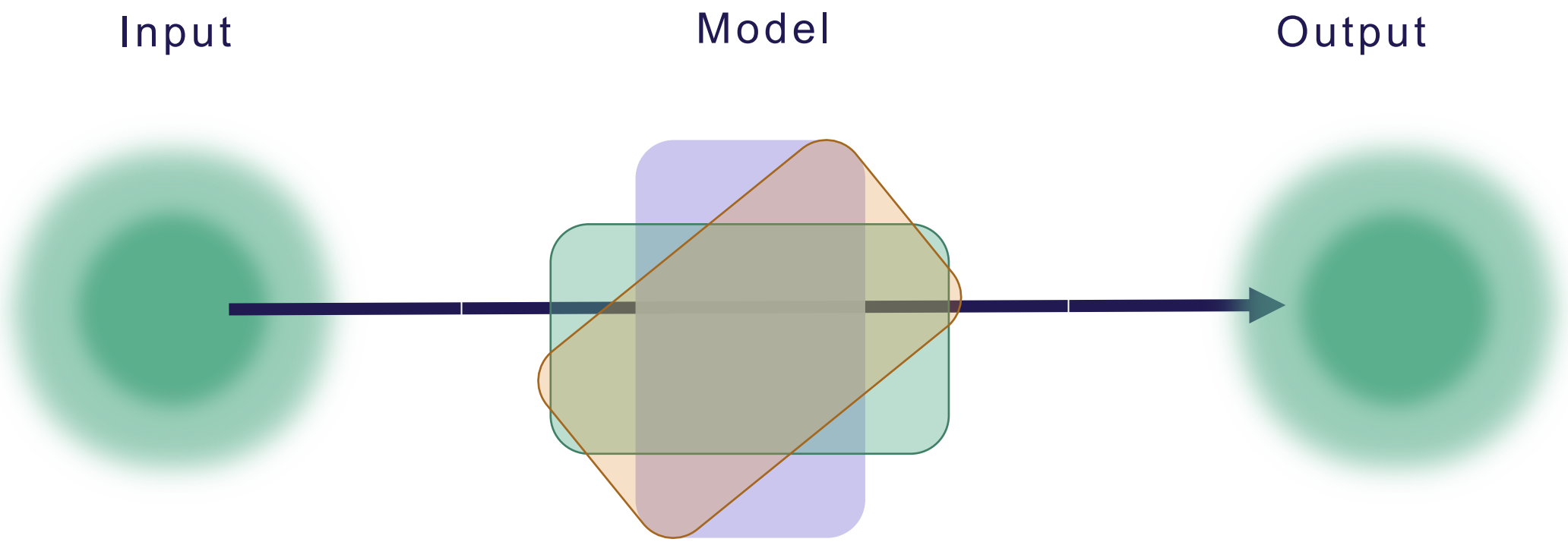
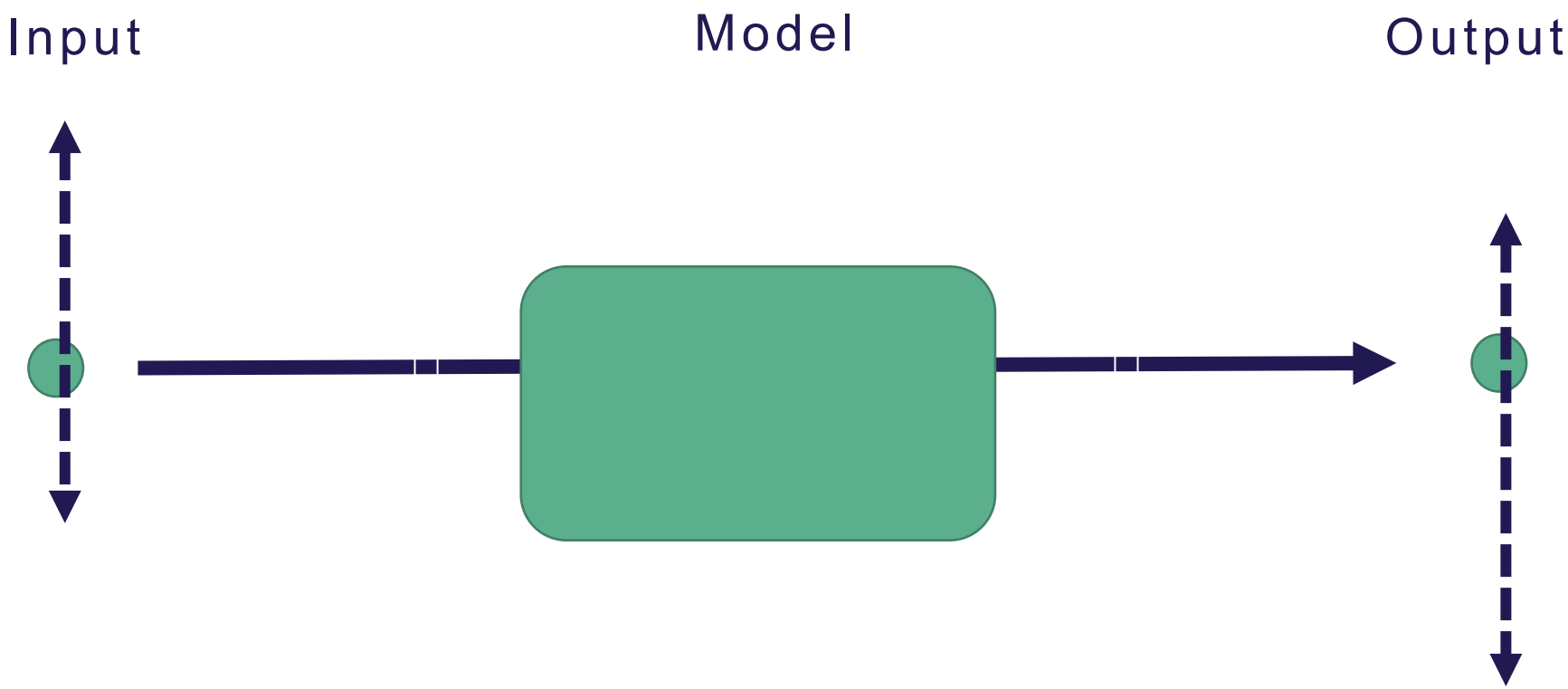
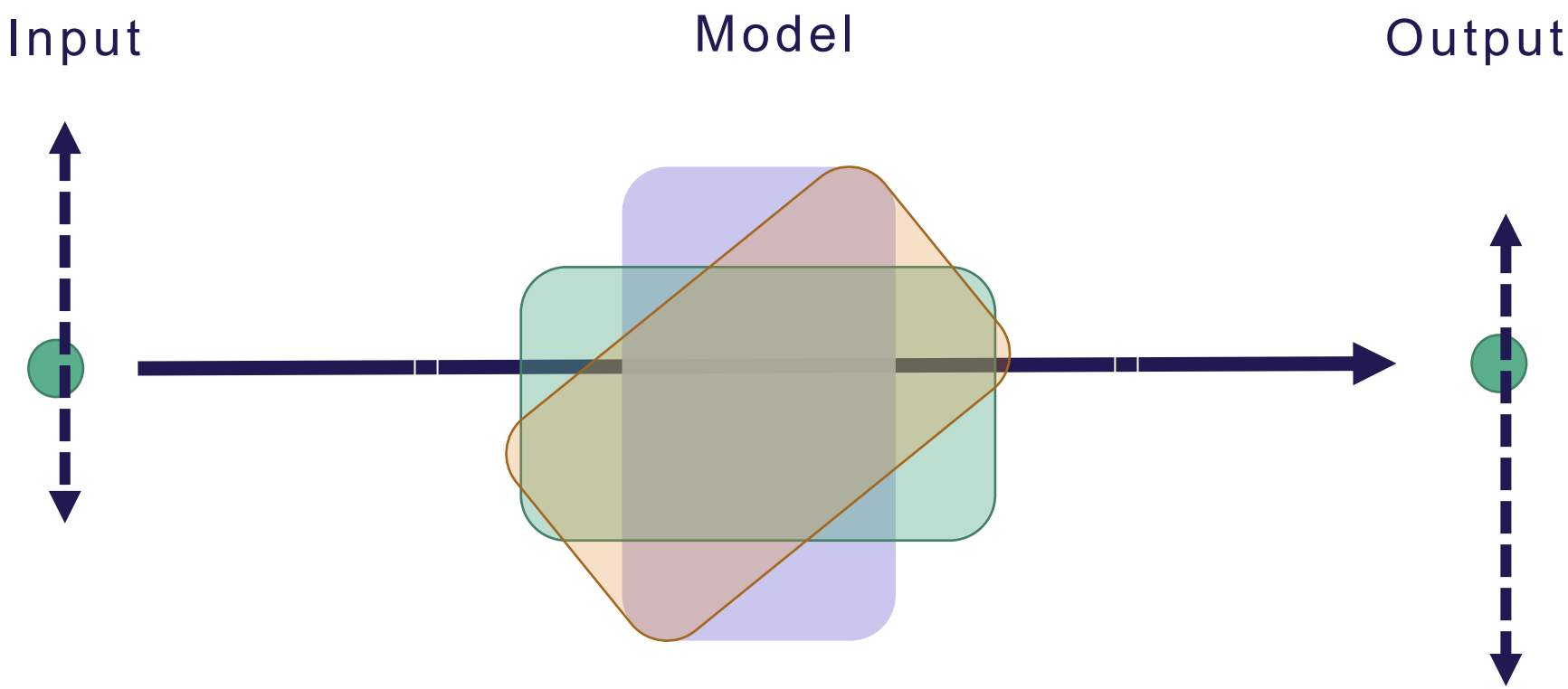


