CIRAIG™

Interuniversity Research Centre for the
Life Cycle of Products, Processes and Services

Week 11 - Uncertainties in LCA Interpretation (Part II)

Course material developed by Laure Patouillard

POLYTECHNIQUE MONTRÉAL

WORLD-CLASS ENGINEERING

Overview of course

1. Interpretations of LCA results
   - **Identification of significant issues / Contribution Analysis**
   - **Verification (completeness, sensitivity, consistency)**
   - **Evaluation of data quality**
2. The critical review process
3. Uncertainties in LCA
4. Concepts applied - openLCA

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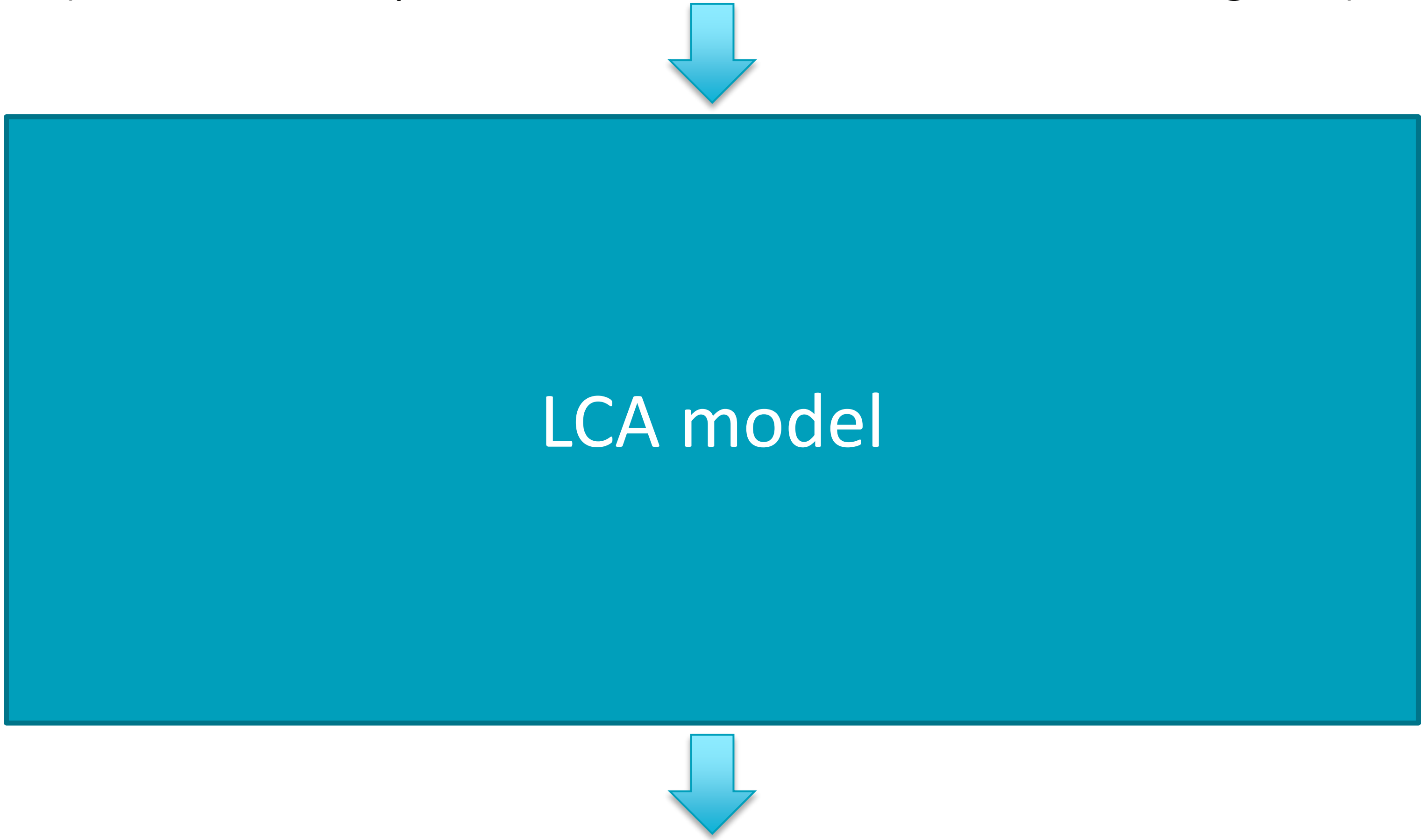
Summary "uncertainty"

1. Introduction
2. Sources of uncertainties LCA
3. The measurement of uncertainty LCA
4. Reduction or control of uncertainty LCA

LCA = Model

<u>Product information</u>

(Lists of the components, details of use and manufacturing, etc.)

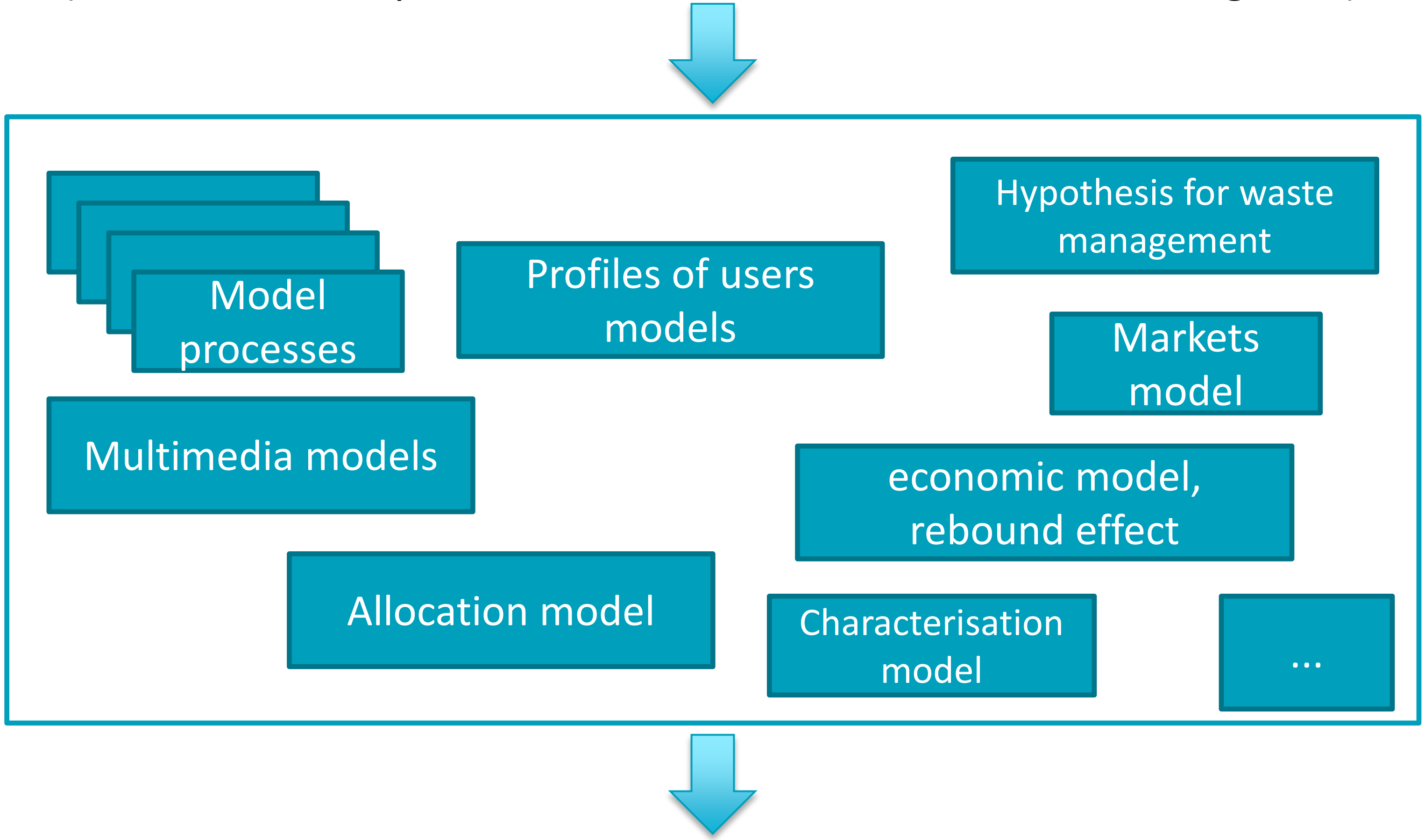


Impact indicator of life cycle

LCA = collection models

<u>Product information</u>

(Lists of the components, details of use and manufacturing, etc.)



