Life Cycle Assessment

A product-oriented method
for sustainability analysis

UNEP LCA Training Kit
Module k – ***Uncertainty in LCA***

Contents

This module requires the delegate to have basic understanding of statistics and matrix algebra.

- **Introduction to uncertainties**
- **Treatment of uncertainties**
- **Elements in uncertainty handling**
- **Sensitivity of LCA results**
- **Using statistics in LCA**

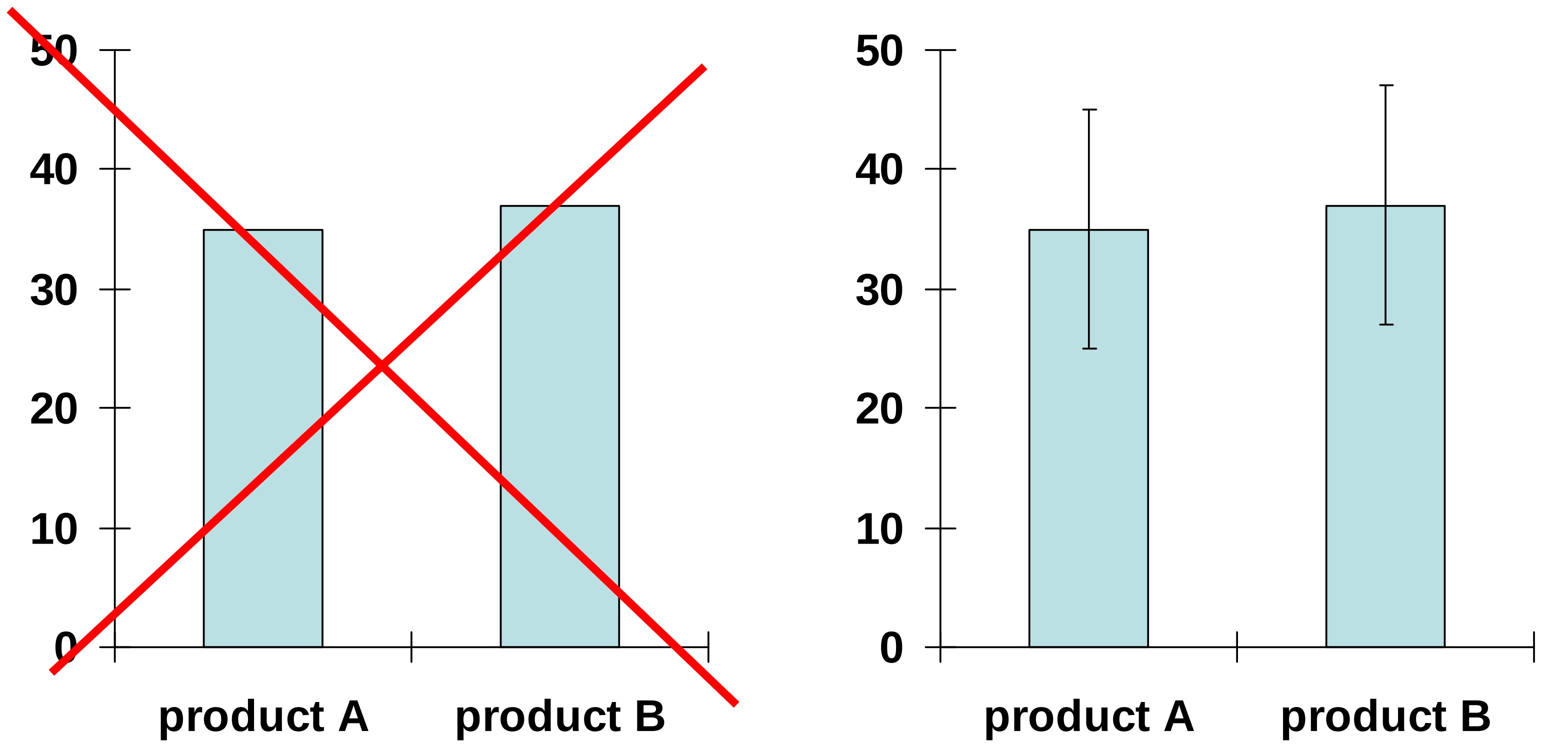
Introduction to uncertainties

- **Uncertainty in LCA is increasingly recognized as being important:**
  - uncertainties in data
  - uncertainties due to methodological choices
  - processing of uncertainties
  - decision-making under uncertainty

How to manage uncertainties?