Sensitivity analysis



Sensitivity analysis



Uncertainty, typical questions

- *How sure am I of my LCA results? How wrong can they be?*
- *Is there any data input that might change substantially?*
- *Does the way the model is constructed reflect reality?*
- *Does my study depend on specific conditions?*
- *Did I make any critical assumption or choice in the study?*
- *Am I using old or new data?*
- *How far am I looking into the future?*
- *Is there something I don’t know about the subject of my LCA study?*

Uncertainty in theory

- Nature: epistemic, aleatory
- Location: quantity, model, context

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UNCERTAINTIES IN LCA

How to treat uncertainties in life cycle assessment studies?

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Abstract

Purpose The use of life cycle assessment (LCA) as a decision support tool can be hampered by the numerous uncertainties embedded in the calculation. The treatment of uncertainty is necessary to increase the reliability and credibility of LCA results. The objective is to provide an overview of the methods to identify, characterize, propagate (uncertainty analysis), understand the effects (sensitivity analysis), and communicate uncertainty in order to propose recommendations to a broad public of LCA practitioners.

Methods This work was carried out via a literature review and an analysis of LCA tool functionalities. In order to facilitate the identification of uncertainty, its location within an LCA model was distinguished between quantity (any numerical data), model structure (relationships structure), and context (criteria chosen within the goal and scope of the study). The methods for uncertainty characterization, uncertainty analysis, and sensitivity analysis were classified according to the information provided, their implementation in LCA software, the time and effort required to apply them, and their reliability and validity. This review led to the definition of recommendations on three levels: basic (low efforts with LCA software), intermediate (significant efforts with LCA software), and advanced (significant efforts with non-LCA software).

Results and discussion For the basic recommendations, minimum and maximum values (quantity uncertainty) and alternative scenarios (model structure/context uncertainty) are defined for critical elements in order to estimate the range of results. Result sensitivity is analyzed via one-at-a-time variations (with realistic ranges of quantities) and scenario analyses. Uncertainty should be discussed at least qualitatively in a dedicated paragraph. For the intermediate level, the characterization can be refined with probability distributions and an expert review for scenario definition. Uncertainty analysis can then be performed with the Monte Carlo method for the different scenarios. Quantitative information should appear in inventory tables and result figures. Finally, advanced practitioners can screen uncertainty sources more exhaustively, include correlations, estimate model error with validation data, and perform Latin hypercube sampling and global sensitivity analysis.

Conclusions Through this pedagogic review of the methods and practical recommendations, the authors aim to increase the knowledge of LCA practitioners related to uncertainty and facilitate the application of treatment techniques. To continue in this direction, further research questions should be investigated (e.g., on the implementation of fuzzy logic and model uncertainty characterization) and the developers of databases, LCIA methods, and software tools should invest efforts in better implementing and treating uncertainty in LCA.

