



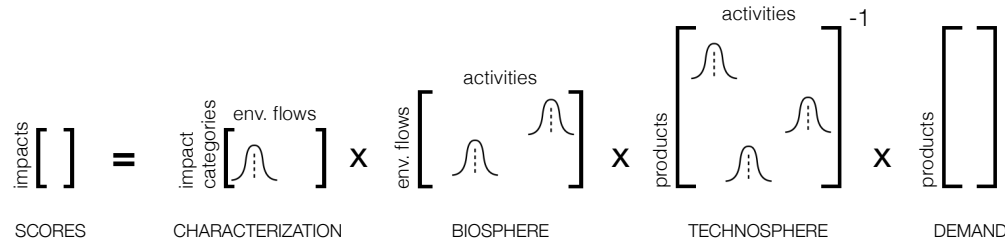
Aleksandra Kim :: Christopher Mutel :: Stefanie Hellweg
Paul Scherrer Institute :: ETH Zurich

Towards more realistic global sensitivity analysis of life cycle assessment studies

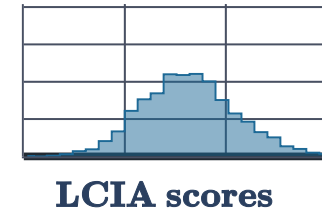
SETAC Europe 32nd Annual Meeting, 15-19 May 2022

Global sensitivity analysis in a nutshell

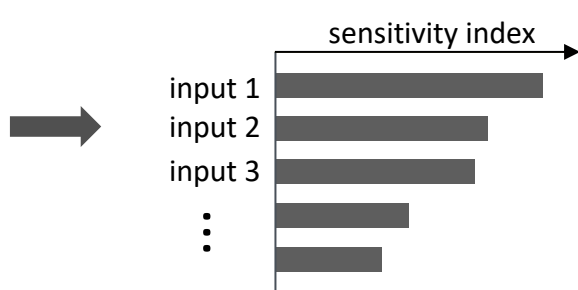
Life cycle assessment (LCA) model



Monte Carlo runs



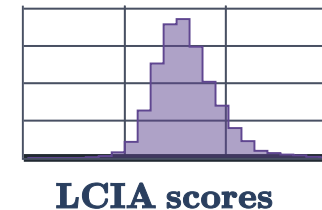
Global sensitivity analysis (GSA)



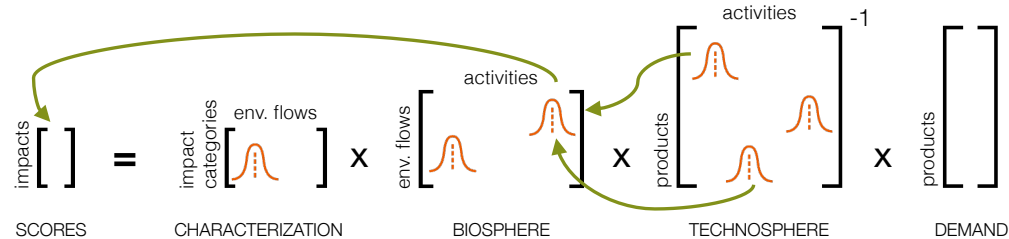
Prioritized
data collection

Improve modeling

Reduce uncertainty



State of the art in GSA of LCA



ca. 100 characterization factors
 > 10'000 biosphere exchanges
 > 100'000 technosphere exchanges

More realistic GSA of LCA:

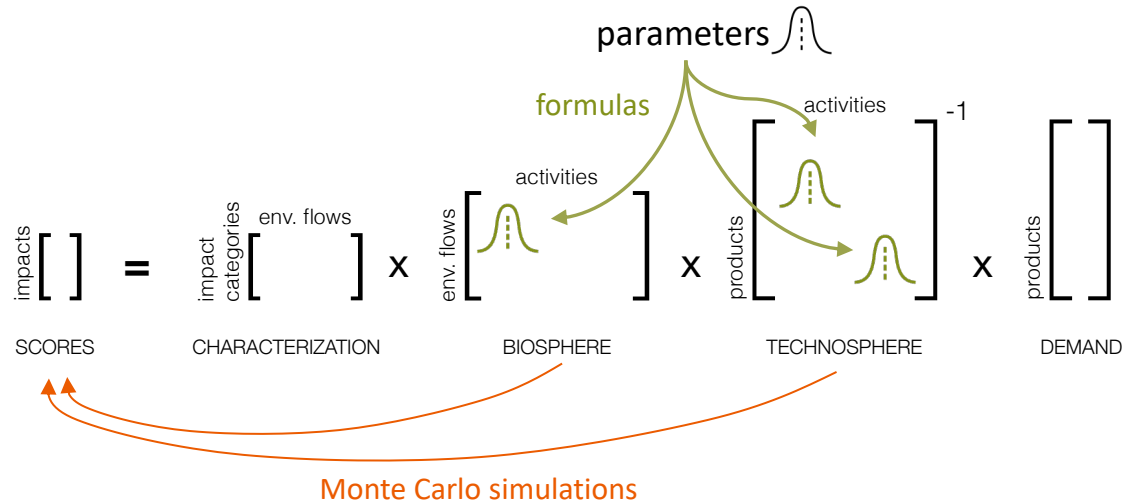
global sensitivity analysis of complete life cycle assessment models
 that reflect dependencies and correlations between environmental processes

Kim, A., Mutel, C.L., Froemelt, A. and Hellweg, S., 2021. Global Sensitivity Analysis of Background Life Cycle Inventories. *Environmental Science & Technology*. DOI: 10.1021/acs.est.1c07438

- Modules
 1. Parameterized exchanges based on ecoinvent formulas
 2. Carbon balances
 3. Electricity mixes based on real data
 4. Uncertainties in ecoinvent markets
- Monte Carlo simulations
 - for a case study of climate change impacts of an average Swiss household

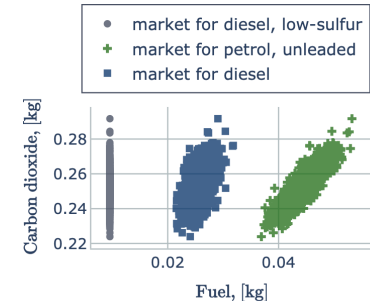
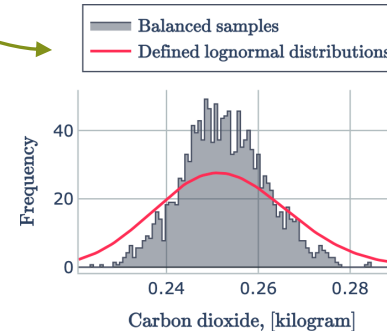
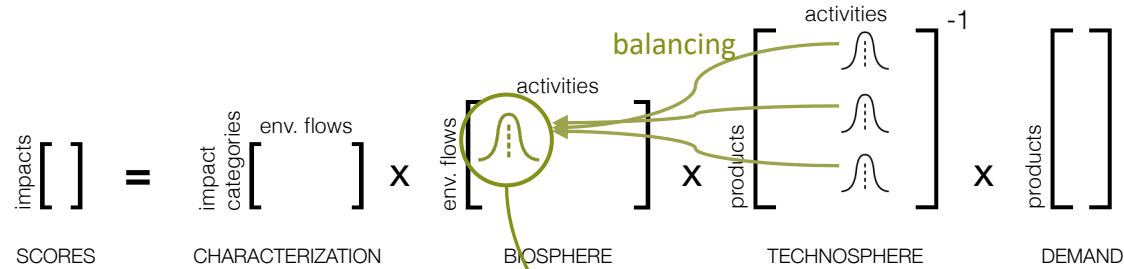
Module 1: Parameterization

How to propagate changes in parameters to technosphere and biosphere?