- **Conduct more research**
  - that’s in every “recommendation for future research”
- **Abandon LCA**
  - not advisable
- **Interpret LCA results cautiously**
  - of course, but how?
- **Involve stakeholders**
  - does this reduce or increase the uncertainty?
- **Rerun the LCA with different data and choices**
  - sounds unsystematic
- **Use Monte Carlo analyses**
  - How to?
- **Use analytical approaches towards uncertainty**
  - How to?

Presenting uncertainties



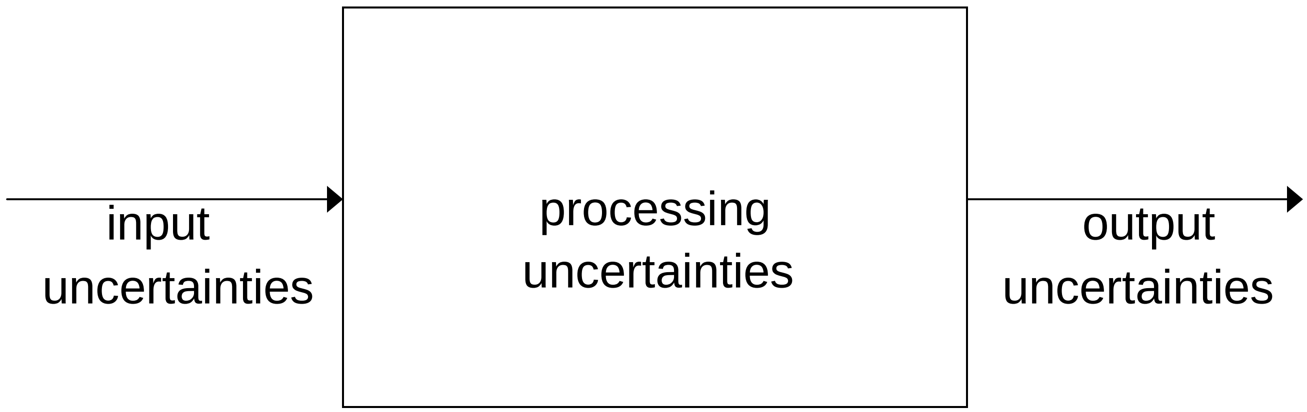
Treatment of uncertainties

- **Four main paradigms:**
  - 1. **“scientific”** approach (more research, better data)
  - 2. **“social”** (constructivist) approach (stakeholders, agreements)
  - 3. **“legal”** approach (authoritative bodies)
  - 4. **“statistical”** approach (Monte Carlo, confidence intervals)

- **What makes paradigm 4 special?**
  - 1, 2, 3 reduce uncertainty
  - 4 incorporates uncertainty

Treatment of uncertainties

- **General modeling framework**



Treatment of uncertainties

- **Processing uncertainties:**
  - parameter variation/scenario analysis
  - sampling methods (Monte Carlo)
  - analytical methods
  - non-traditional methods (fuzzy set, Bayesian)

Treatment of uncertainties

- **Input uncertainties:**
  - several values/choices
  - distributions
  - variances
  - data quality indicators (DQIs)

Treatment of uncertainties

- **Output uncertainties:**
  - results for different options
  - histograms
  - confidence intervals

Elements in uncertainty handling

- **Standardization**
  - **terminology**
    (example: what is the difference between sensitivity and uncertainty analysis)
  - **symbols**
    (example: what do we mean with μ?)
  - **data format**
    (example: how to report a lognormal distribution?)