Keywords Communication · LCA software · Life cycle assessment · Sensitivity analysis · Uncertainty analysis · Uncertainty characterization

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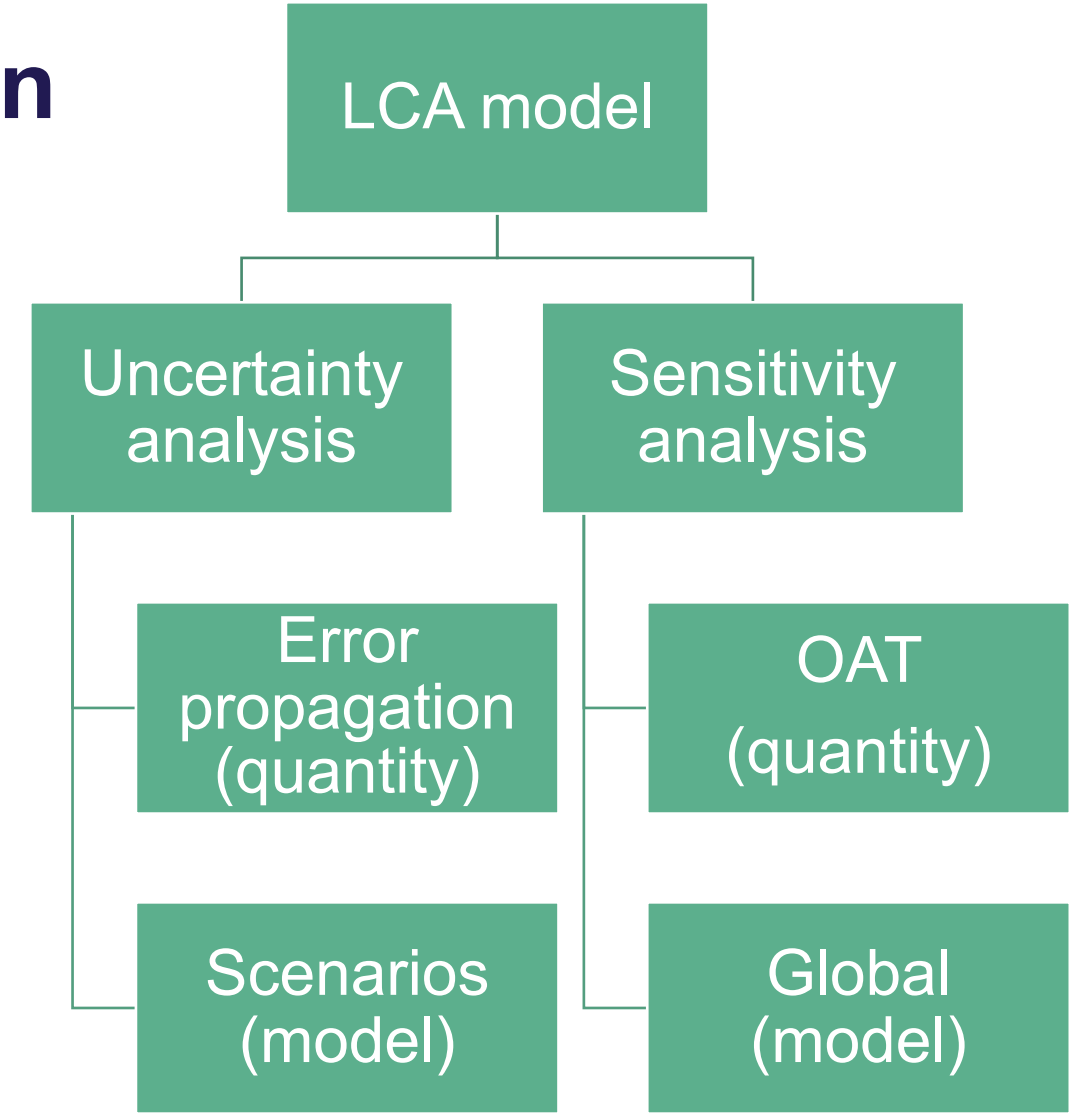
1 Introduction

Life cycle assessment (LCA) methodology is now a recognized and widespread approach for evaluating the environmental impacts of products, technologies, and policies. The use of LCA as a decision support tool can, however, be hampered by the numerous uncertainties embedded in the calculation, as well as the fact that the results cannot be verified, validated, or confirmed due to many constraints (technical, conceptual, legal,

Uncertainty in practice



A toolbox…

PROSPECTIVE ASSESMENT OF TECHNOLOGIES

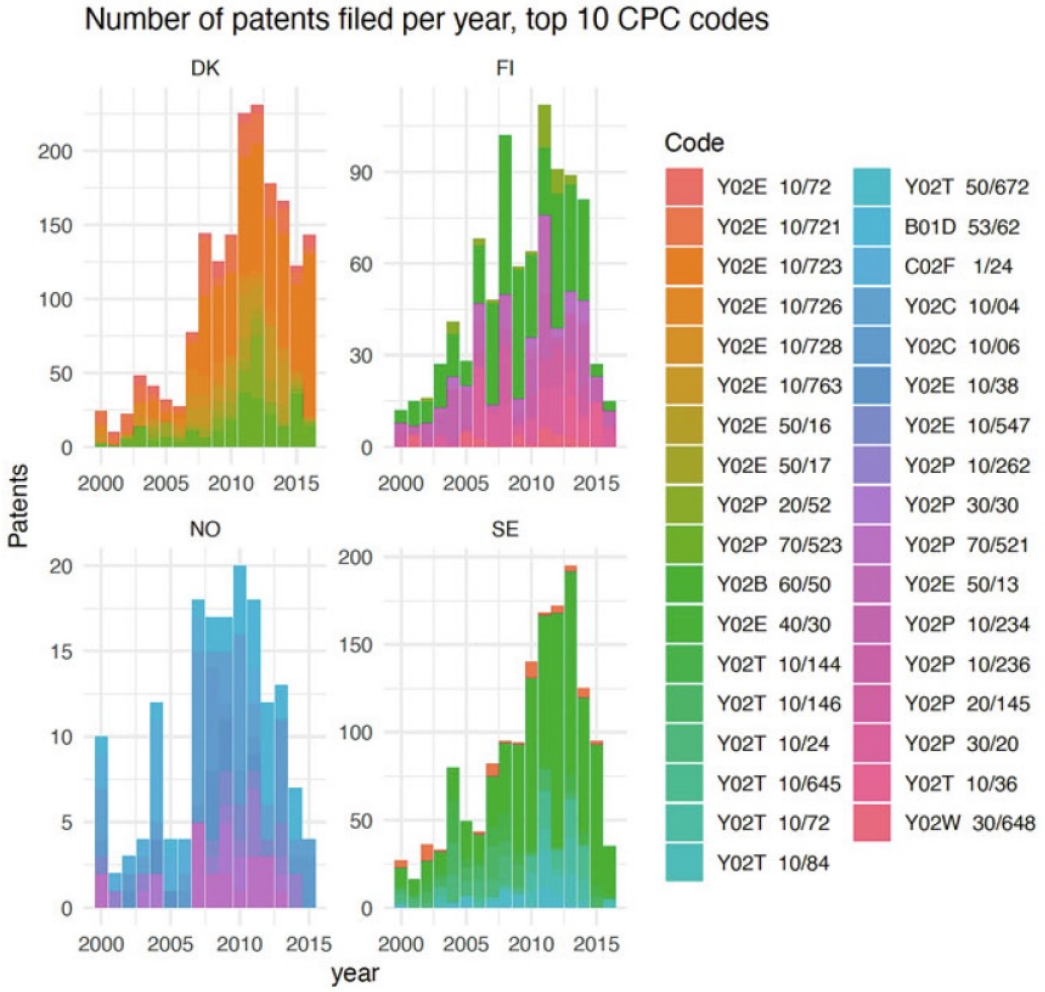
Multiple meanings of ”Prospective”

