



WIR SCHAFFEN WISSEN – HEUTE FÜR MORGEN

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# Towards more realistic global sensitivity analysis of life cycle assessment studies

SETAC Europe 32<sup>nd</sup> Annual Meeting, 15-19 May 2022

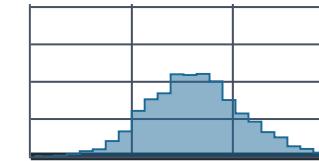
# Global sensitivity analysis in a nutshell

## Life cycle assessment (LCA) model

$$\text{impacts} \quad [ ] = \quad \text{impact categories} \quad [ \text{env. flows} ] \times \text{env. flows} \quad [ \text{activities} ] \times \text{activities} \quad [ \text{products} ]^{-1} \times \text{products} \quad [ \text{activities} ] \times \text{DEMAND}$$

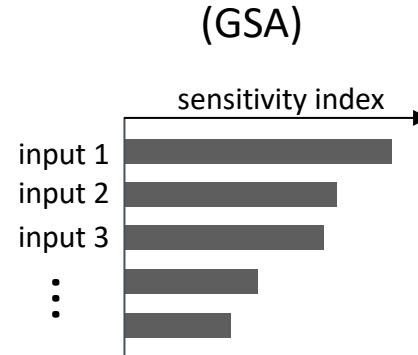
SCORES      CHARACTERIZATION      BIOSPHERE      TECHNOSPHERE      DEMAND

## Monte Carlo runs



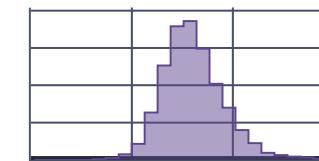
**LCIA scores**

## Global sensitivity analysis (GSA)



Prioritized  
data collection

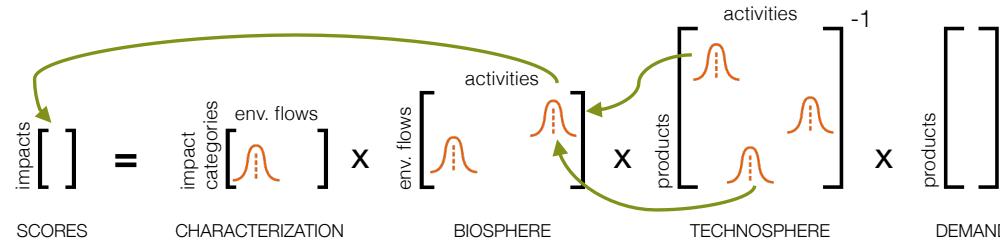
## Reduce uncertainty



**LCIA scores**

Improve modeling

# 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

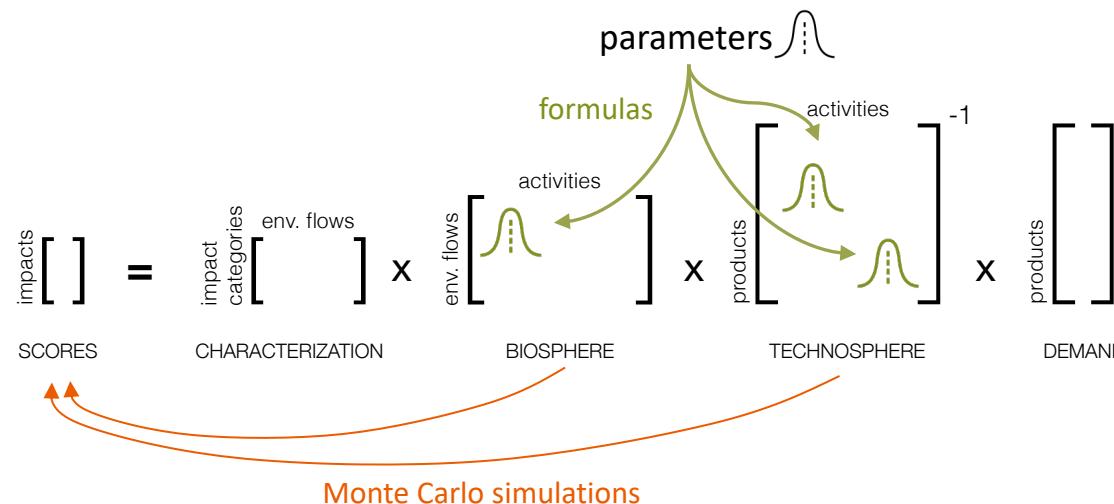
Kim, A., Mutel, C.L., Froemelt, A. and Hellweg, S., 2021. Global Sensitivity Analysis of Background Life Cycle Inventories. *Environmental Science & Technology*. DOI: 10.1021/acs.est.1c07438