Impact indicator of life cycle

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LCA and validation

Validation:

- Comparison between LCA model and a true system

Impossible to validate an LCA model:

- Impossible to isolate the model
- The concept of ”product system" is a mental construct (conceptual model)

It is still possible to validate the elements of the model individually

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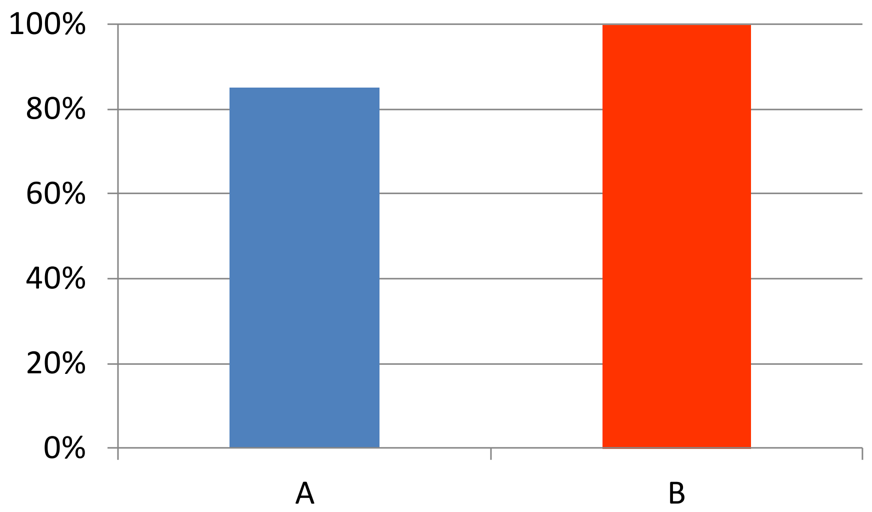
LCA results: Deterministic representation

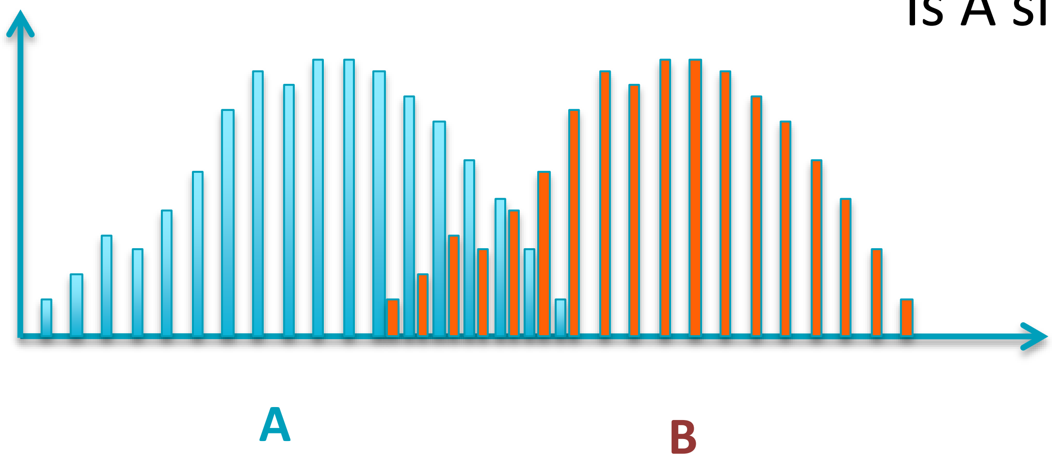
A = 0.375 DALY / UF
B = 0.441 DALY / UF

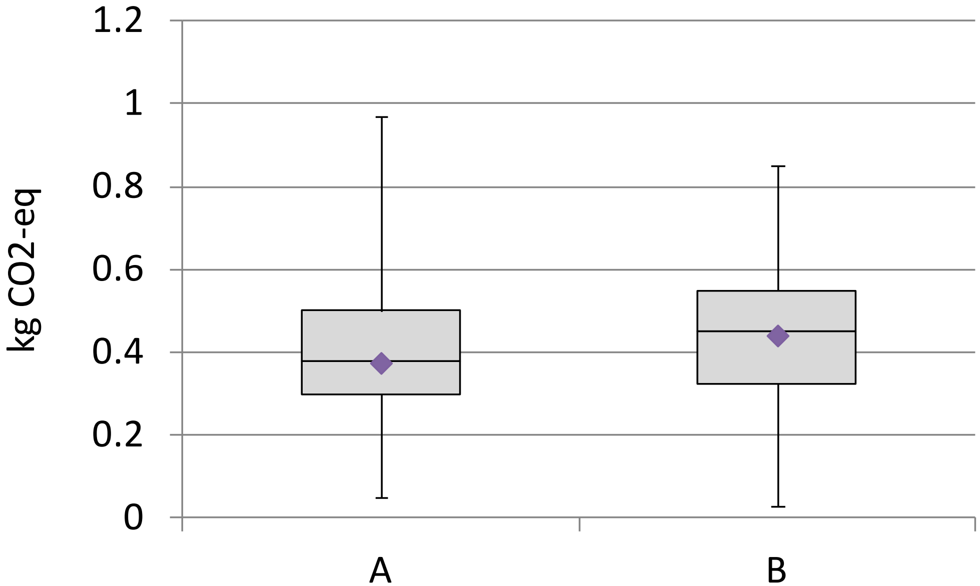


Is A significantly better than B?

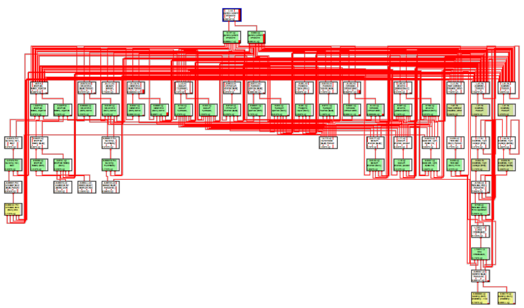
LCA results: Probabilistic representation

Is A significantly better than B?





What is uncertainty?



Uncertainty

LCA model

Reality

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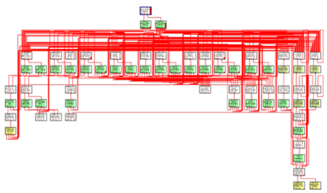
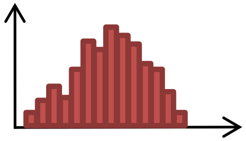
What is the objective of considering uncertainty in LCA?



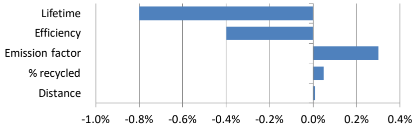
Uncertainty

1. Reveal uncertainty



Uncertainty analysis

2. Understand origin of uncertainty



Sensitivity analysis

3. Reduce uncertainty

Uncertainty

Improve knowledge

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Why the interest in the uncertainties of LCA?

- Support decision making by giving available information on the credibility of LCA results
- Plan the reduction of uncertainty in a structured way
- Improve transparency, to avoid exaggerating the credibility of the results

Note: Ignoring or hiding the uncertainties could lead to situations where two "valid" studies lead to opposite conclusions. It may discredit LCA.

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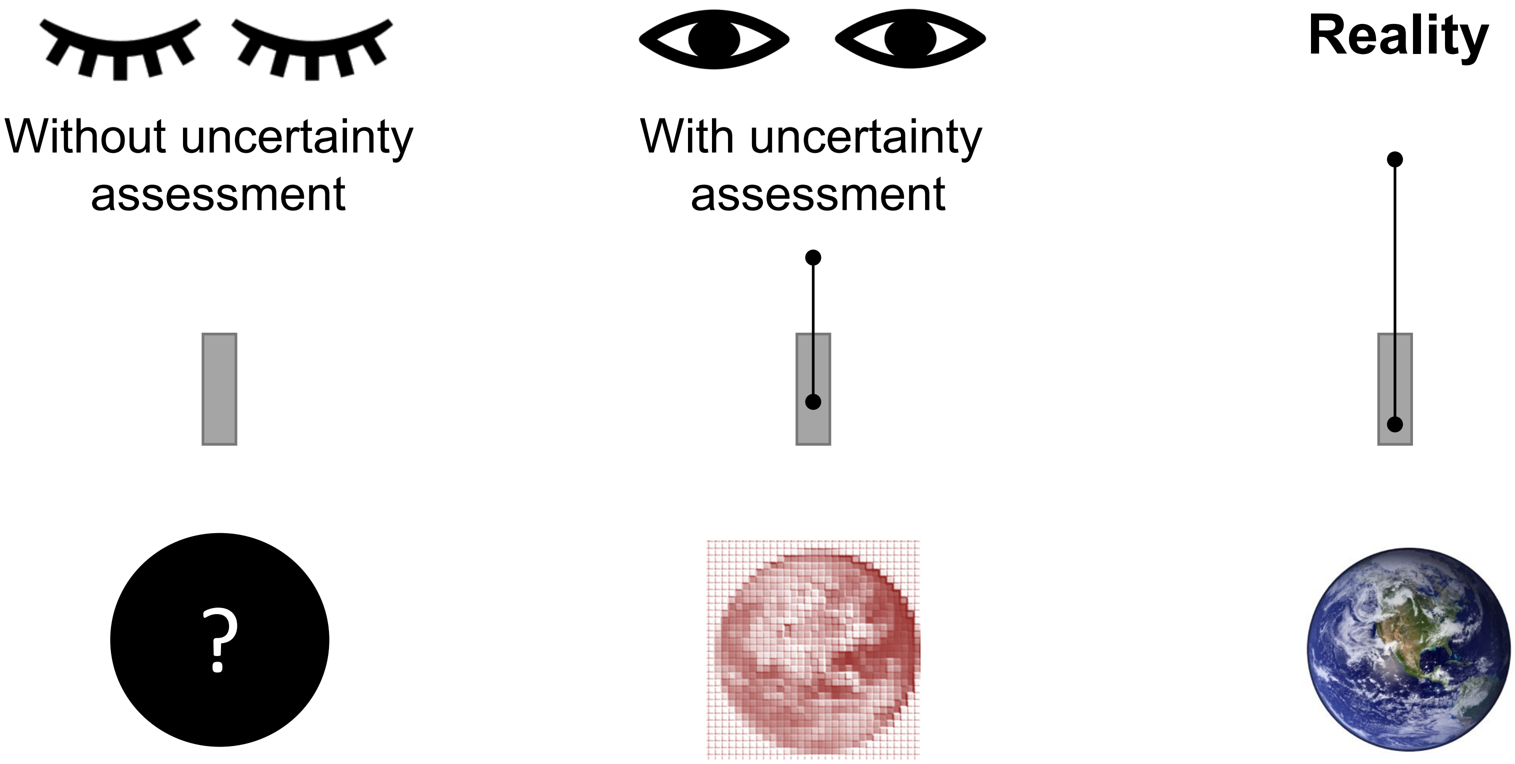
Not showing uncertainty does not mean that uncertainty does not exist!