Elements in uncertainty handling

- **Education**
  - **concepts**

    (what is a significant difference?)
  - **reporting**

    (how many digits?)
  - **value of not reducing but incorporating uncertainty**

Elements in uncertainty handling

- **Development**
  - **approaches**

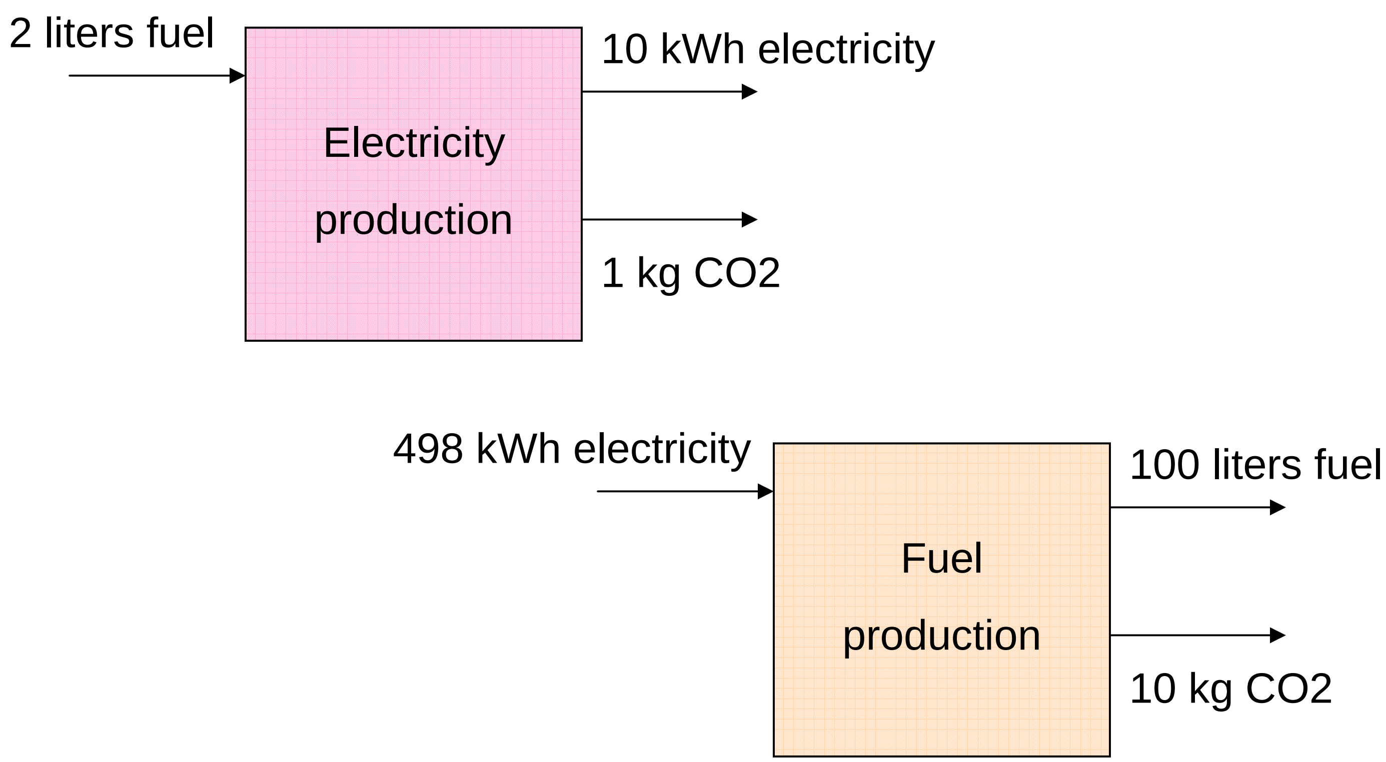
    (Monte Carlo, bootstrapping, principal components analysis, condition number, etc.)
  - **software**

    (many approaches)
  - **databases**

    (that support many approaches)
  - **guidelines**

    (for applying which approach in which situation)