# Outline

- 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

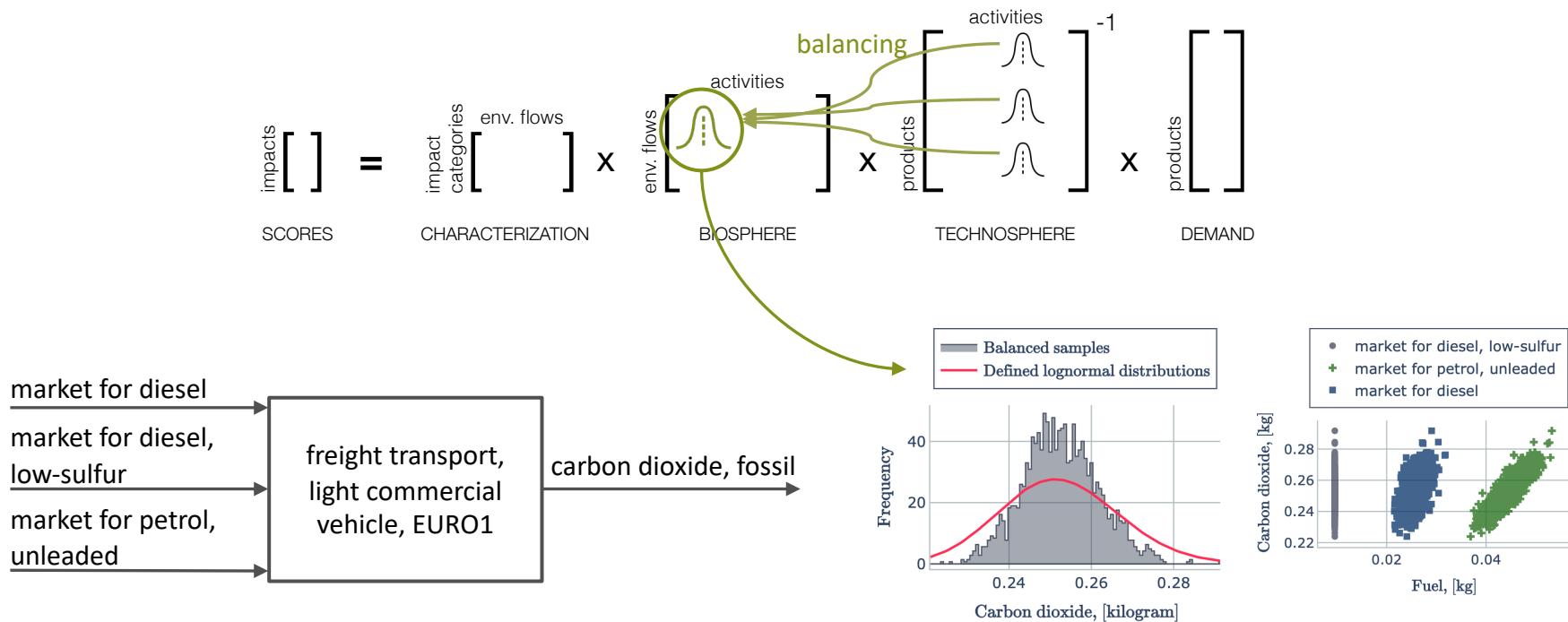
# Module 1: Parameterization

How to propagate changes in parameters to technosphere and biosphere?



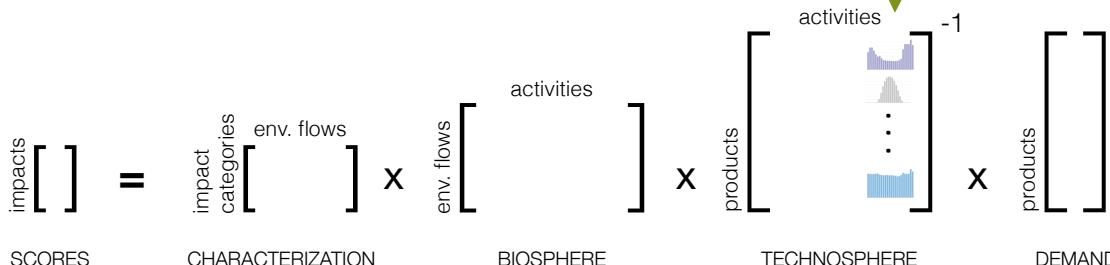
# Module 2: Carbon balances for combustion

- How to propagate changes in technosphere to biosphere?