Summary "uncertainty"

1. Introduction
2. Types and sources of uncertainty in LCA
3. The measure of uncertainty in LCA
4. Reduction or control of the uncertainty in LCA

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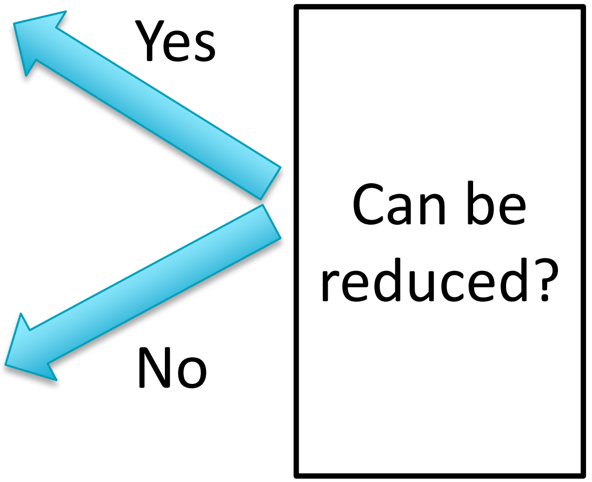
Distinction by uncertainty type: Uncertainty vs. variability

- Uncertainty (epistemic uncertainty):
  - **Lack of knowledge about the real value of a quantity e.g.:**
    - Inaccurate measurement, lack of information or irrelevant information, hypotheses in the models...
- Variability (stochastic uncertainty):
  - **inherent variations in the real world, e.g.:**
    - profiles of the use of a product, lifetime of a product, emissions of a factory, climatological parameters, human weight, breathing rate...



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Distinction by source: Variability

- Temporal variability
- Spatial variability
- Source / object variability:
  - **variations between each individual system related to operations or characteristics**
    - E.g. two plants producing electricity from the same technology does not necessarily have the same individual returns

(Huijbregtset al. 2003)

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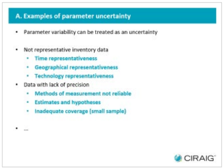
Distinction **by source**: Uncertainty

A. Uncertainty related to the parameters :

- **associated with the incomplete knowledge of the real value a parameter**



A. Examples of parameter uncertainty

- Parameter variability can be treated as an uncertainty
- Not representative inventory data
  - Time representativeness
  - Geographical representativeness
  - Technology representativeness
- Data with lack of precision
  - Methods of measurement not reliable
  - Estimates and hypotheses
  - Inadequate coverage (small sample)
- …

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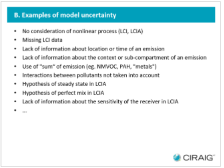
B. Uncertainty related to the models :

- **associated with the simplifications (unavoidable when creating a model) → introduces uncertainty in the predictions of the models.**



B. Examples of model uncertainty

- No consideration of nonlinear process (LCI, LCIA)
- Missing LCI data
- Lack of information about location or time of an emission
- Lack of information about the context or sub-compartment of an emission
- Use of "sum" of emission (eg. NMVOC, PAH, "metals")
- Interactions between pollutants not taken into account
- Hypothesis of steady state in LCIA
- Hypothesis of perfect mix in LCIA
- Lack of information about the sensitivity of the receiver in LCIA
- …

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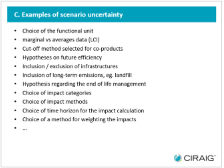
C. Uncertainty related to the scenarios :

- **associated with the choice of normative choices during the elaboration of the LCA model**



C. Examples of scenario uncertainty

- Choice of the functional unit
- marginal vs averages data (LCI)
- Cut-off method selected for co-products
- Hypotheses on future efficiency
- Inclusion / exclusion of infrastructures
- Inclusion of long-term emissions, eg. landfill
- Hypothesis regarding the end of life management
- Choice of impact categories
- Choice of impact methods
- Choice of time horizon for the impact calculation
- Choice of a method for weighting the impacts
- …

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(Huijbregtset al. 2003)

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A. Examples of parameter uncertainty

- Parameter variability can be treated as an uncertainty
- Not representative inventory data
  - **Time representativeness**
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- Data with lack of precision
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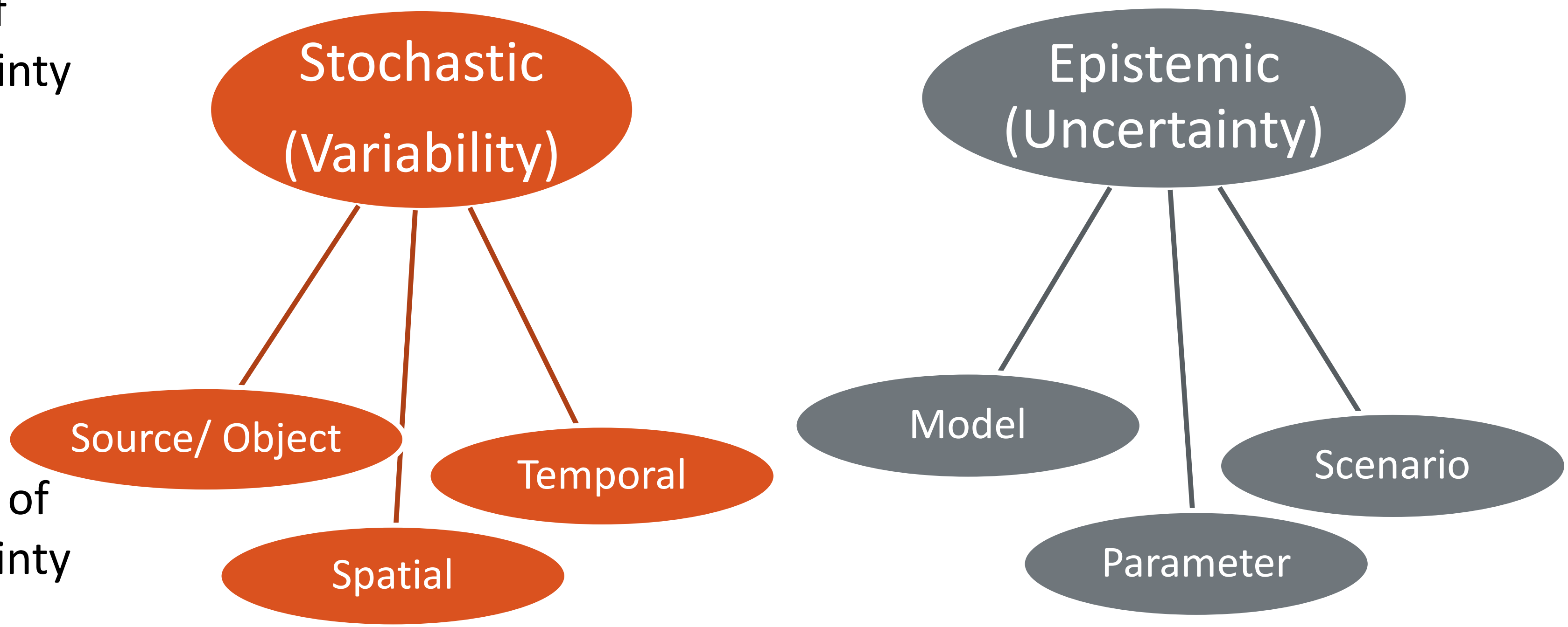
- ...