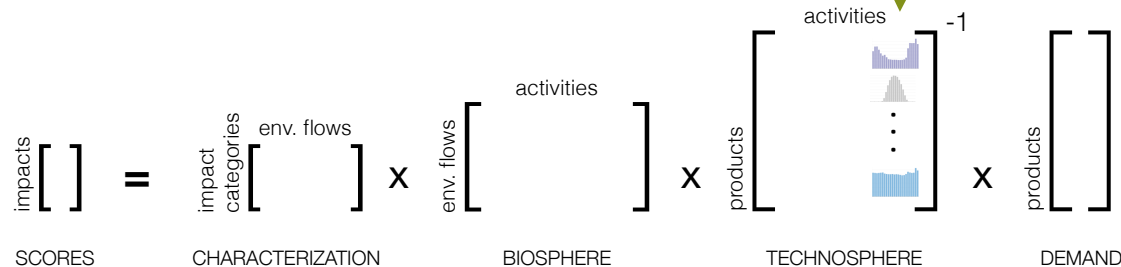
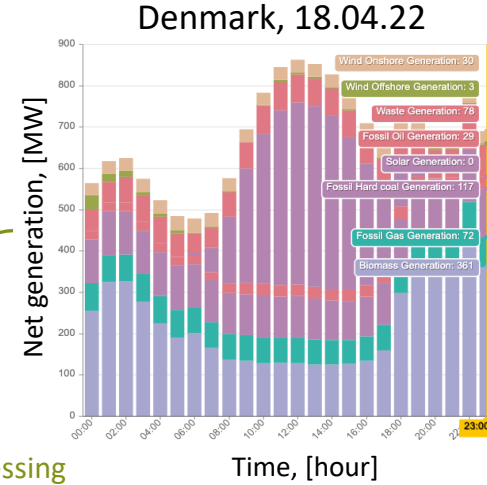


Module 2: Carbon balances for combustion

- How to propagate changes in technosphere to biosphere?



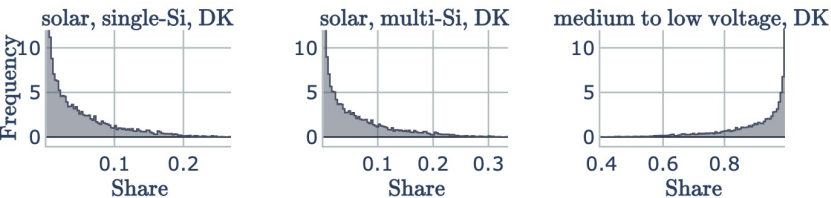
- How to include actual / reported data?
 - Currently electricity markets do not have any uncertainty
 - ENTSO-E transparency platform provides time-series of actual power generation per production type



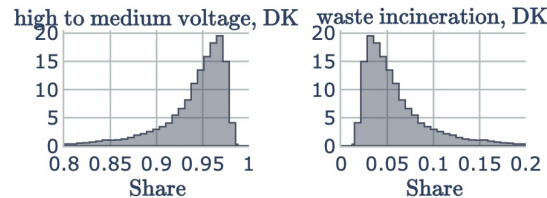
Hirth, L., Mühlenpfordt, J. & Bulkeley, M., 2018. The ENTSO-E transparency platform – a review of Europe's most ambitious electricity data platform. *Applied Energy*. DOI: 10.1016/j.apenergy.2018.04.048