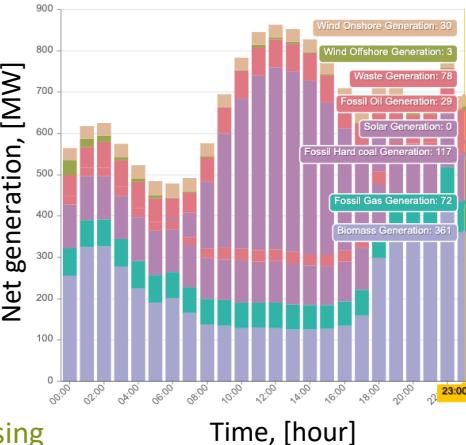


# Module 3: Electricity mixes

- 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

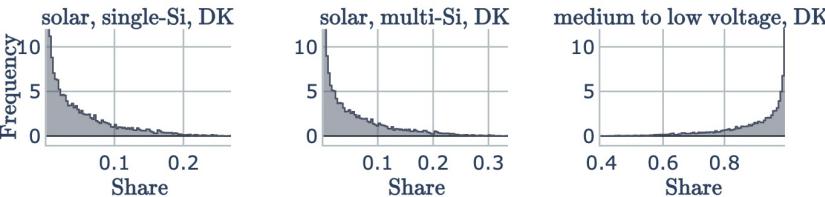


Denmark, 18.04.22

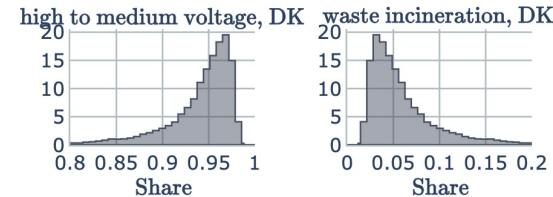


# Module 3: ENTSO-E data for Denmark

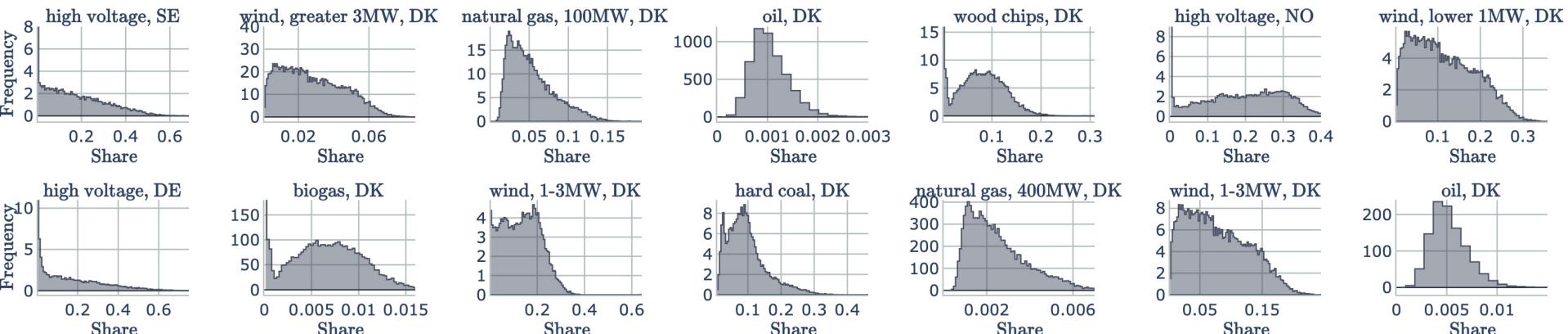
Market for electricity, LOW voltage



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

$$\begin{aligned}
 \text{impacts} & \left[ \quad \right] = \text{impact categories} \left[ \quad \right] \times \text{env. flows} \left[ \quad \right] \times \text{env. flows} \left[ \quad \right] \times \text{activities} \left[ \quad \right] \times \text{products} \left[ \quad \right]^{-1} \\
 & \text{SCORES} \qquad \text{CHARACTERIZATION} \qquad \text{BIOSPHERE} \qquad \text{TECHNOSPHERE} \qquad \text{DEMAND}
 \end{aligned}$$