In summary

Types of uncertainty

Sources of uncertainty



Cannot be reduced

Can be reduced

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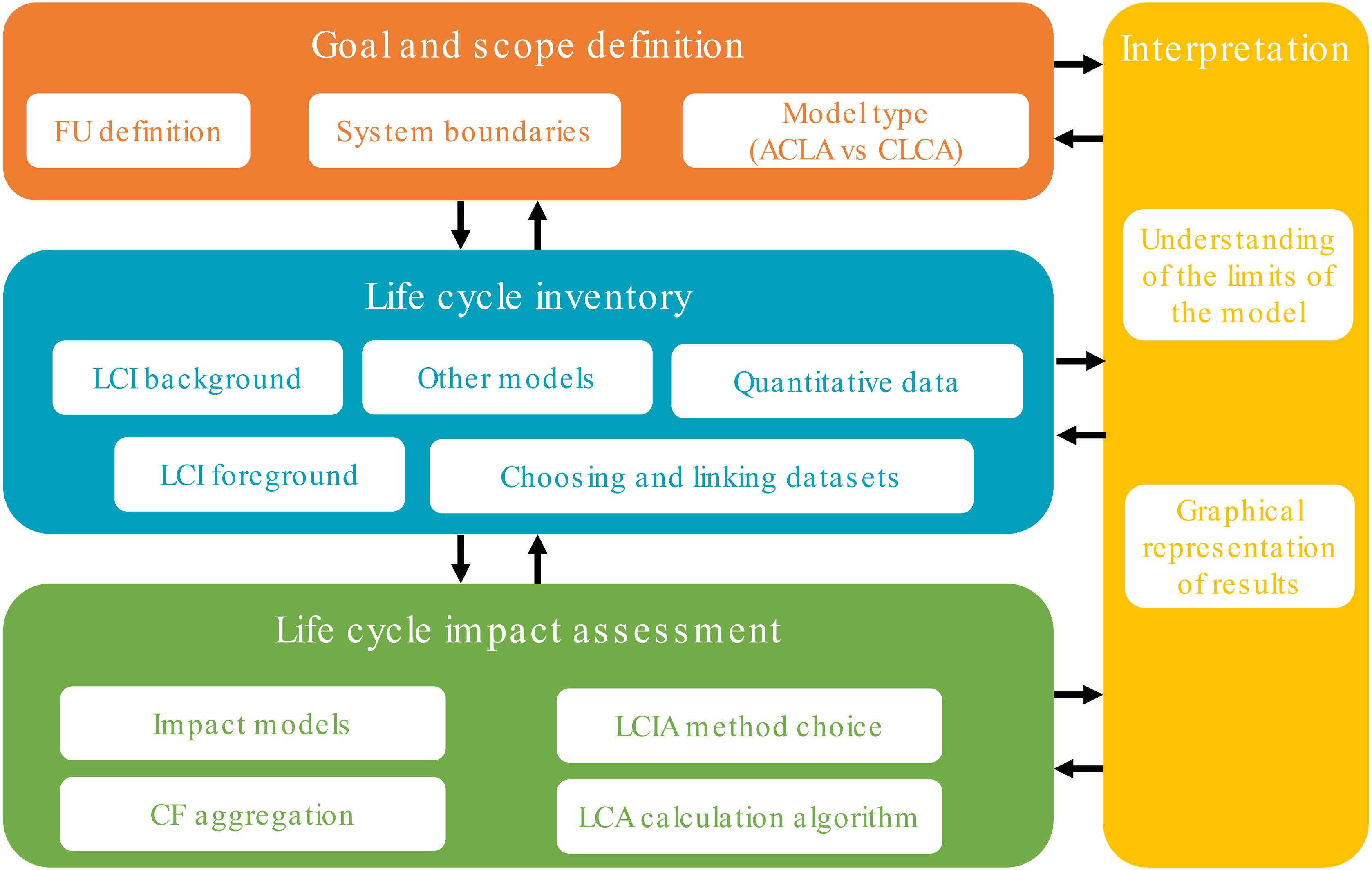
What are the sources of uncertainty in LCA?



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Summary "uncertainty"

1. Introduction
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4. Reduction or control of the uncertainty in LCA

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Measuring (and managing) of uncertainties in LCA

- ISO 14044 and uncertainties
- Sensitivity analysis
- Uncertainty analysis

Uncertainty and ISO 14044

- ISO 14044 specified:
  - **That we must provide information on "the uncertainty of information, eg data, models and assumptions."**
  - **That an " Analysis of the results in terms of sensitivity and uncertainty <u>must be done</u> for the studies used in comparative assertions intended to be disclosed to the public. "**

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Uncertainty analysis vs sensitivity analysis

Evaluation of uncertainty in LCA has two main Goals :

- **Uncertainty analysis: inform about the degree of certainty of conclusions of a study taken into account**
  - The propagation of uncertainty of all of the data input

- **Sensitivity analysis : estimates the effects on the results of each individual choice regarding the methods and input data**
  - Explain the effect of a choice on the results of a study
  - Evaluation of the effect of the uncertainty of an input data on the uncertainty of the results

Both approaches are complementary!

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Uncertainty vs sensitivity analysis - Definitions ISO 14044

- **Uncertainty analysis :**
  - "Systematic procedure to quantify the uncertainty introduced in the results of a life cycle inventory by the cumulative effects of the inaccuracy of the model, uncertainty about incoming and variability of data"

- **Sensitivity analysis:**
  - "Systematic procedure to estimate the effects on the results of a study of choices regarding methods and data"

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Uncertainty analysis - different approaches

- **Qualitative approach**
  - **Describe at least qualitatively what are your main sources of uncertainty and how it may affect your results**
  - Rules of thumb

- **Quantitative approach**

Input data → Propagation → Results

- Input data
  - Estimation of PDF
  - Pedigree approach
- Propagation
  - Monte Carlo, analytic method,...
- Results
  - Histogram, Confidence intervals,...

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Uncertainty analysis - Quantitative approach

"[...] quantify the uncertainty introduced [...] by the cumulative effects of the inaccuracy of the model, uncertainty on inputs and data variability "

- General approach:
  1. **Estimate the uncertainty of individual parameters (input data)**
  2. **Cumulate the uncertainty to the final results (propagation)**
  3. **Communicate the results**

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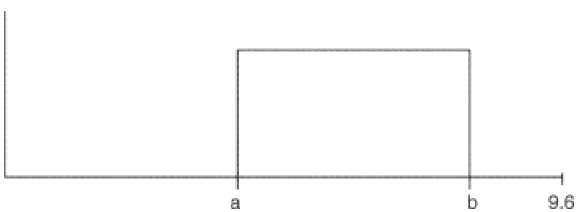
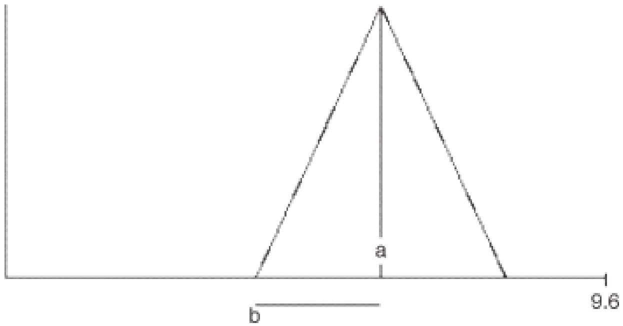
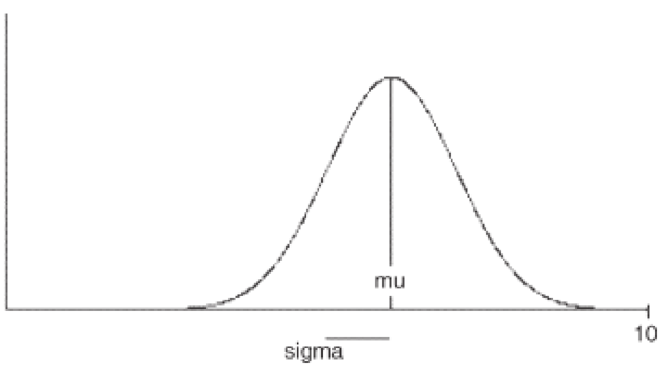
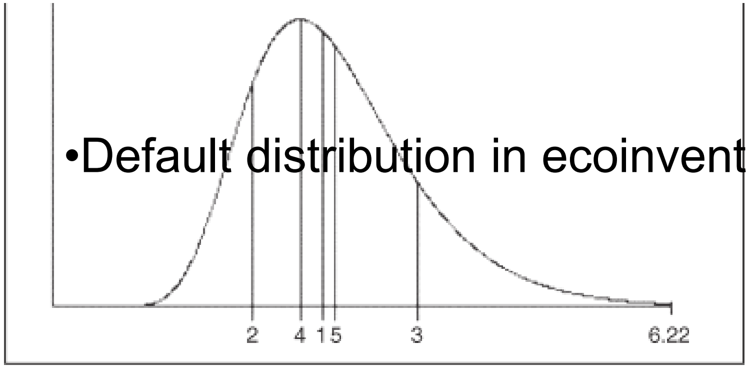
Estimate uncertainty of individual parameters

- Two important aspects:
  - **To choose the type of the Probability Density Function(PDF)**
  - **Estimate the PDF of parameters**









•Default distribution in ecoinvent

Fig. 4: The probability density function of the lognormal distribution with parameters ξ=1 and ϕ=0.3

Estimated settings PDFs

- Two important aspects:
  - **To choose the type of the Probability Density Function(PDF)**
  - **Estimate the PDF of parameters**
    - Statistical analysis, if possible
      - maximum likelihood, moments method, …
    - If not:
      - estimate using expert judgment
      - Default estimates
      - Pedigree approach

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Pedigree approach

- used to estimate the uncertainties of inventory flow

- Approach:
  - **Attribute a "Basic uncertainty"**
    - Based on a statistical analysis of available data, OR
    - using default values
  - **Additional uncertainty to account for imperfection in the data**
    - Reliability (method to obtain the data)
    - Completeness (sample size)
    - Temporal representativeness
    - Geographical representativeness
    - Technological representativeness