- Attributional LCA as retrospective: ”traces back” impacts (in the past)
- Consequential LCA as prospective: Models consequences of decisions (in the future).

vs

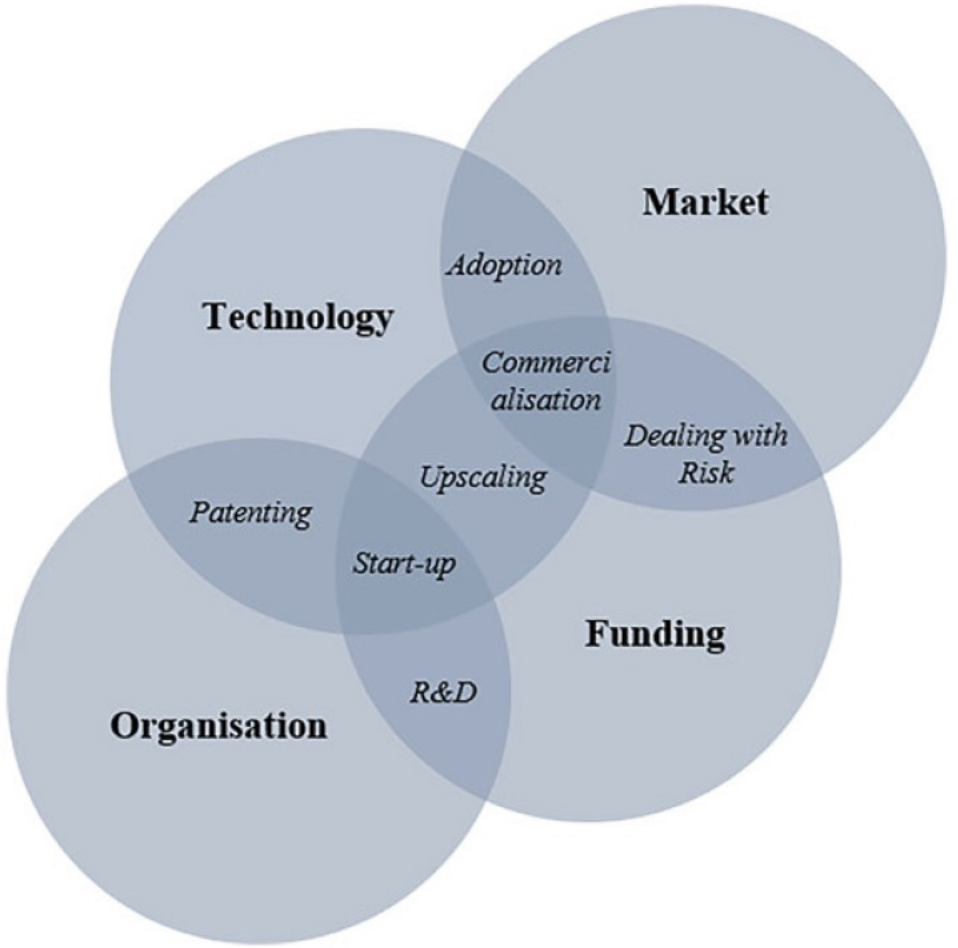
- “Prospective” as “ex-ante”. Anticipate impacts of technologies that are emerging and not yet mature/at scale/marketed. Focus on the uncertainties in the assessment process.

New green technology



Green Tech for Green Growth? Insights from Nordic Environmental Innovation

Massimo Pizzol and Mikael Skou Andersen



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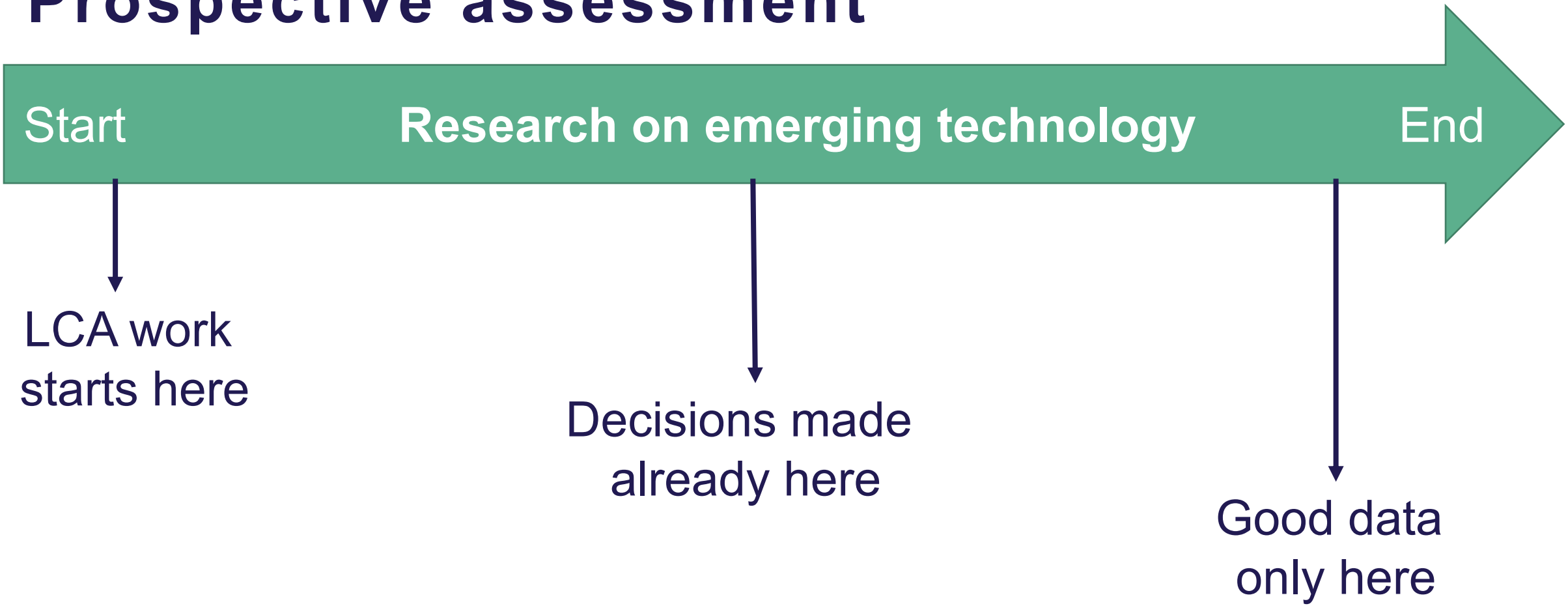
V. Prokop et al. (eds.), *Business Models for the Circular Economy*, Sustainability and Innovation, https://doi.org/10.1007/978-3-031-08313-6_8

Forecasting green technology

- Pilot scale ≠ full scale
- Not even the developers know how & when (time to market usually underestimated)
- Future context unclear (resource availability? Energy mix?)