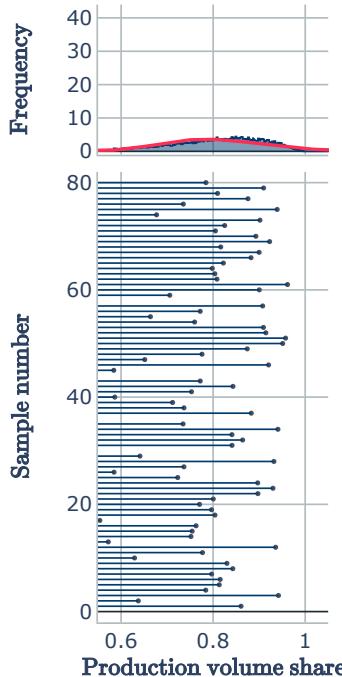
activities  
 +  
 +  
 = 1

- 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?

# Module 4: Example of Dirichlet samples

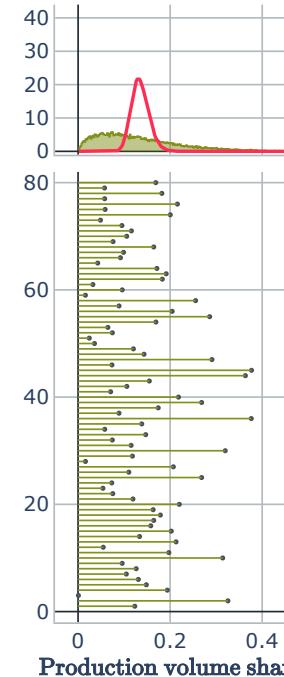
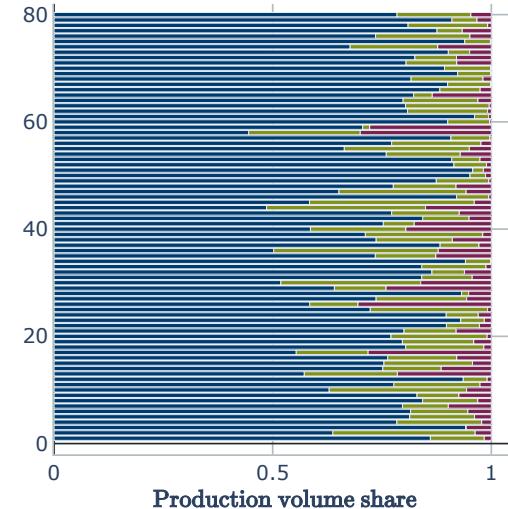
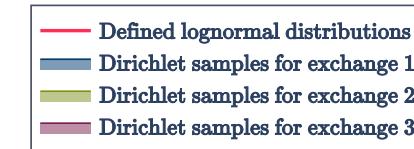
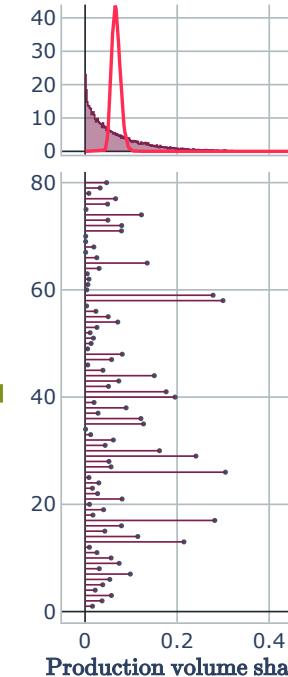
- Market:
- Exchanges