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Pedigree approach: Empirically based uncertainty factors

Table 6 Summary of tentative uncertainty factors for all pedigree matrix indicators, as GSD

Indicator score	1	2	3	4	5
Reliability	1	1.54[a]	1.61	1.69	(n.a.)
Completeness	1	1.03	1.04	1.08	(n.a.)
Temporal correlation	1	1.03	1.10	1.19	1.29
Geographical correlation	1	1.04	1.08	1.11	(n.a.)
Further technological correlation	1	1.18	1.65	2.08	2.80

[a] Interim

Ciroth, A., Muller, S., Weidema, B., & Lesage, P. (2016). Empirically based uncertainty factors for the pedigree matrix in ecoinvent. *International Journal of Life Cycle Assessment*, *21*(9), 1338–1348. https://doi.org/10.1007/S11367-013-0670-5/TABLES/6

Table 1 Ecoinvent 3.0 pedigree matrix

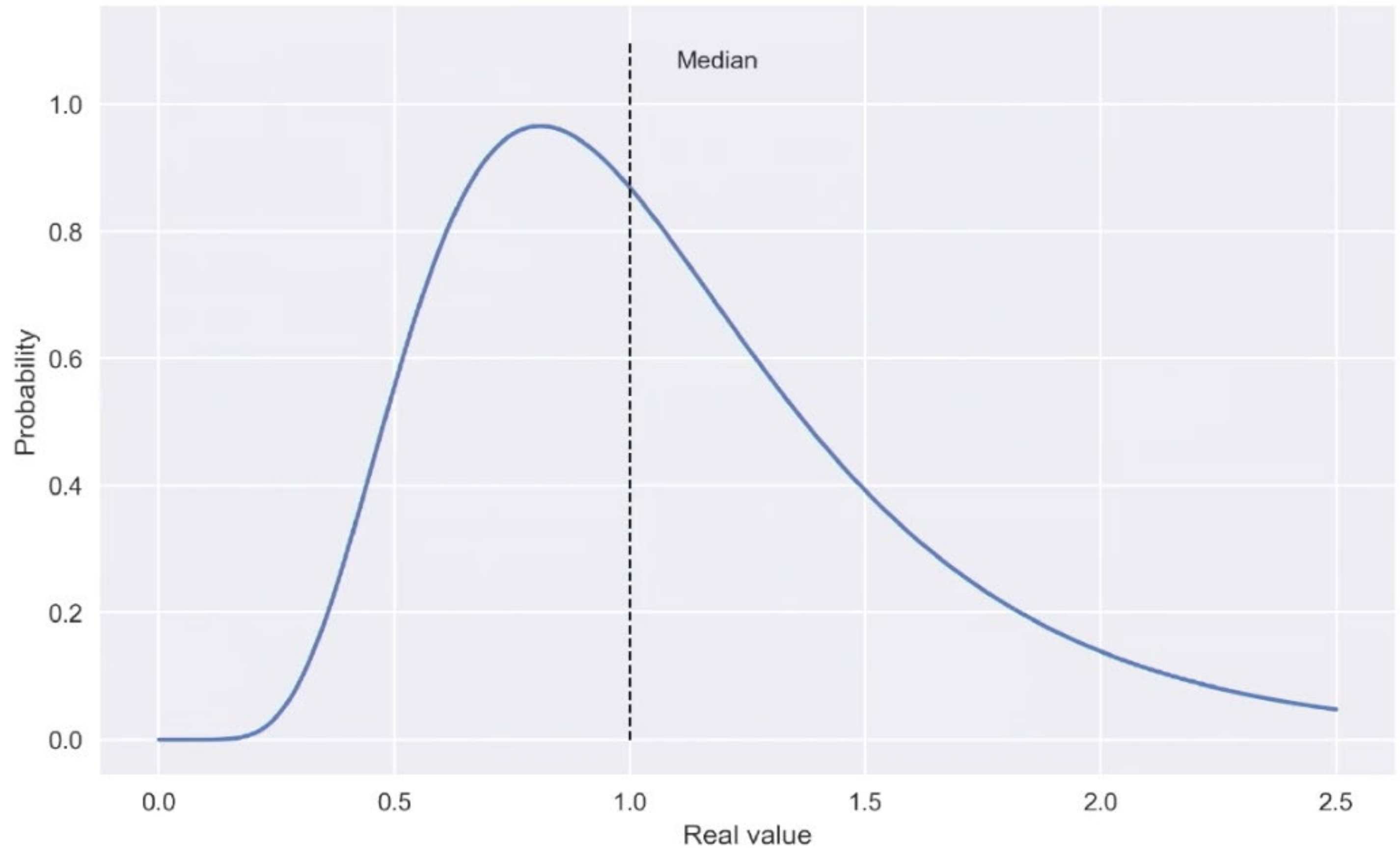
Indicator score	1	2	3	4	5 (default)
Reliability	Verified[a] data based on measurements[b]	Verified data partly based on assumptions *or* non-verified data based on measurements	Non-verified data partly based on qualified estimates	Qualified estimate (e.g. by industrial expert)	Non-qualified estimate
Completeness	Representative data from all sited relevant for the market considered, over an adequate period even out normal fluctuations	Representative data from >50 % of the sites relevant for the market considered, over an adequate period to even out normal fluctuations	Representative data from only some sited (≪50 %) relevant for the market considered *or* >50 % of sites but from shorter periods	Representative data from only one site relevant for the market considered *or* some sites but from shorter periods	Representativeness unknown or data from a small number of sites *and* from shorter periods
Temporal correlation	Less than 3 years of difference to the time period of the dataset	Less than 6 years of difference of the time period of the dataset	Less than 10 years of difference to the time period of the dataset	Less than 15 years of difference to the time period of the dataset	Age of data unknown or more than 15 years of difference to the time period of the dataset
Geographical correlation	Data from area under study	Average data from larger area in which the area under study is included	Data from area with similar production conditions	Data from area with slightly similar production conditions	Data from unknown *or* distinctly different area (North America instead of Middle East, OECD-Europe instead of Russia)
Further technological correlation	Data from enterprises, processes and materials under study	Data from processes and materials under study (i.e. identical technology) but from different enterprises	Data from processes and materials under study from different technology	Data on related processes or materials	Data on related processes on laboratory scale *or* from different technology

[a] Verification may take place in several ways, e.g. by on-site checking, by recalculation, through mass balances or cross-checks with other sources

[b] Includes calculated data (e.g. emissions calculated from inputs to an activity), when the basis for calculation is measurements (e.g. measured inputs). If the calculation is based partly on assumptions, the score would be 2 or 3.

Is the Pedigree matrix good?

1. petrol, unleaded → petrol production, low-sulfur (EUR w/o CH)



Is the Pedigree matrix good?

Yes, as a starting point

BUT

Default values for uncertainty should not be allowed (Mutel, C., 2021)

Uncertainty of the characterization factors

- The variability and uncertainty in LCIA could be much more important than that of LCI
- ON the other hand, almost all the literature in uncertainty is on LCI
- The "IMPACT World +" method will give uncertainty estimates for all the characterization factors

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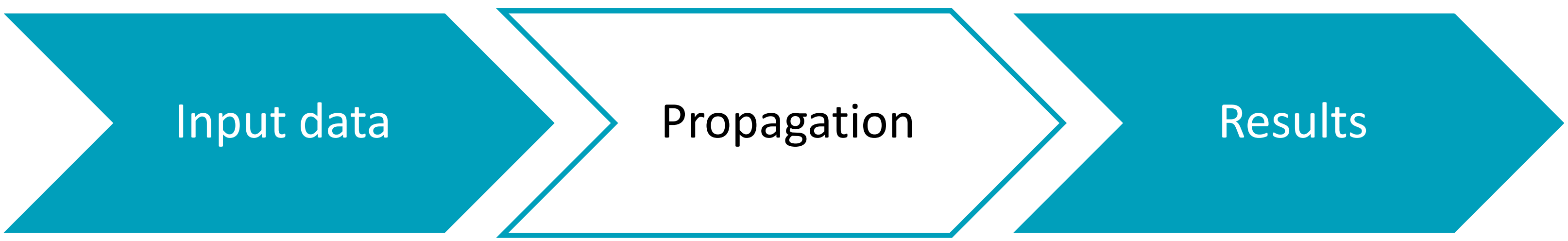
Uncertainty analysis - Quantitative approach