Photo by ThisisEngineering RAEng on Unsplash

Prospective assessment



LCA of emerging tech
= predict the future (which is uncertain)
= dealing with uncertainty

Uncertainty in prospective assessment

- We just need more data….. → There is no more data
- Variability vs. uncertainty… → In practice, both irreducible unknowns
- Scenarios have no uncertainty…→ Blurry boundary scenarios / results

Photo by Katie Moum on Unsplash

A paradigm shift

Current paradigm:

Focus on the single LCA numerical result.

Looking for the “right” number.

Narrowing scope.

Uncertainty last (“nice to have”).

Think how to model then think about uncertainty.

“Uncertainty first” paradigm:

Focus on assumptions and data ranges.

There is a “cloud” of numbers.

Expanding scope.

Separate signal from noise.

Think uncertainty then think how to model.

Examples from AAU research

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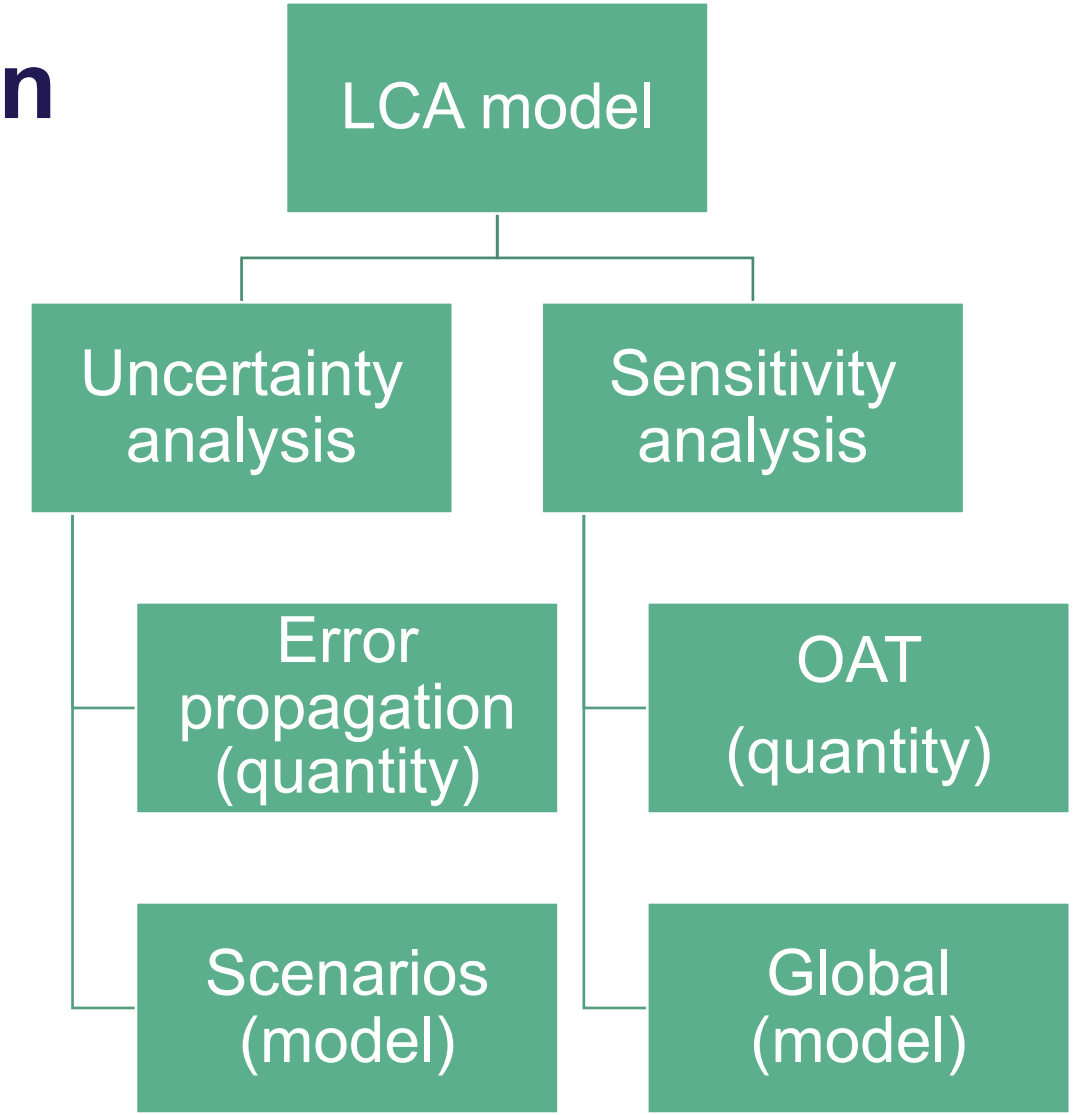
Uncertainty in practice