Sensitivity of LCA results

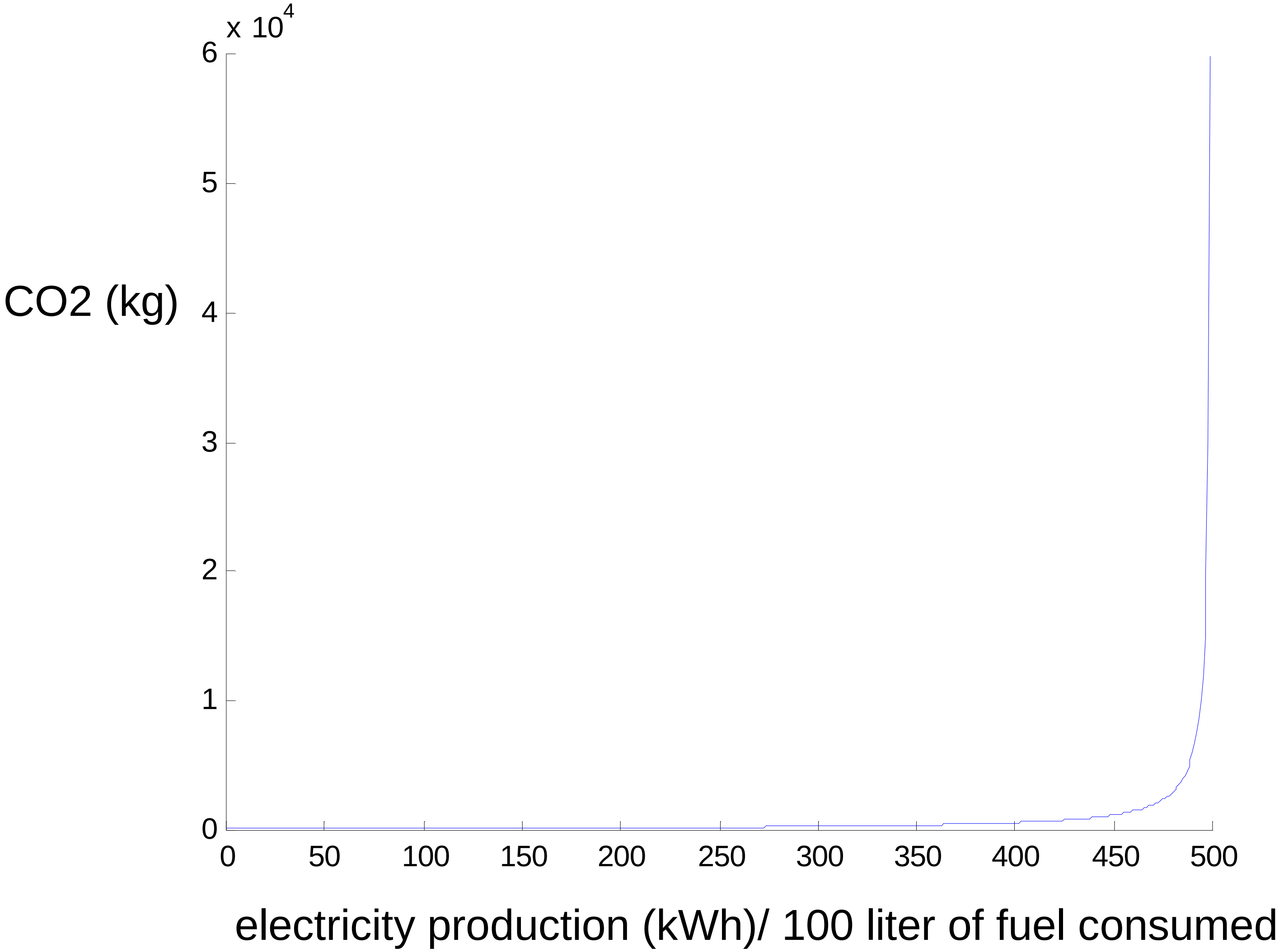


- Reference flow: 1000 kWh electricity
- Inventory result: 30,000 kg CO_2

Sensitivity of LCA results

- Change “498” into “499” (i.e. 0.2% change)
- “30.000” is changed into “60.000” (i.e. 100% change)
- Magnification of uncertainty by a factor 500 is possible in a system that is
  - small
  - Linear
- Can we understand this?