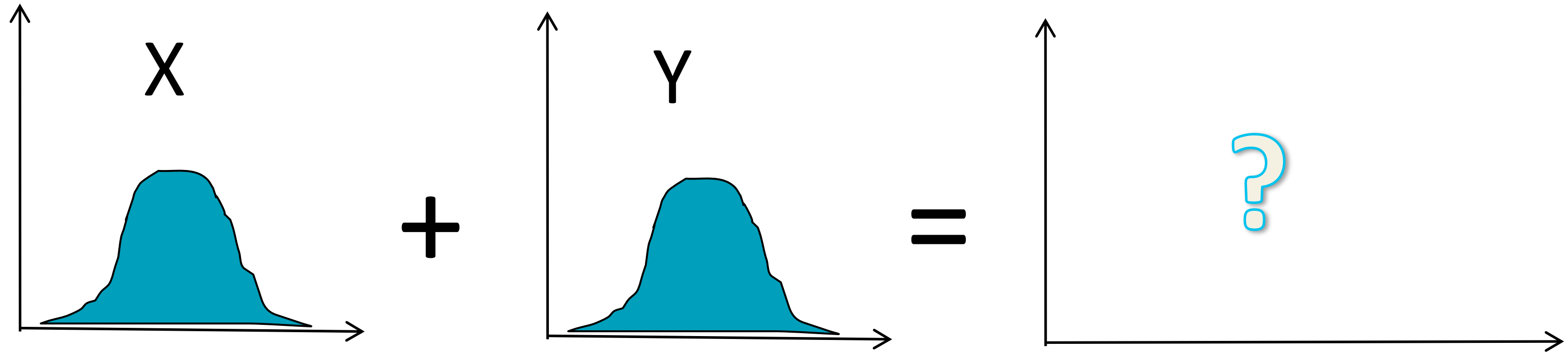
"[...] quantify, uncertainty introduced [...] by the cumulative effects of the inaccuracy of the model, uncertainty about incoming and data variability "



- General approach:
  1. **Estimate uncertainty of individual parameters (data input)**
  2. **Cumulate the uncertainty to the final results (propagation)**
     - Analytical methods for uncertainty propagations
     - Fuzzy logic
     - Stochastic modeling (Monte Carlo, Latin Hypercube)
  3. **Communicate the results**

Monte Carlo - Basic principle

Iteration 1



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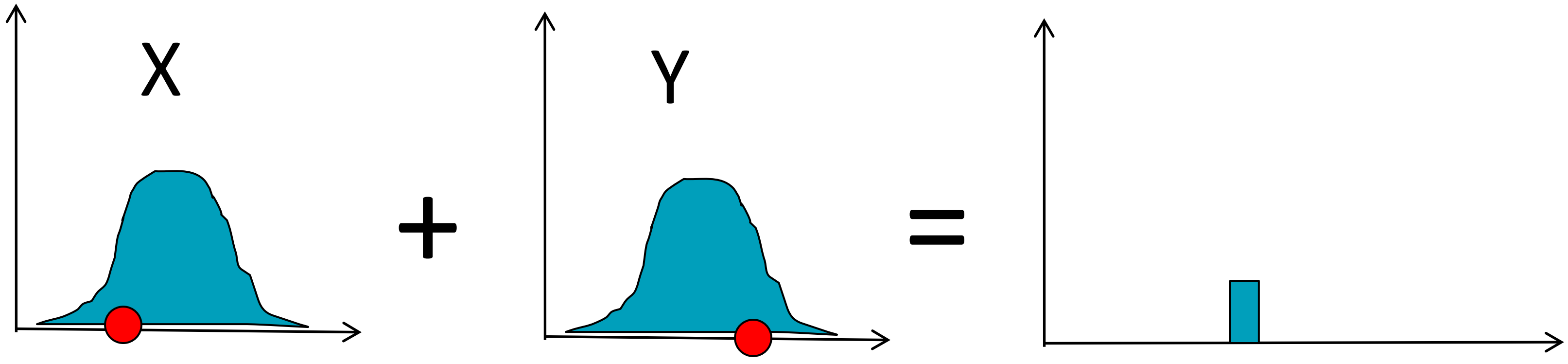
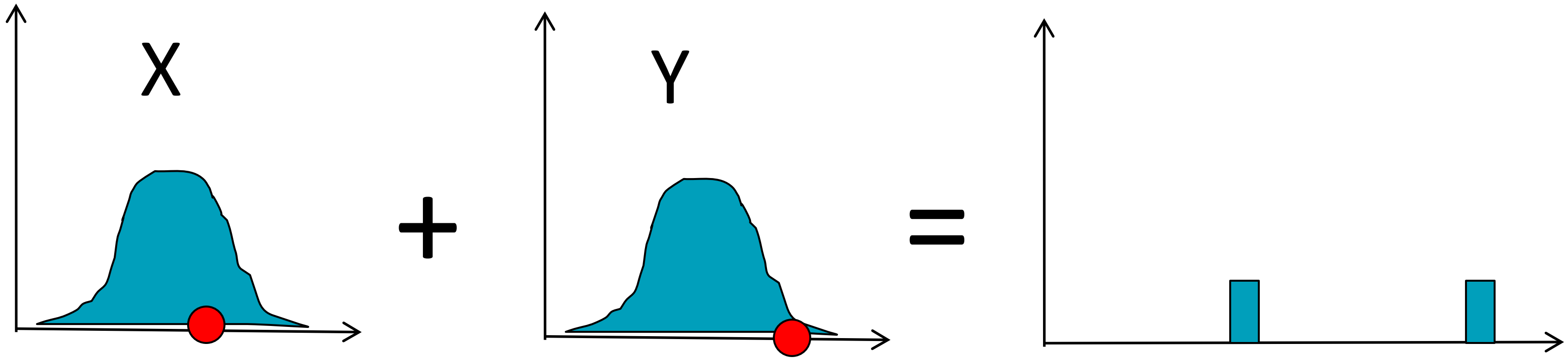
Monte Carlo - Basic principle

Iteration 1



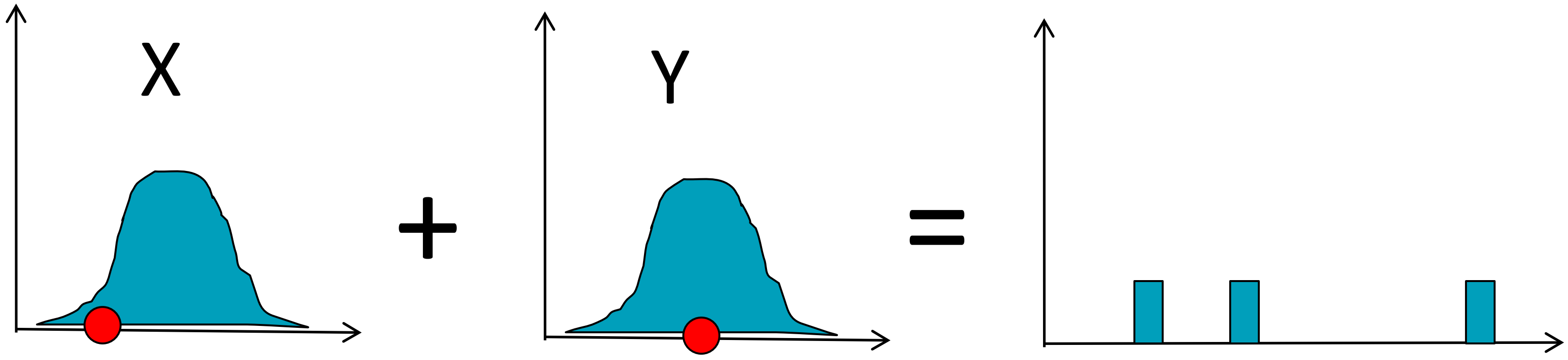
Monte Carlo - Basic principle

Iteration 2



Monte Carlo - Basic principle

iteration 3



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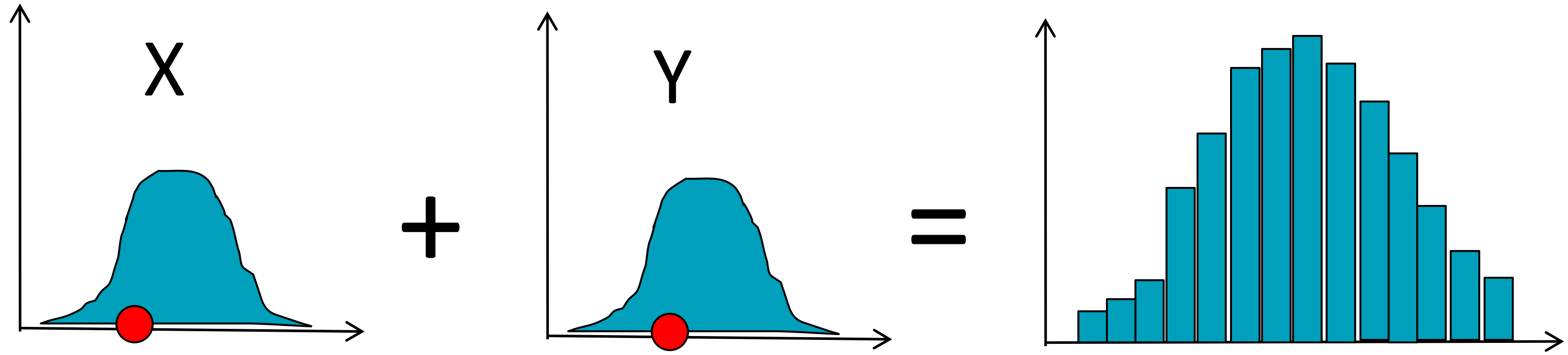
Monte Carlo - Basic principle

iteration 1000



Analysis uncertainty - Approach quantitative

"[...] quantify, uncertainty introduced [...] by the cumulative effects of the inaccuracy of the model, uncertainty about incoming and data variability "

- General approach:
  1. **Estimate uncertainty of individual parameters (data input)**
  2. **Cumulate the uncertainty to the final results (propagation)**
  3. **Communicate the results**
     - Histogram
     - Confidence intervals
     - Coefficient of variation,...

