Application of Dempster-Shafer theory to integrate methods to propagate variability and epistemic uncertainty in agricultural LCA

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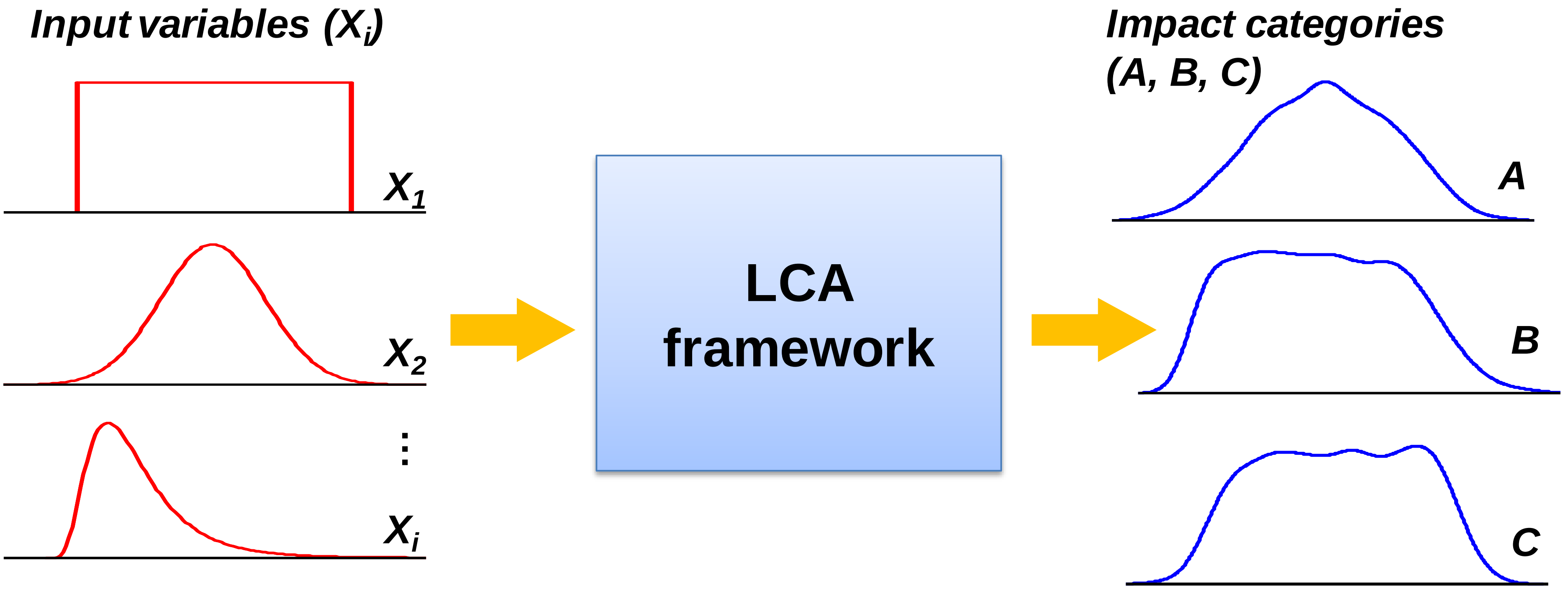
Presentation Outline

- Quantitative analysis of uncertainty in LCA
- Multiple types of uncertainty and propagation
- Numerical example
- Conclusions

Quantitative analysis of uncertainty in LCA

- **Probability distribution & Monte Carlo simulation**



- **Randomness of input variables**
- **Assumptions about the shapes of distributions (large sample size)**

Multiple types of uncertainty and propagation

- **Variability** refers to inherent properties of individuals in the real world. It is due to natural heterogeneity in physical phenomena, and it is **not reducible**.

  e.g. Inherent differences in milk yields among farms results in large variability in the carbon footprint of milk production.

- **Epistemic uncertainty** results from incomplete knowledge about the system studied. If is defined as the lack of knowledge, imprecision, ignorance and human errors, and it is **reducible**.

  e.g. Poor data quality in estimates of GHG emission factors

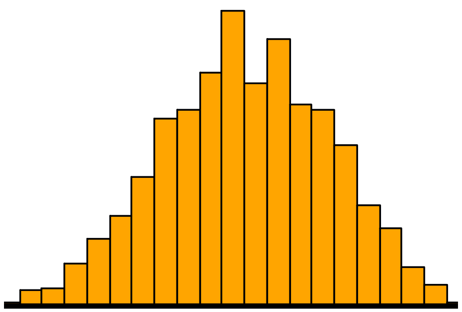
- **Aim of this study:** represent different types of uncertainty using methods well-suited to each and propagate them together in a single framework.