Sensitivity of LCA results



Sensitivity of LCA results

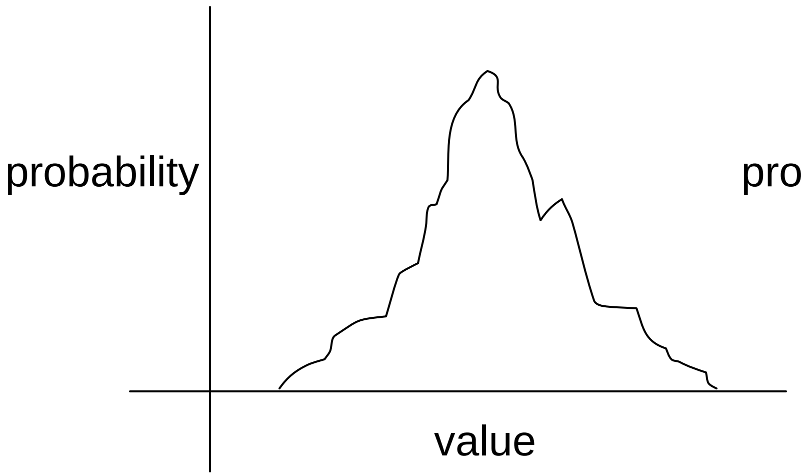
- **Sometimes, a small change of a parameter can induce a large change.**
  - of which the magnification factor >> 1
  - or << –1
- **A parameter is sensitive only in a certain range.**
  - only for a certain reference flow

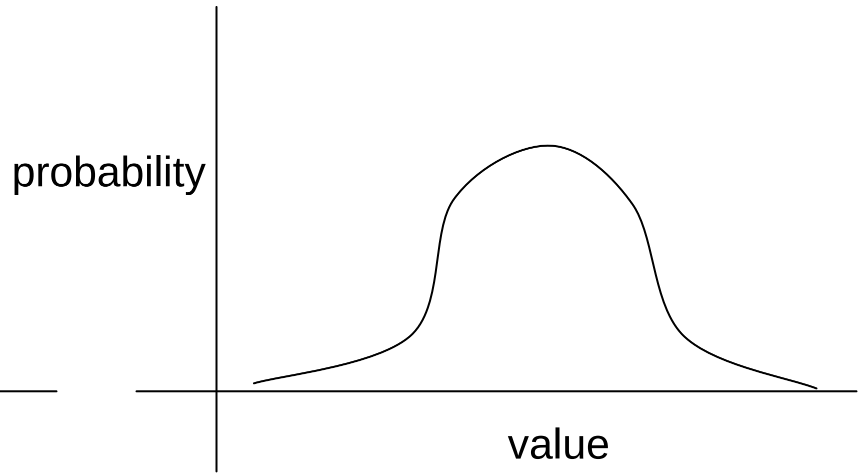
Sensitivity of LCA results

- Precise knowledge of these parameters is critical for the outcome of the LCA.
- Changing these parameters by new design, new technology, etc. significantly influences the environmental performance.
- These sensitive parameters are important for computational stability.

Using statistics in LCA

- **Probability distribution**
  - Full empirical distribution
  - Textbook normal distribution often assumes mean μ=12 and deviation σ=3
  - Unspecified distribution can note parameters such as mean, standard deviation, and bias, ...





Using statistics in LCA

- **Distribution**
  - population versus sample
- **Parameter**
  - population (“true value”) versus sample (“estimated value”)
- **Confidence interval**
  - interval in which the true value is expected to be found with a predefined certainty (e.g., 95%)
  - This is often approximately 4 standard deviations wide.