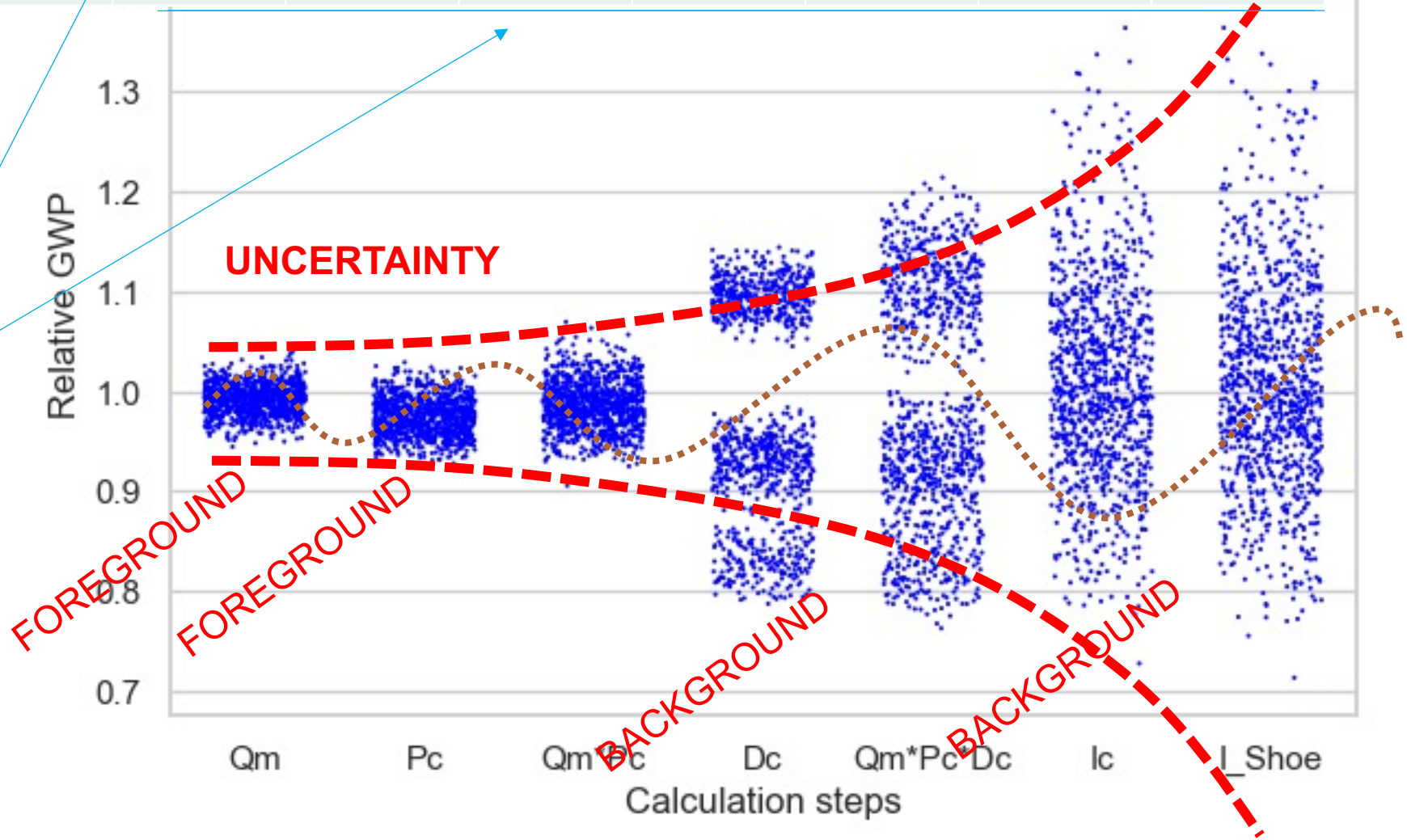


A toolbox…

Chemicals in footwear

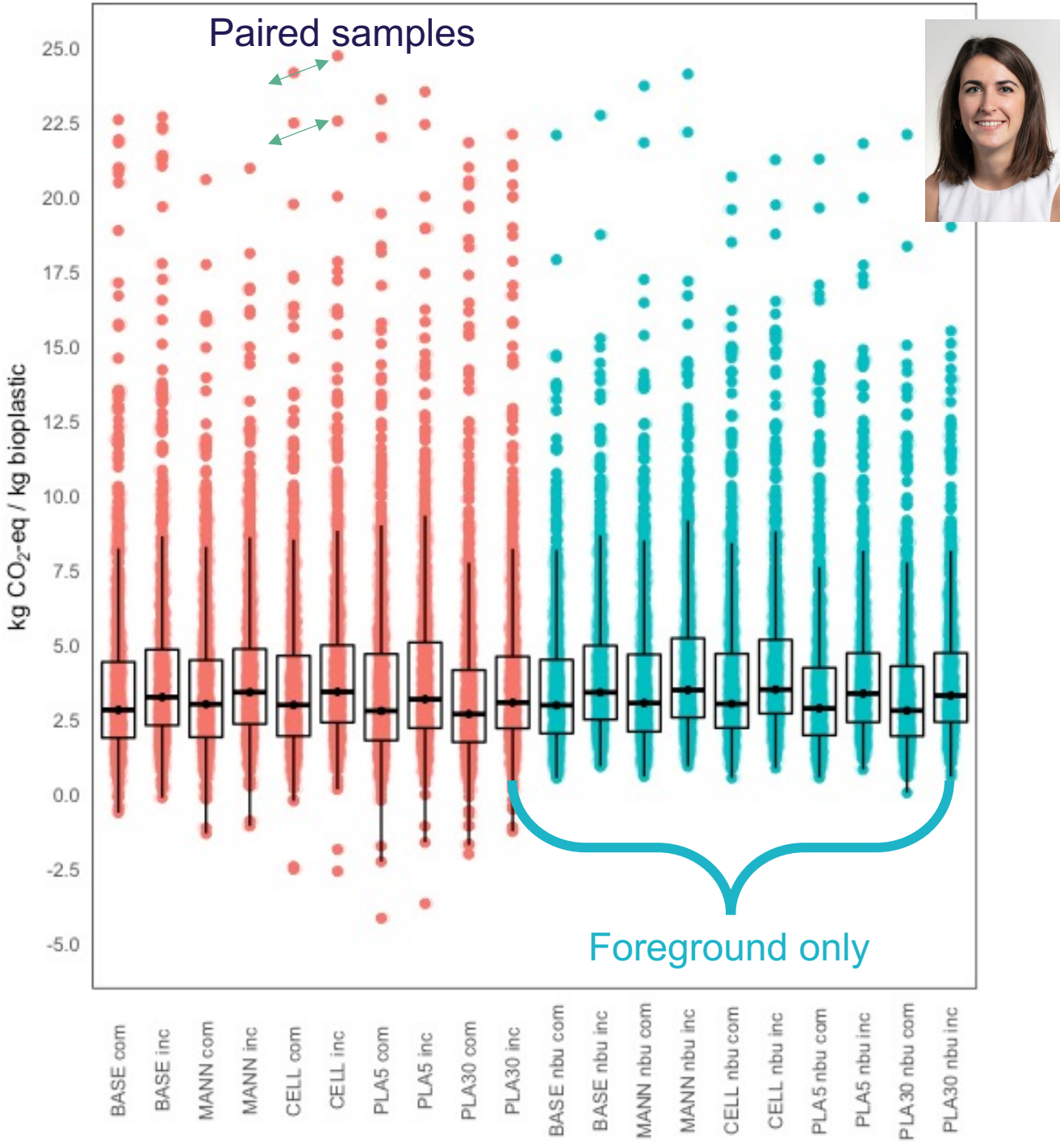
- Separate effect of each modelling choice
- Central value
- Increasing spread
- Database uncertainty high

mean	1.025	0.995	0.987	0.970	0.983	1.001	1.008
std	0.016	0.018	0.023	0.110	0.117	0.109	0.112



Biobased-plastic from seaweed

- Pedigree matrix + Monte Carlo
- Remove effect of background system
- Foreground uncertainty still high
- Role of:
  - pilot scale data (very uncertain)
  - pedigree procedure (artificial)
  - system structure (impacts in foregr.)