pressure water reactor



Electricity from nuclear for aluminium production

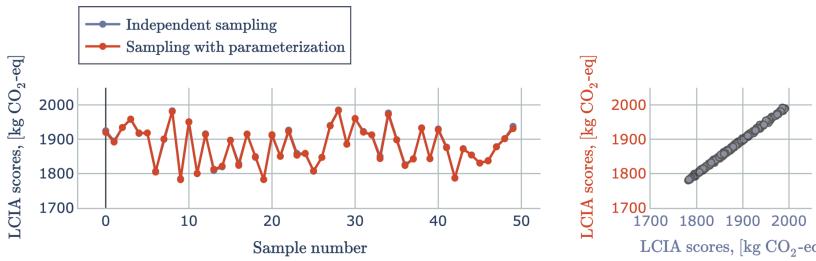
boiling water reactor

pressure water reactor,  
heavy water moderated

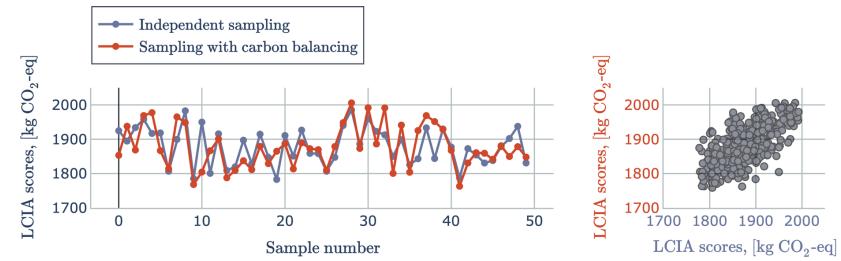
# Monte Carlo simulations

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

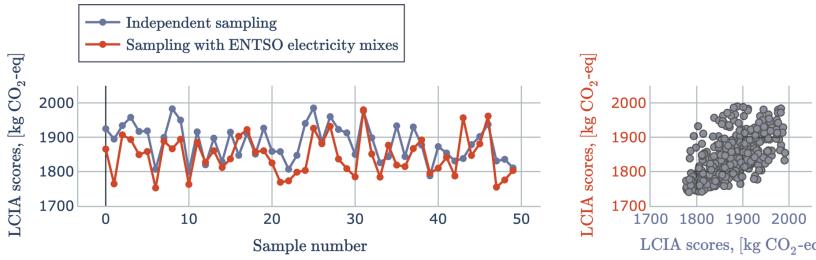
## Module 1: parameterization



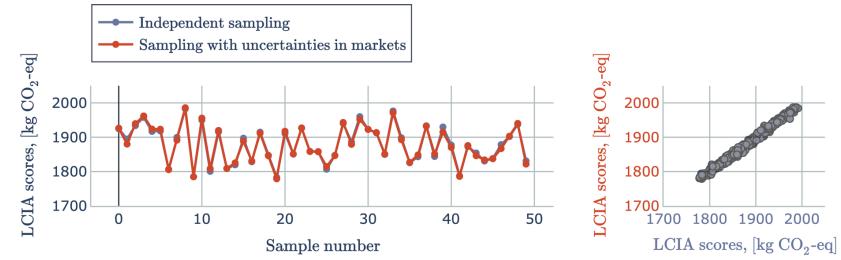
## Module 2: carbon balancing



## Module 3: electricity mixes



## Module 4: implicit markets



# Outlook

- 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

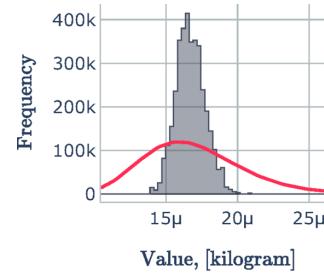
# Module 1: Example of parameterized activities

- Activity
- Parameters
- Exchanges

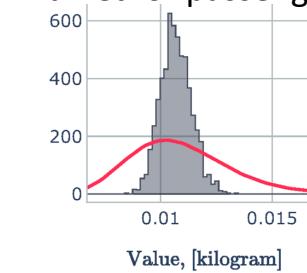
Parameterized samples  
— Defined lognormal distributions