Multiple types of uncertainty and propagation

Input variables

Variability

Probability analysis

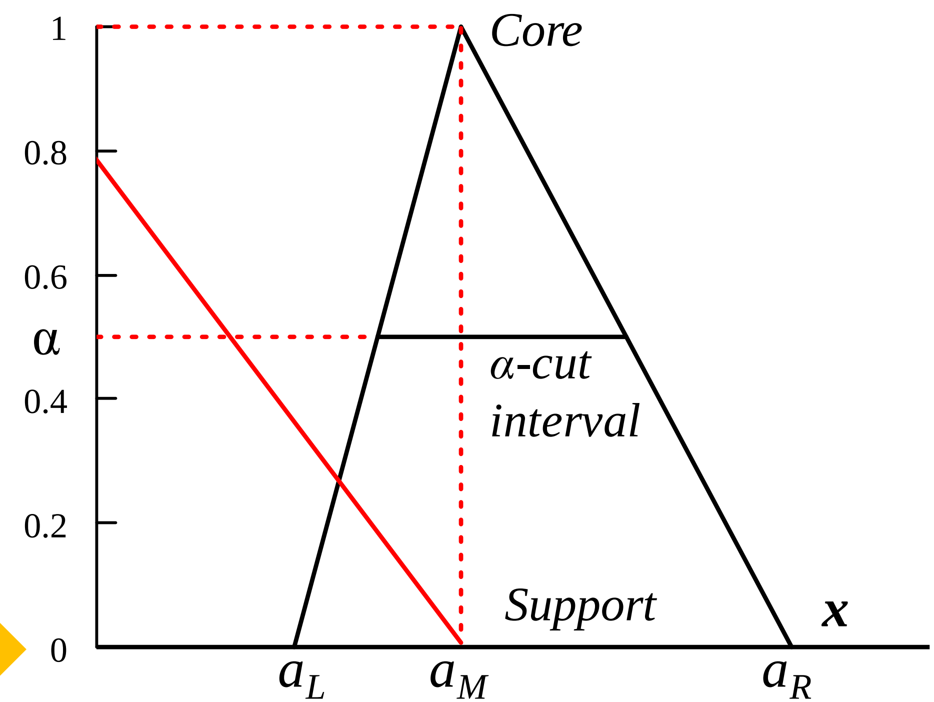


Parameter uncertainty

Non-probability analysis

Fuzzy intervals

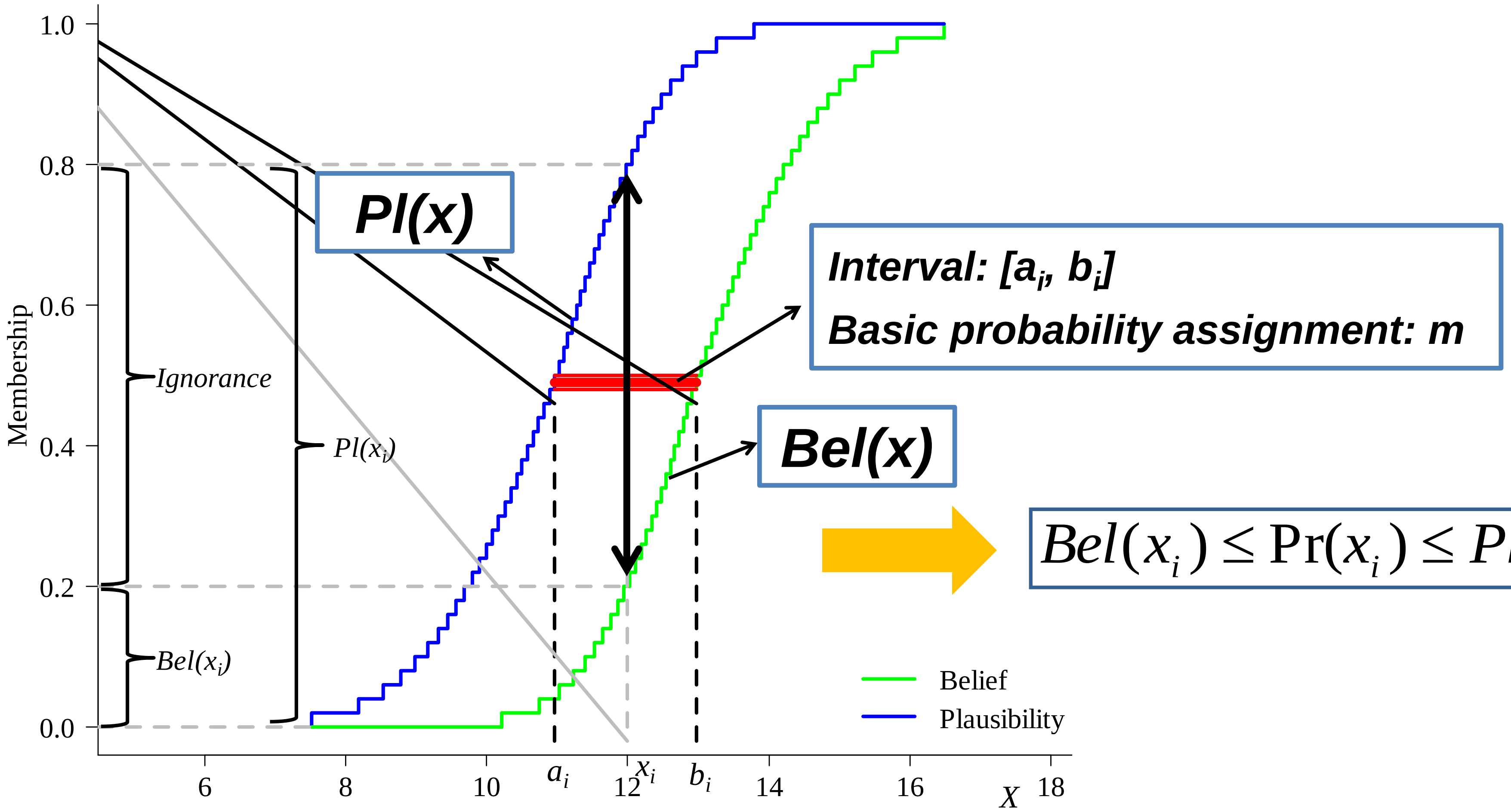
Membership function



- **Using methods well-suited to different types of uncertainty, including randomness and imprecision, represents the state of knowledge more realistically.**