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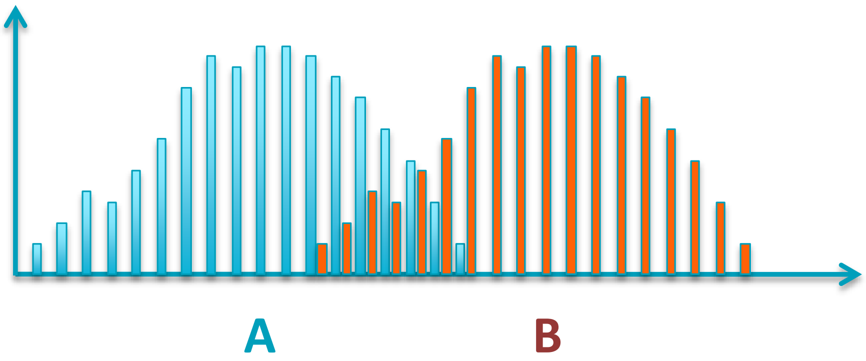
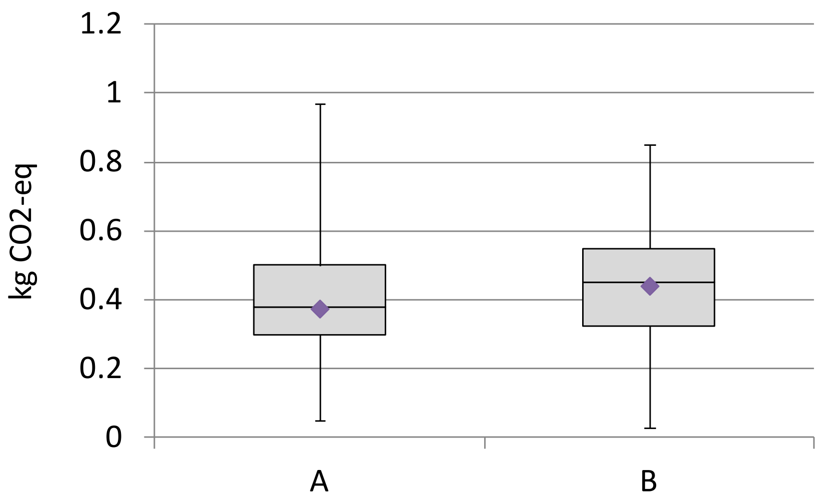
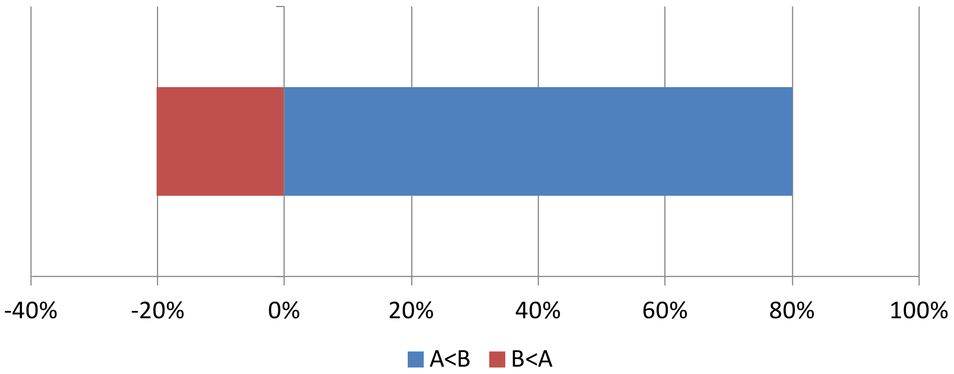
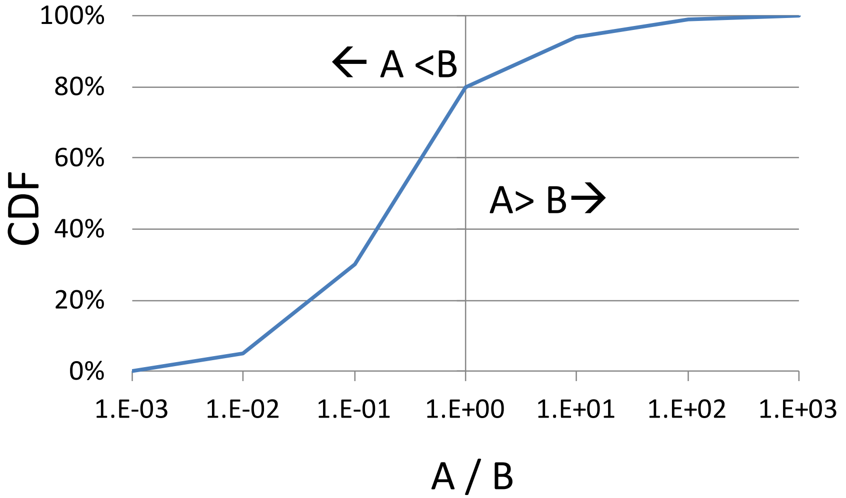
Communicate of probabilistic results: Example









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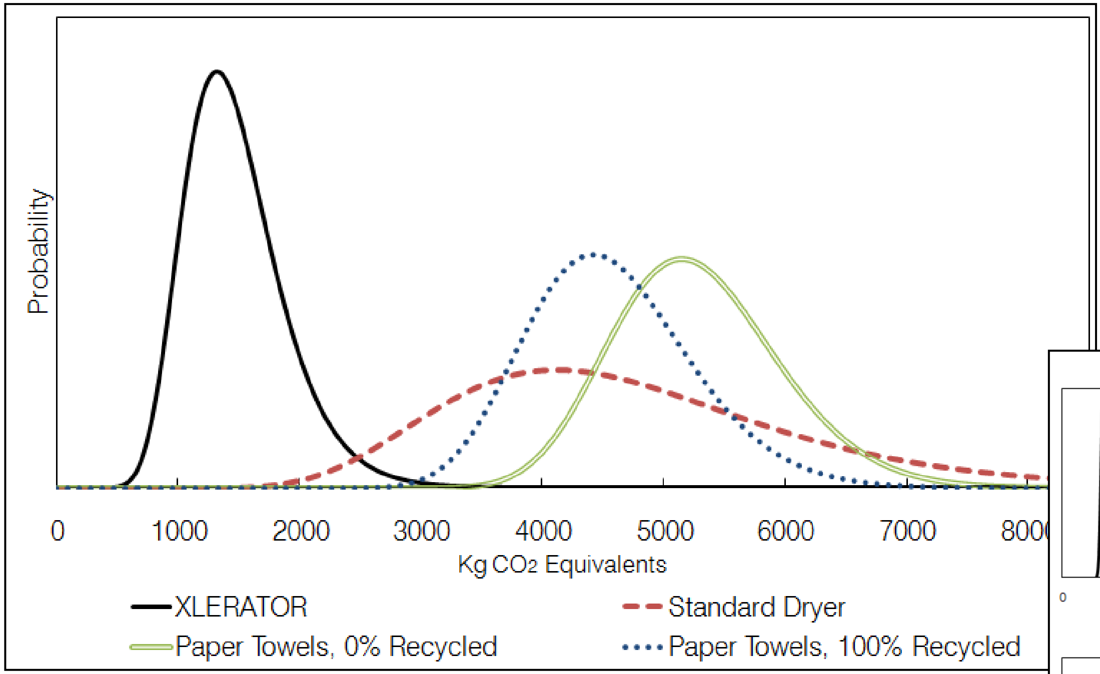
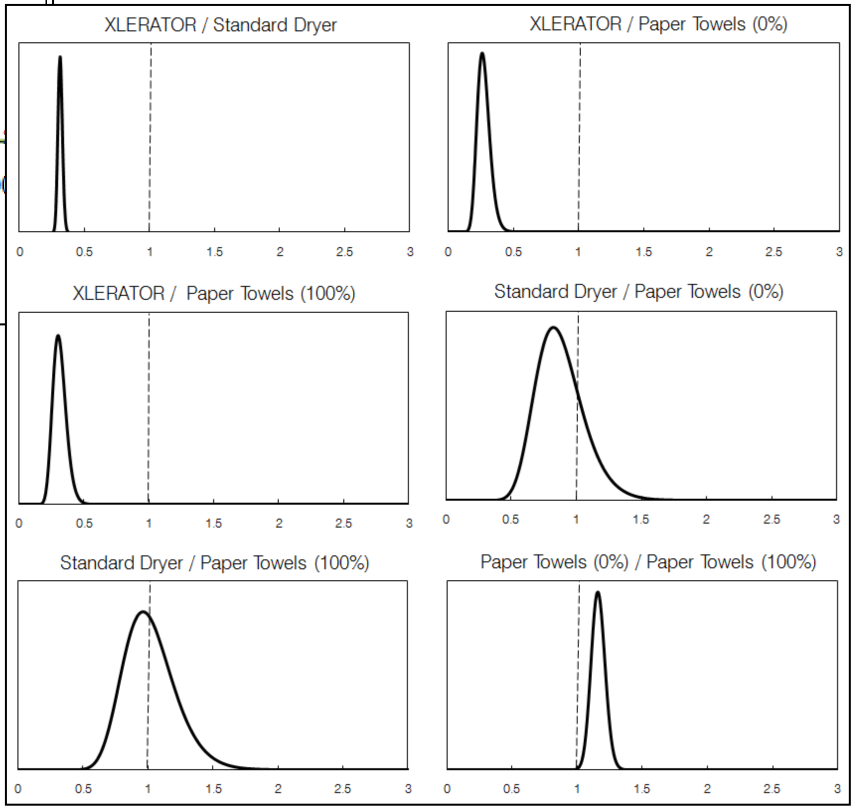
Communicate of probabilistic results: Example