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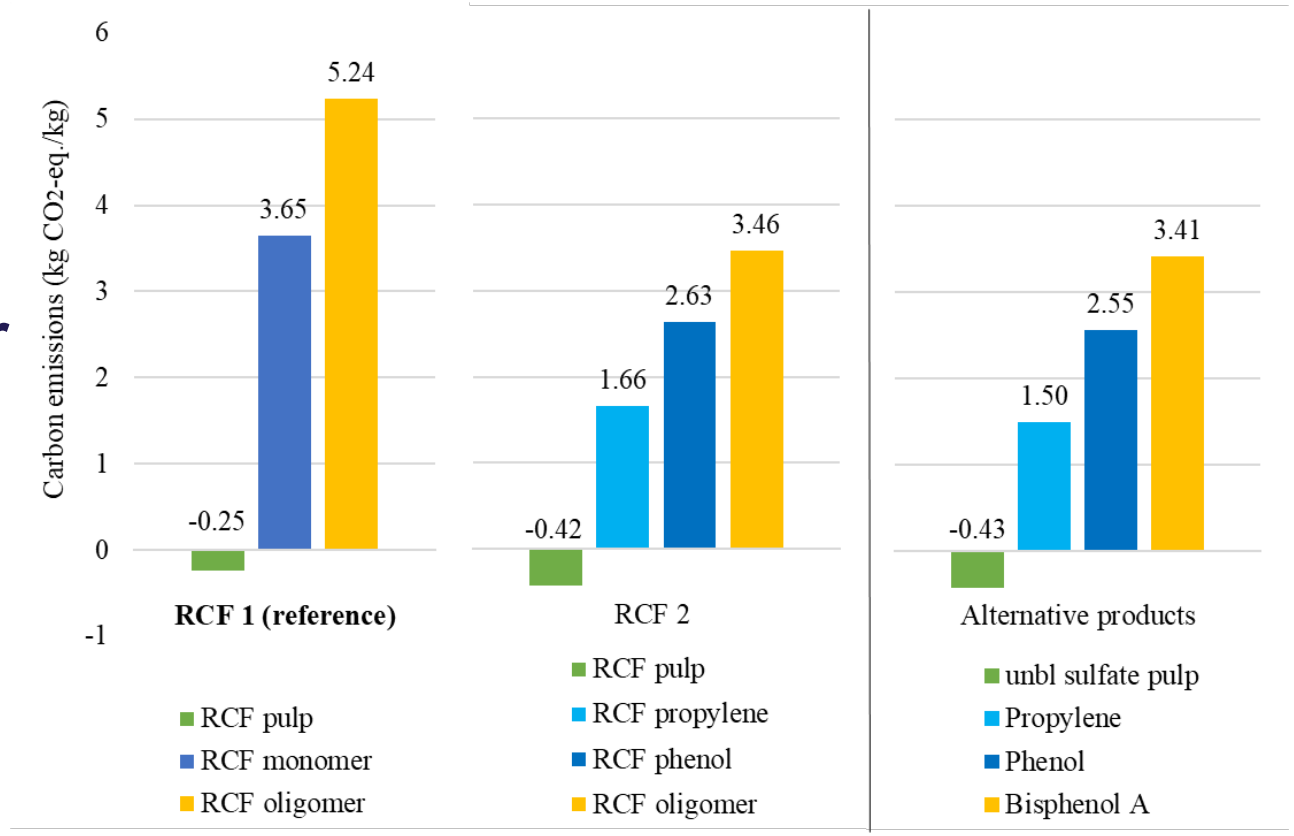
Ayala, Thomsen, Pizzol. Life Cycle Assessment of pilot scale production of seaweed-based bioplastic (submitted)

Lignin valorization in biorefinery

- Several novel high-value products (pulp, monomer, and oligomer)
- Main and co-product **not clear nor static** → analysis from multiple functional options
- Sensitivity analysis on what will be replaced in future market