Multiple types of uncertainty and propagation

Dempster-Shafer theory (DST), a theory of evidence



$$Bel(x_i) \leq \Pr(x_i) \leq Pl(x_i)$$

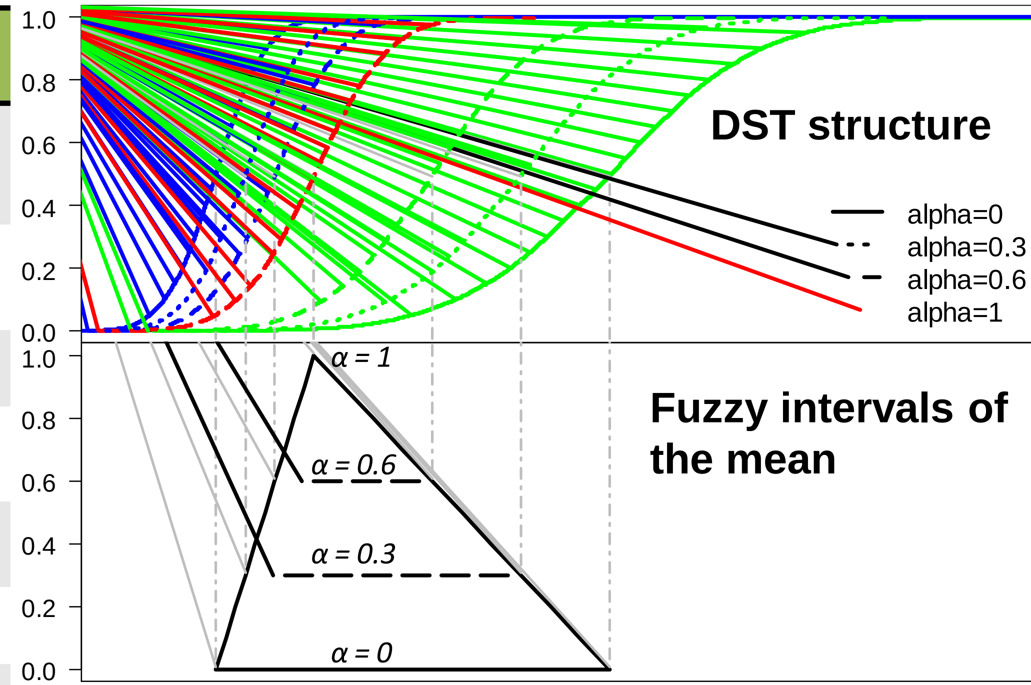
Multiple types of uncertainty and propagation

$$Y = f\,(\underbrace{X_1, X_2, \ldots, X_i,}_{\text{Fuzzy intervals}} \quad \& \quad \underbrace{X_{i+1}, \ldots, X_{i+k}}_{\text{Probability distribution}})$$