Example of dried Hands XLERATOR





Sensitivity Analysis

Assessment of the effect of the uncertainty of the input data on the uncertainty of results

Local sensitivity

- Study the effects of small variations in input data on LCA results
  - "One at a time" with +/- x%
  - Perturbations matrix analysis

Global sensitivity

- Allows to study all ranges of input data variation on LCA results
  - Analytical sensitivity
  - Correlation, Regression
  - Sobol Indices

Example of Global Sensitivity Analysis (GSA)

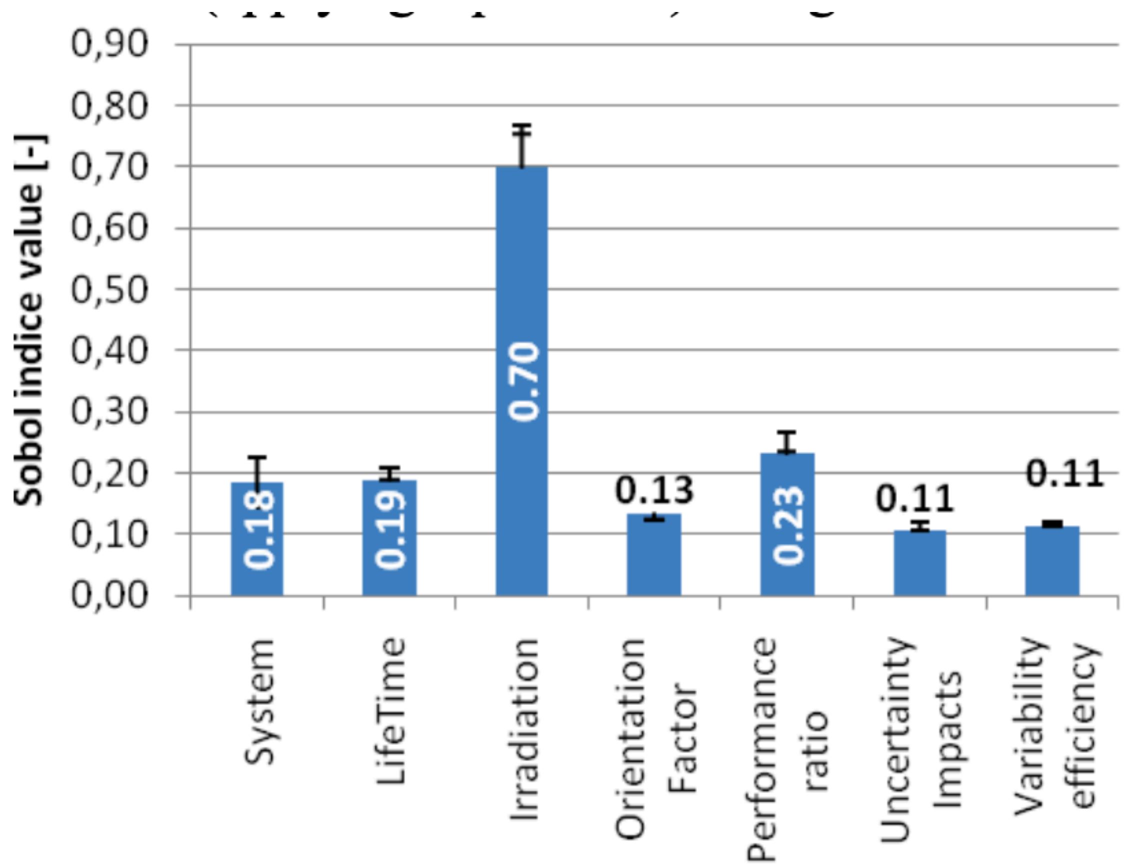


Figure 5: Sobol indices for the residential PV electricity

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Summary "uncertainty"

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2. Sources of uncertainty in LCA
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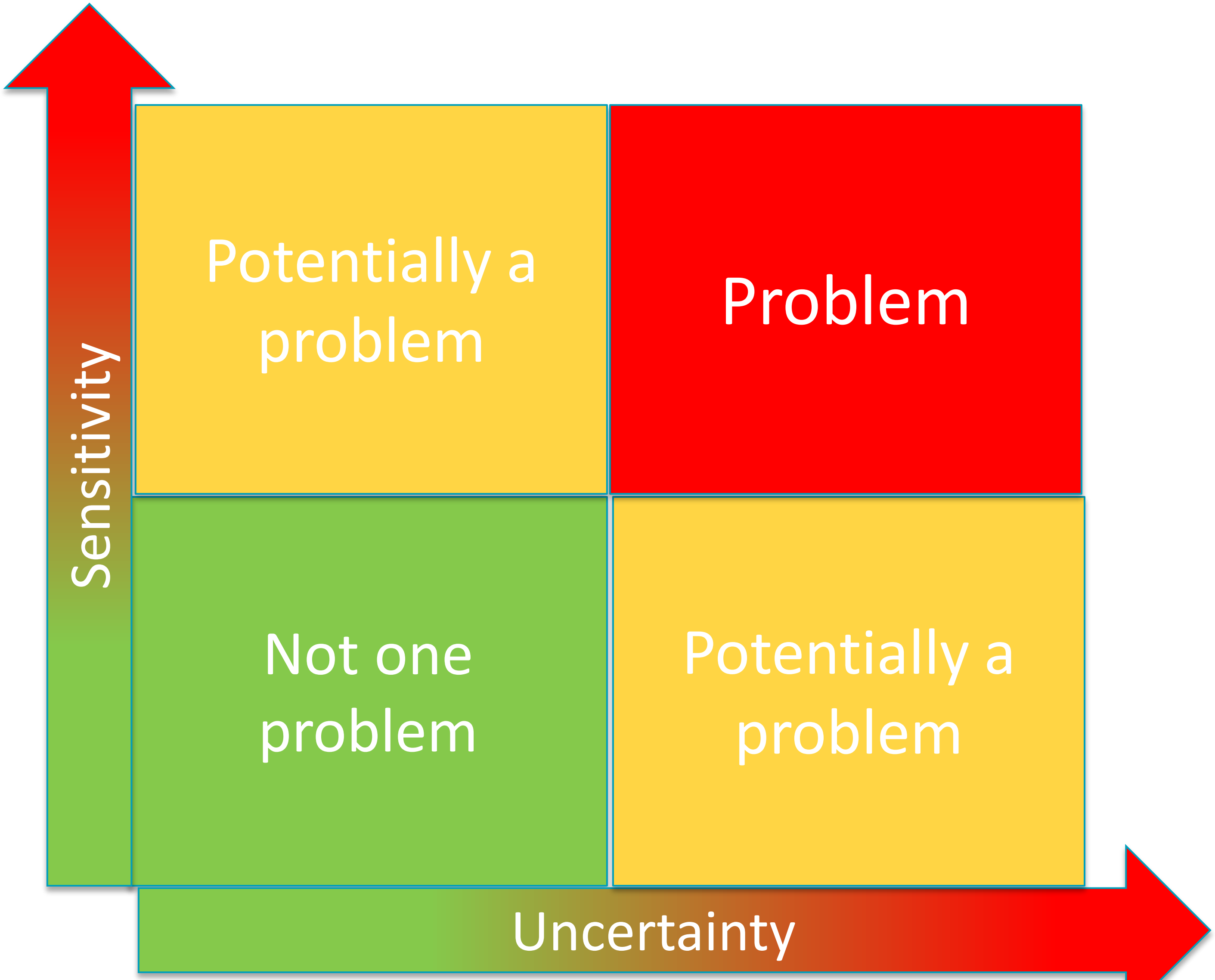
How to identify concretely the data to improve?



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Reduction or control of the uncertainty in LCA

Here is a few techniques to reduce the uncertainties in LCA:

- **Uncertainty related to the parameters:**
  - Simply: getting more reliable information (additional literature review, meeting expert, measurements)
  - Lack of LCI data? Use or create a proxy, use INPUT-OUTPUT data
  - Lack of representative data: adapt data (ideally based on a reliable and consistent data collection)
- **Uncertainties of the scenarios:**
  - Standardization/Product category rules (Reduce the choices that LCA analysts have to to do)
  - Critical review or peer review

Reduction or control of the uncertainty in LCA

- **Uncertainty related to the models:**
  - Use more "sophisticated" models when relevant
    - Time or space differentiation in inventory, economic models...

  - Note: reduction of model uncertainty increases uncertainty of parameters

(complex models → more parameters).