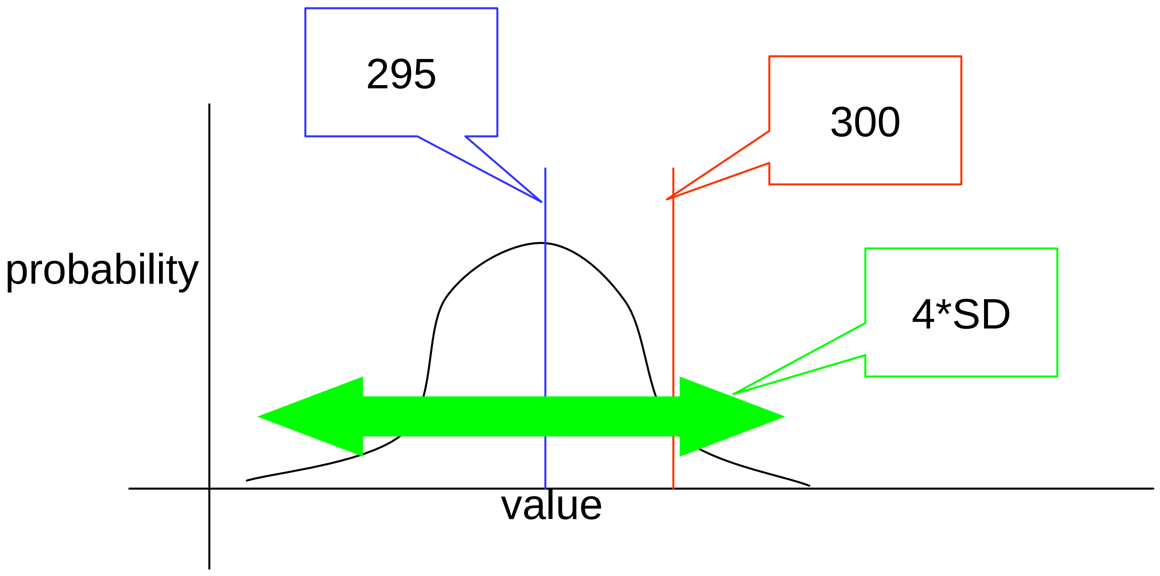
Using statistics in LCA

- **Statistical test**
  - analysis that combines statistical theory and empirical data
  - to test whether a predefined null-hypothesis can be rejected at a predefined significance level

- **Null-hypothesis**
  - translation of a question into an explicit statement that can be submitted to statistical testing
  - stand-alone, e.g. "CO_2 -emission = 300 kg"
  - comparative, e.g. "CO_2 -emission of product A and B is equal"

Using statistics in LCA

- **Decision**
  - determine the probability of the null-hypothesis
  - e.g., if CO_2 -emission = 295 kg with a standard deviation of 1 the null-hypothesis will be rejected
  - or, if CO_2 -emission = 295 kg with a standard deviation of 3 it will not be rejected (but not accepted!)



Using statistics in LCA

- **Significance**
  - if the null-hypothesis is rejected at the specified significance level, there is a significant difference/effect/etc.
  - For instance, if "CO_2-emission = 300 kg" is rejected, the CO_2 -emission is significantly different from 300 kg
  - or, if "CO_2 -emission of product A and B is equal" is rejected, there is a significant difference between the CO_2-emission of these products
- **Significant versus large**
  - a significant difference may be small or large
  - a large difference may be insignificant or significant

Using statistics in LCA

- **Numerical treatment**
  - parametric variation, e.g., scenarios (not very systematic)
  - sampling methods, e.g., Monte Carlo analysis

- **Analytical treatment**
  - based on formulas for error propagation

Monte Carlo analysis in 5 steps

1. **Consider every input parameter as a stochastic variable with a specified probability distribution**
   – For instance, CO_2-emission of electricity production follows a normal distribution with a mean of 1 kg and a standard deviation of 0.05 kg