Fuzzy intervals — ***Probability distribution***

	α=0	α=0.1	…	α=1
X_1	$[a_1, b_1]_{\alpha=0}$	$[a_1, b_1]_{\alpha=0.1}$	…	$[a_1, b_1]_{\alpha=0.1}$
X_2	$[a_2, b_2]_{\alpha=0}$	$[a_2, b_2]_{\alpha=0.1}$	…	$[a_2, b_2]_{\alpha=0.1}$
…				
X_i	$[a_i, b_i]_{\alpha=0}$	$[a_i, b_i]_{\alpha=0.1}$	…	$[a_i, b_i]_{\alpha=0.1}$
X_{i+1}	$x_{i+1,j}$	$x_{i+1,j}$	…	$x_{i+1,j}$
…				
X_{i+k}	$x_{i+k,j}$	$x_{i+k,j}$	…	$x_{i+k,j}$

Cumulative distribution functions



Numerical example: methods

- An LCA model to estimate direct environmental impacts (climate change, acidification and eutrophication) of dairy farms in France based on the EDEN-E (Evaluation de la Durabilité des ExploitatioNs) dataset (van der Werf et al. 2009).
- Variability in structural characteristics (e.g., milk production, nitrogen fertilization, energy use) was represented with multivariable probability distributions, which also preserved rank-order correlations among their values.
- Three scenarios were defined, each representing epistemic uncertainty in emission factors differently:
  - S1: ignoring it
  - S2: representing it with triangular probability distributions
  - S3: representing it with fuzzy intervals
- Uncertainty was propagated with Monte Carlo simulation using R software