Module 3: ENTSO-E data for Denmark

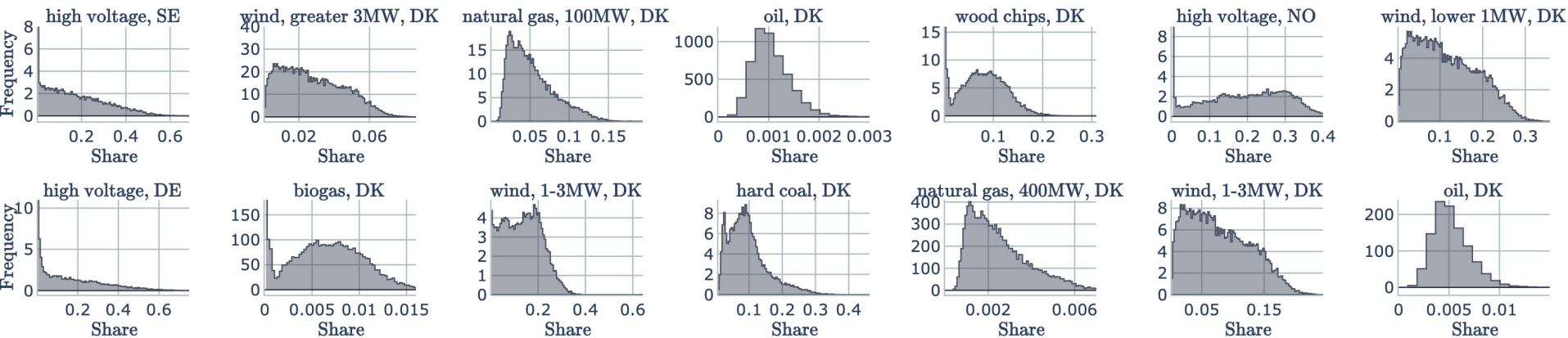
Market for electricity, LOW voltage



Market for electricity, MEDIUM voltage



Market for electricity, HIGH voltage



*DE – Germany, DK – Denmark, NO – Norway, SE – Sweden

— ENTSO-E reported data

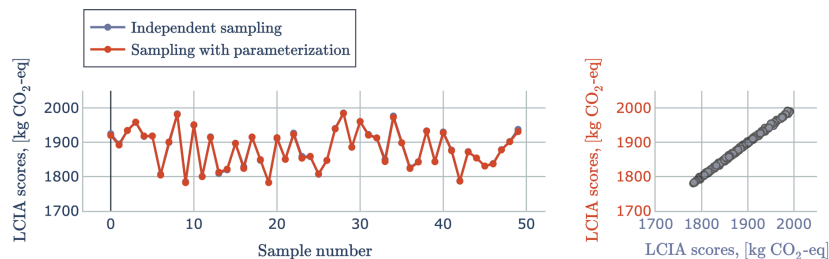
Module 4: Uncertainties in implicit markets

$$\begin{array}{ccccccccc}
 \text{impacts} & & & & & & \text{activities} & & \\
 \left[\begin{array}{c} \\ \end{array} \right] & = & \begin{array}{c} \text{impact} \\ \text{categories} \end{array} & \begin{array}{c} \text{env. flows} \\ \left[\begin{array}{c} \\ \end{array} \right] \end{array} & \times & \begin{array}{c} \text{env. flows} \\ \left[\begin{array}{c} \\ \end{array} \right] \end{array} & \begin{array}{c} \text{activities} \\ \left[\begin{array}{c} \\ \end{array} \right] \end{array} & \times & \begin{array}{c} \text{products} \\ \left[\begin{array}{c} \\ \end{array} \right] \end{array} \\
 \text{SCORES} & & \text{CHARACTERIZATION} & & & \text{BIOSPHERE} & & \text{TECHNOSPHERE} & \text{DEMAND} \\
 & & & & & & & \begin{array}{c} \text{activities} \\ \left[\begin{array}{c} \\ \end{array} \right]^{-1} \\ \text{+} \\ \text{+} \\ \text{+} \\ \hline \text{= 1} \end{array} & \times & \begin{array}{c} \text{products} \\ \left[\begin{array}{c} \\ \end{array} \right] \end{array}
 \end{array}$$

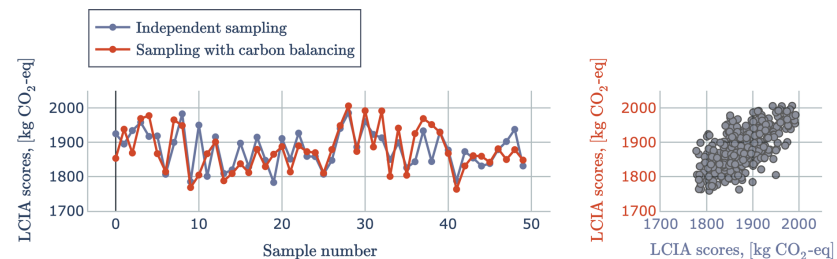
- Find implicit markets with approximate / fuzzy string matching
- Use Dirichlet distribution to preserve fixed unit sum
- How to ensure that uncertain production volume shares sum up to 1?