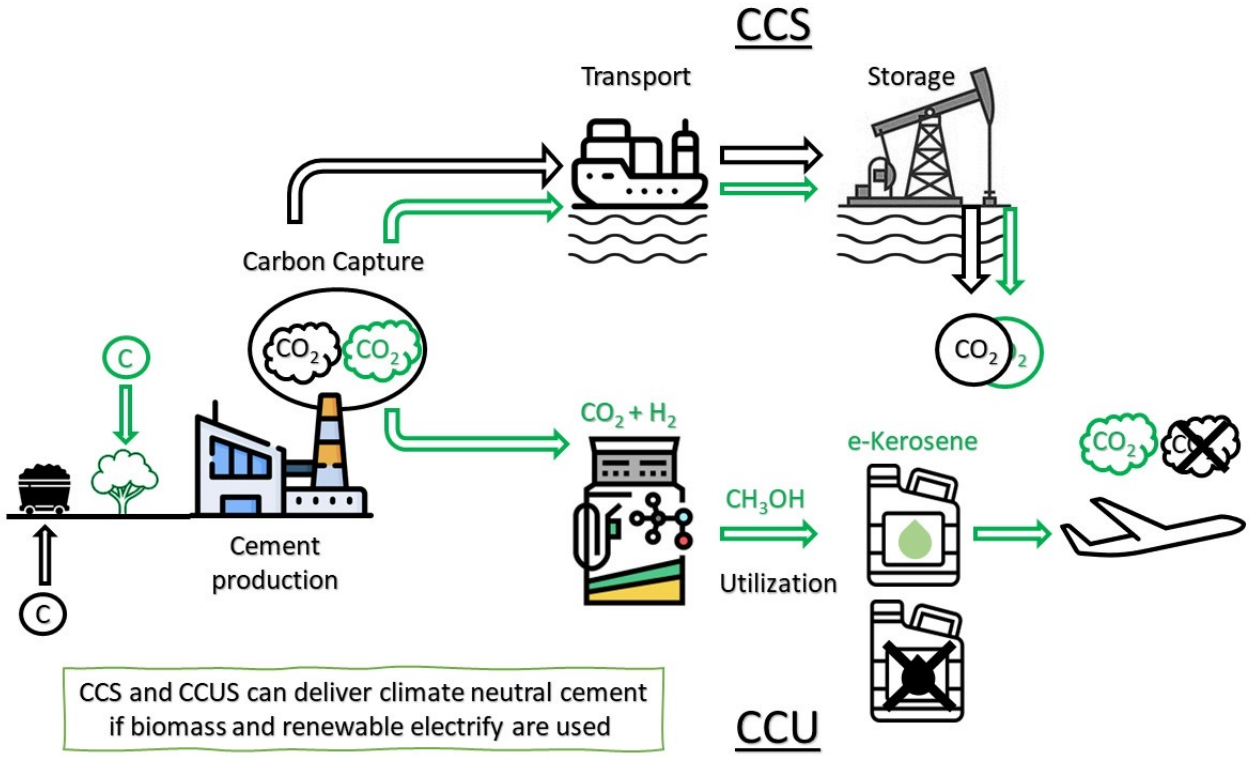


Carbon capture in cement production

Explorative technological scenarios

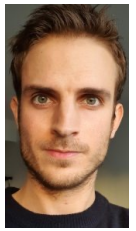
- Business as Usual, CCUS, CCS
- Year 2020, 2030 and 2050
- Heat source (El/gas boiler, heat pump)
- Use of alternative fuel in diff %
- Prospective background system

Obtain distribution of results around neutrality target, isolate desired conditions

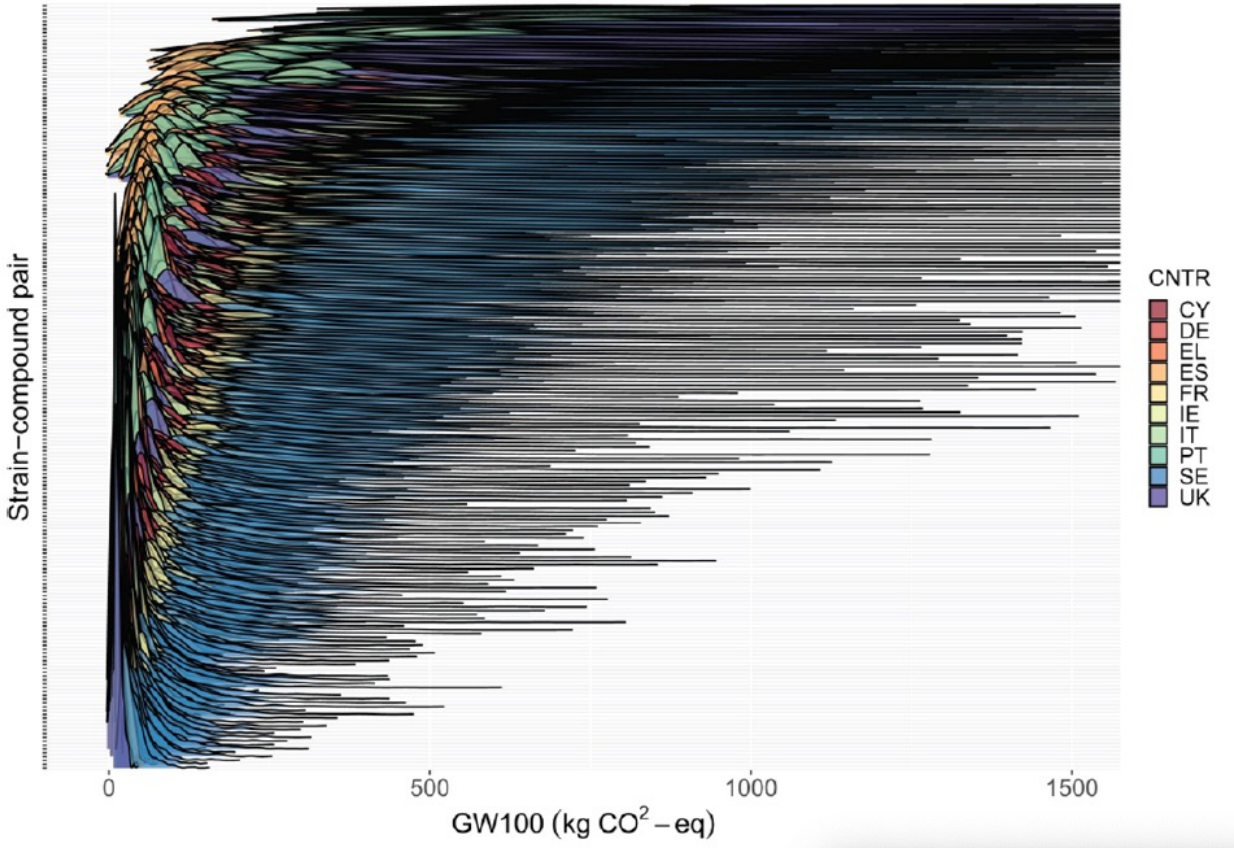


Davila, Sacchi, Pizzol. Preconditions for CCUS to deliver climate neutrality in cement production (submitted)

High value compounds from microalgae



- How to model the production of a molecule that has not been found yet?
- Uncertainty is **multi-dimensional** (geographical, technological, biological)
- Parametrized models, large simulation, exploring the uncertainty space to find combinations that fit conditional success



Jouannais, P. *et al.* (2022) 'Stochastic LCA Model of Upscaling the Production of Microalgal Compounds', *Environmental Science & Technology*.
Jouannais, P. and Pizzol, M. (2022) 'Stochastic Ex-Ante LCA under Multidimensional Uncertainty : Anticipating the Production of Undiscovered Microalgal Compounds in Europe'.

Concluding remarks

Modelling for uncertainty

We can make a lot of LCA models…but can we make good ones?

- Less focus on results, more focus on process
- *There is no 'number-answer'* *
- Explorative attitude, embrace the uncertainty space
- Assumption-testing
- Modelling ethics rather than standardisation

*cit. Andrea Saltelli cit. Anthony Fauci

New skillset and new mindset

When LCA calculation can be automatized…

…focus on simulation design and statistical data analysis *(just the sufficient amount of results to explore uncertainty…)*

When the (future) reality is difficult to describe univocally…

…focus on scenario design via co-creation with stakehoders *(LCA practitioner does not decide alone…)*

Wrap-up

- Prospective assessment of technology: it is about uncertainty
- Think uncertainty first
- Use the entire uncertainty-toolbox
- Tailor vision, skills, and mindset

Upcoming work

- Low-TRL case study on lignin valorisation
- Guide on uncertainty in LCA, focus on bio-based systems
- Stay updated: alignedproject.eu

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This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement N° 101059430

Thank you

- Prospective assessment of technology: it is about uncertainty
- Think uncertainty first
- Use the entire uncertainty-toolbox
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