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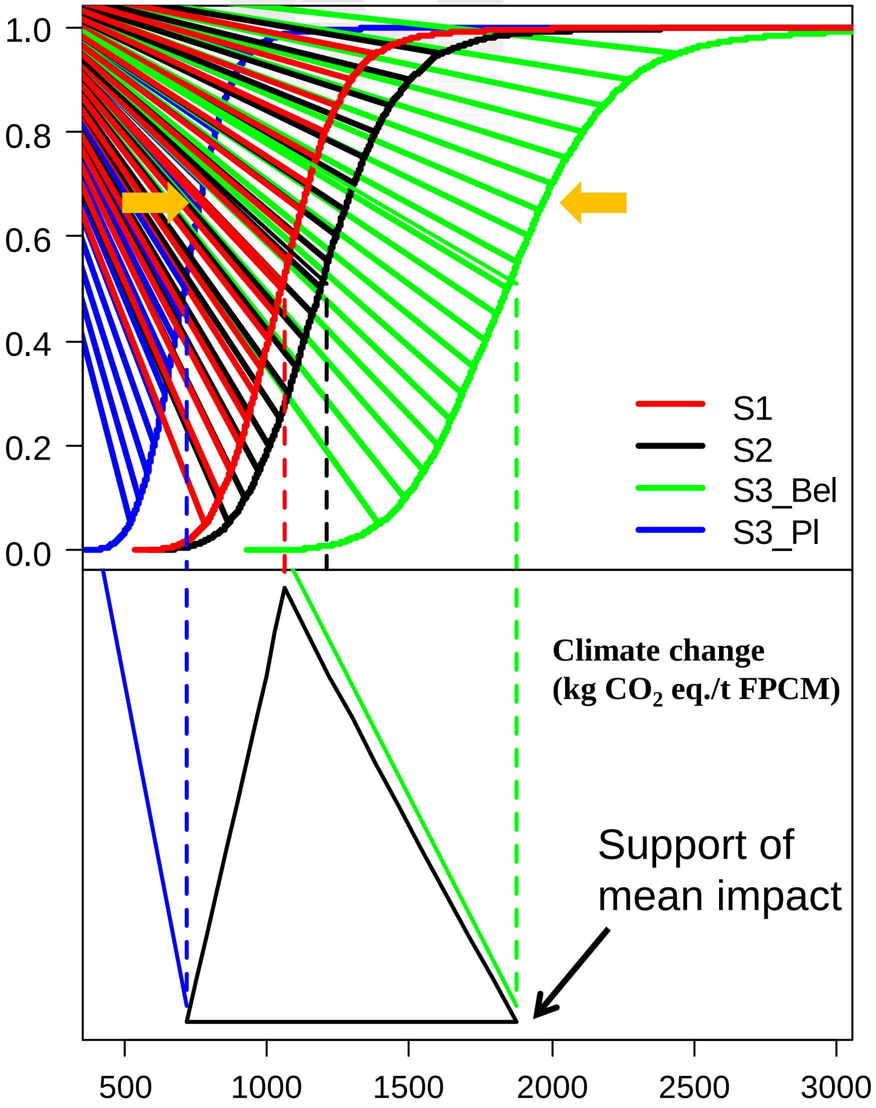
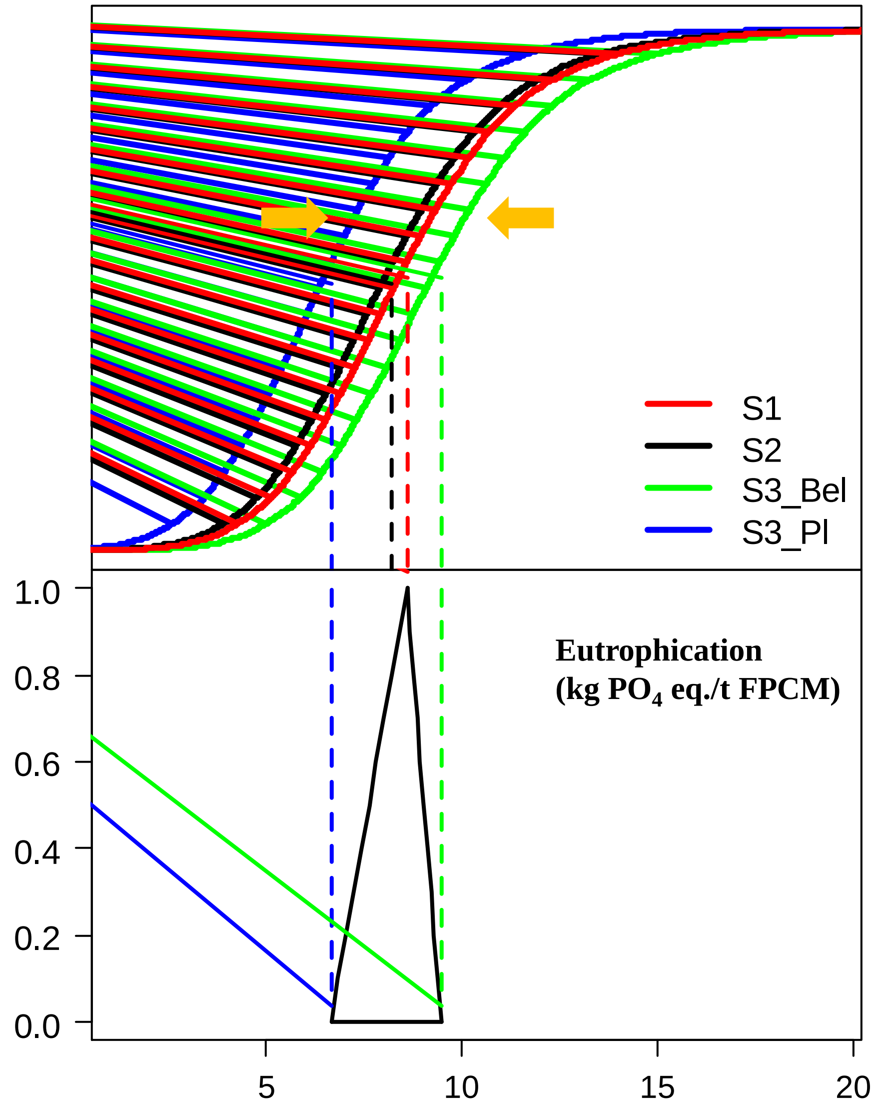
Numerical example: impacts per t of milk





Conclusions

- Different types of uncertainty can be represented differently in the same framework → represent variability well (i.e. use appropriate distribution) and the contribution of epistemic uncertainty to overall uncertainty.
- Dempster-Shafer theory provides a more conservative range of uncertainty → addresses imprecise information.
- Computational efficiency needs to be improved to handle more complex models → 2^m combinations (m = number of imprecise input variables).
- Correlations among imprecise variables are difficult to control.
- Interpretation of DST-based results may be less useful for decision makers → use a confidence index to generate a weighted probability distribution.

Thank you for your attention.

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