- Case study: climate change impacts of average Swiss household consumption

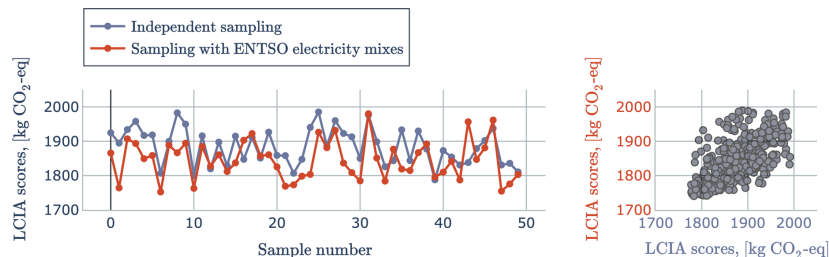
Module 1: parameterization



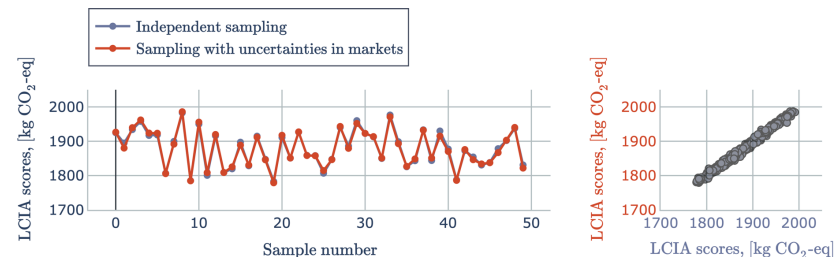
Module 2: carbon balancing



Module 3: electricity mixes



Module 4: implicit markets



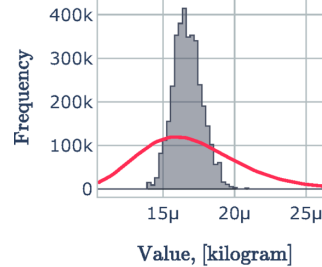
- Conclusions
 - Correlated and dependent sampling is possible
 - Effect of sampling modules on LCIA impact scores can range from completely negligible to rather significant, which ultimately depends on the case study and considered impact category
 - Better sampling strategies that introduce correlations and dependencies between model inputs can be added as separate modules
 - Sampling modules can be added to any case study
 - Brightway 2.5 allows seamless integration of additional modules

Module 1: Example of parameterized activities

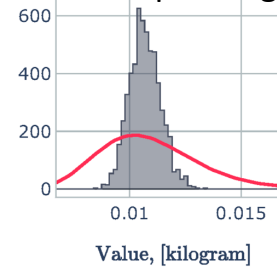
- Activity transport, passenger car, medium size, liquefied petroleum gas, EURO 5
- Parameters road, brake and tyre emissions per kilogram of vehicle, vehicle weight with and without passengers, vehicle lifetime
- Exchanges