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

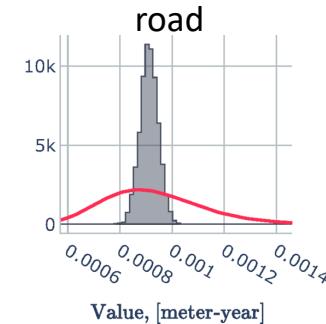
road wear emissions



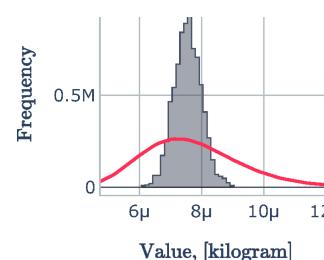
market for passenger car



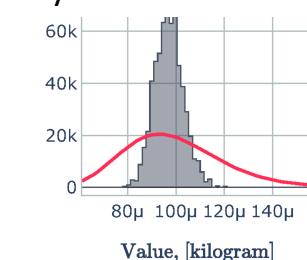
road



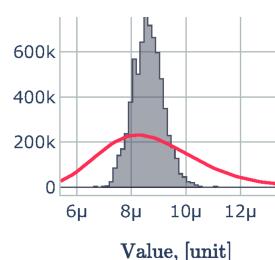
brake wear emissions



tyre wear emissions



car maintenance

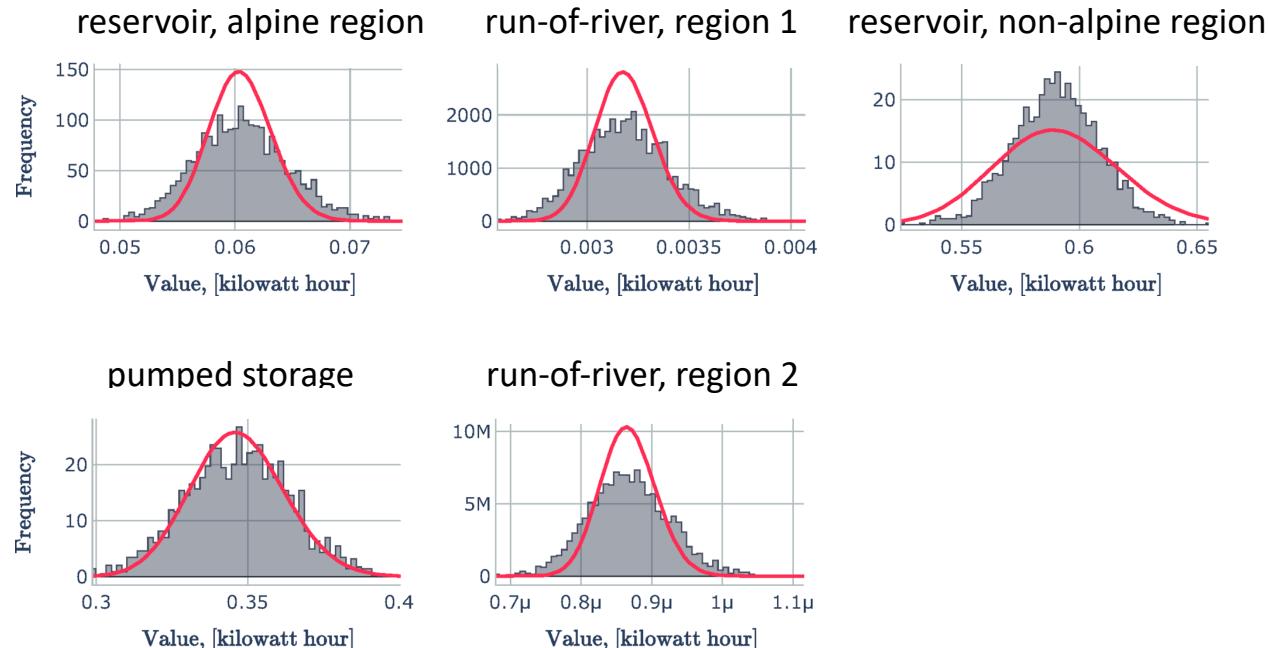


# Module 1: Example of parameterized activities

- Activity
- Parameters
- Exchanges

hydroelectricity production for aluminium industry  
shares of reservoir, run-of-river and pump storage in different regions

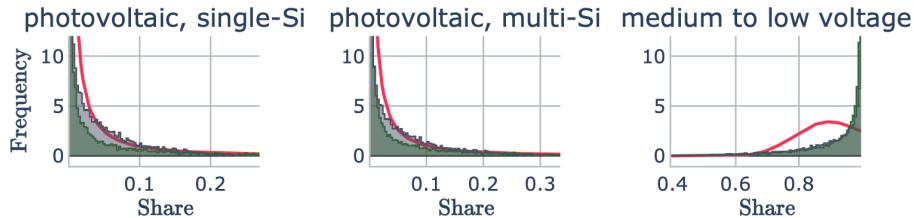
Parameterized samples  
Defined lognormal distributions



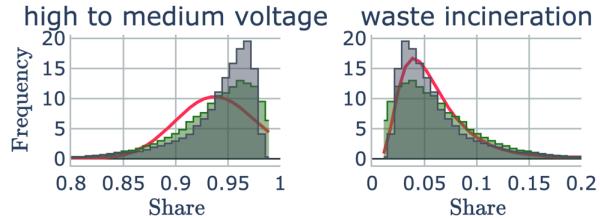
# Module 4: Validation of Dirichlet on ENTSO-E data for Denmark

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

market for electricity, low voltage



market for electricity, medium voltage



market for electricity, high voltage