2. **Construct the LCA-model with one particular realization of every stochastic parameter**
   – For instance, CO_2-emission of electricity production is 0.93 kg

Monte Carlo analysis in 5 steps

3. **Calculate the LCA-results with this particular realization**
   – e.g., CO_2-emission of system is 28,636 kg

4. **Repeat this for a large number of realisations**
   – e.g., number of runs N = 1000

5. **Investigate statistical properties of the sample of LCA-results**
   – e.g., the mean, the standard deviation, the confidence interval, the distribution

Using statistics in LCA

- **Analytical treatment in 2 steps**

1. **Consider every input parameter as a stochastic variable with a specified mean and standard deviation** (or variance)
   - For instance, CO_2-emission of electricity production has a mean of 1 kg and a standard deviation of 0.05 kg
2. **Apply classical rules of error propagation**
   - For instance, elaborate formula for standard deviation (or variance) of CO_2-emission of system

Using statistics in LCA

- Example: area of sheet of paper

$$A = l \times h$$

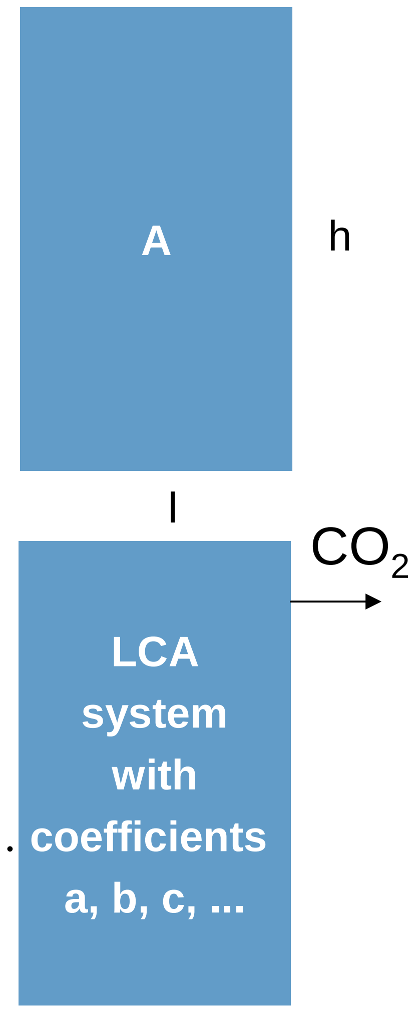
$$\mathrm{var}(A) = \left(\frac{\partial A}{\partial l}\right)^2 \mathrm{var}(l) + \left(\frac{\partial A}{\partial h}\right)^2 \mathrm{var}(h)$$

$$\mathrm{var}(A) = h \times \mathrm{var}(l) + l \times \mathrm{var}(h)$$

- Same idea for LCA:

$$\mathrm{CO2} = f(a,b,c,\ldots)$$

$$\mathrm{var}(\mathrm{CO2}) = \left(\frac{\partial f}{\partial a}\right)^2 \mathrm{var}(a) + \left(\frac{\partial f}{\partial b}\right)^2 \mathrm{var}(b) + \left(\frac{\partial f}{\partial c}\right)^2 \mathrm{var}(c) + \cdots$$



Using statistics in LCA

- **Numerical**
  - is simple to understand
  - does not require explicit formulas
  - can deal with model choices as well
- **Analytical**
  - is fast
  - does not require runs
  - does not require probability distributions
  - enables a decomposition into key issues

Using statistics in LCA

- **LCA requires explicit formulas.**
  - for LCIA widely published

$$h_j = \sum_i Q_{ji} g_i \quad \text{or} \quad \mathbf{h} = \mathbf{Qg}$$

  - but for LCI?

$$g_i = ? \quad \text{or} \quad \mathbf{g} = ?$$

- **The answer can be found in matrix algebra.**

You may want to review some of these apporaches to dealing wth uncertainaty in LCA.

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The last module addresses carbon footprinting.

Module	contents
I	Carbon footprint