 Parameterized samples
 Defined lognormal distributions

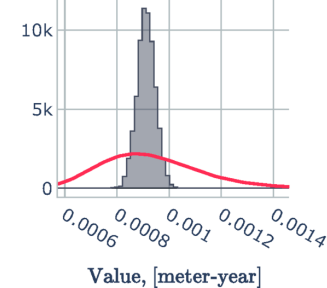
road wear emissions



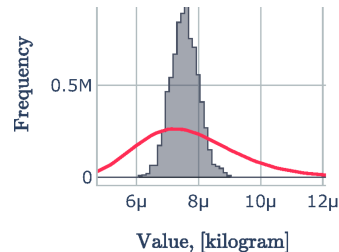
market for passenger car



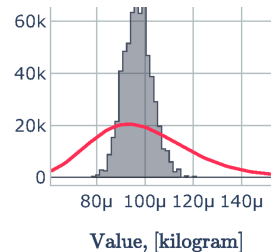
road



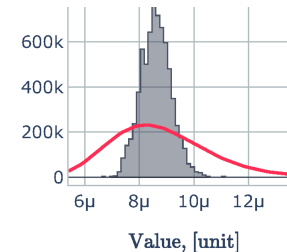
brake wear emissions



tyre wear emissions



car maintenance



Module 1: Example of parameterized activities

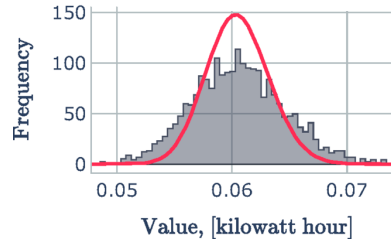
- Activity
- Parameters
- Exchanges

hydroelectricity production for aluminium industry

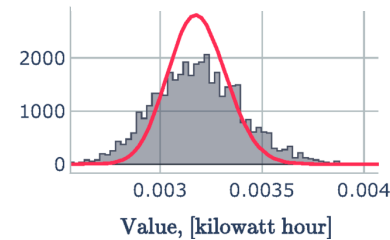
shares of reservoir, run-of-river and pump storage in different regions

Parameterized samples
Defined lognormal distributions

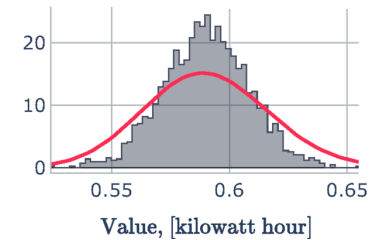
reservoir, alpine region



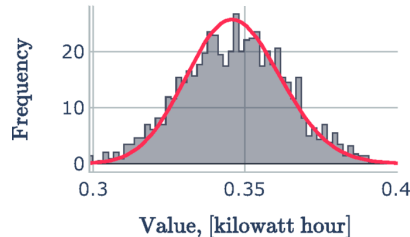
run-of-river, region 1



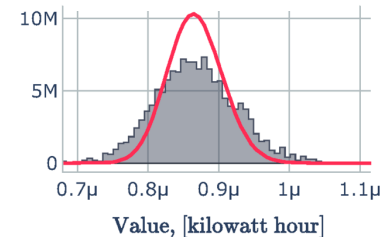
reservoir, non-alpine region



pumped storage



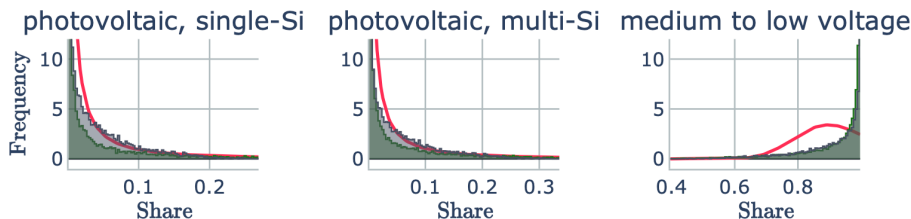
run-of-river, region 2



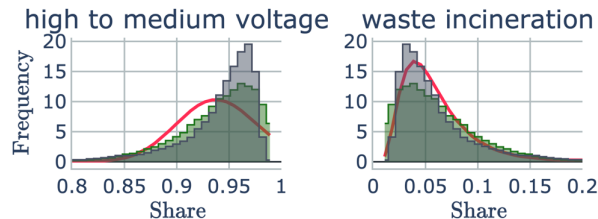
Module 4: Validation of Dirichlet on ENTSO-E data for Denmark

■ ENTSO-E reported data
 — Defined lognormal distributions
 ■ Dirichlet samples

market for electricity, low voltage



market for electricity, medium voltage



market for electricity, high voltage

