Consistent normalization approach for LCA, based on a study-specific reference system

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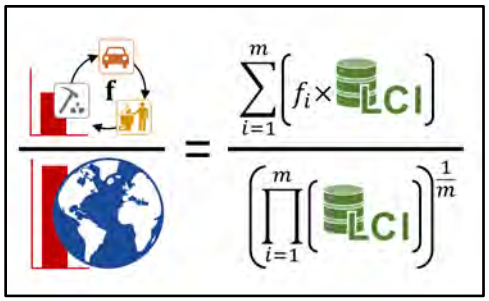
life cycle & sustainability assessment

Overview

- Issue: Consistent normalization reference values



- Approach: use LCI database as reference

ecoinvent Centre

- Application: Ecoinvent 3.5 & available normalisation reference sets

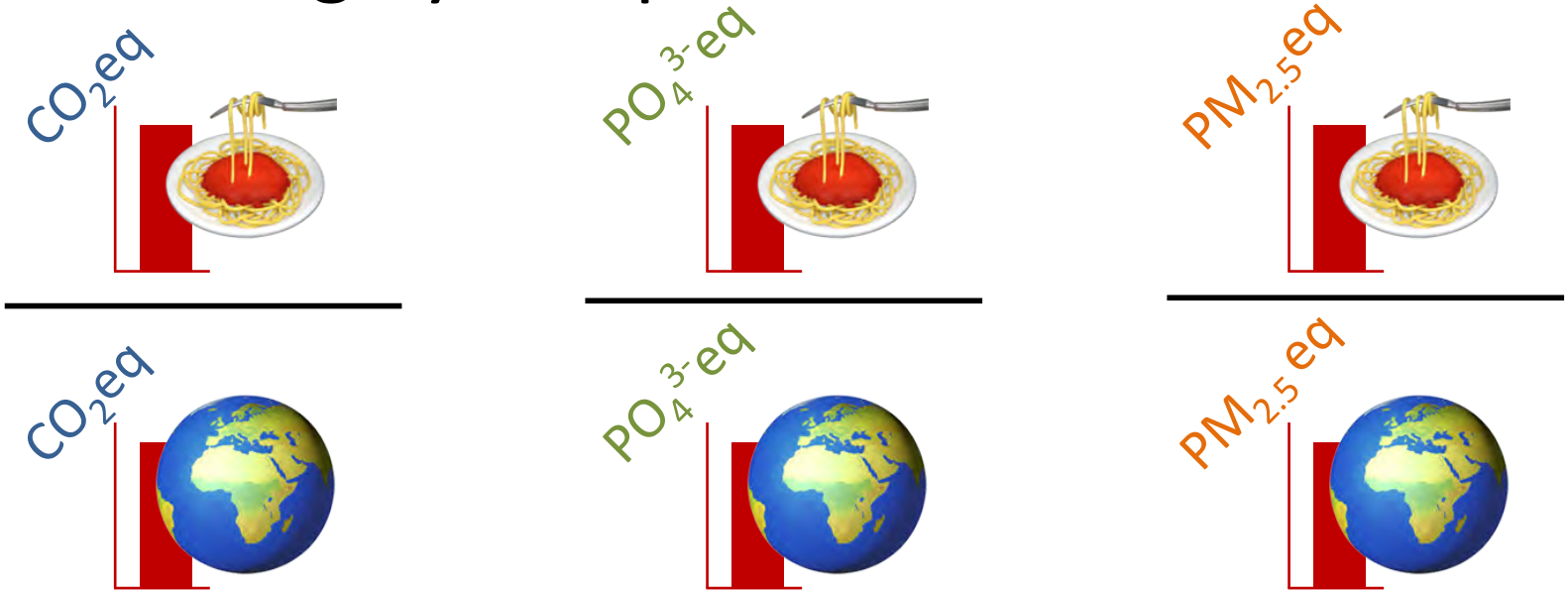
Life Cycle Assessment

- Quantifying the impacts

Life Cycle Assessment

- Quantifying the impacts

- Meaning by comparison



Determination of impacts

- Based on Life Cycle Inventory database
- LCA matrix algebra
- involved processes (perimeter)
- modelling choices
- inventoried substances

- Statistics from international agencies & institutions
- A structured collection and aggregation work
- involved processes (perimeter)
- modelling choices
- inventoried substances

Determination of impacts

○ Based on Life Cycle Inventory database	≠	○ Statistics from international agencies & institutions
○ LCA matrix algebra	≠	○ A structured collection and aggregation work
○ involved processes (perimeter)	?	○ involved processes (perimeter)
○ modelling choices	?	○ modelling choices
○ inventoried substances	?	○ inventoried substances

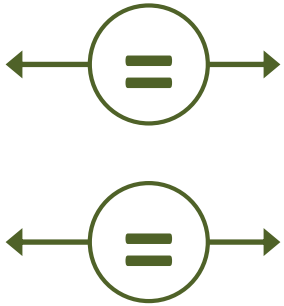
Need of methods providing consistent and sufficiently complete references at a global scale. (Pizzol et al., 2017)

Starting point

- Based on Life Cycle Inventory database
- LCA matrix algebra

- involved processes (perimeter)
- modelling choices

- inventoried substances



- Statistics from international agencies & institutions
- A structured collection and aggregation work

- involved processes (perimeter)
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- inventoried substances

Starting point

○ Based on Life Cycle Inventory database	=	○ Statistics from international agencies & institutions
○ LCA matrix algebra	=	○ A structured collection and aggregation work
○ involved processes (perimeter)	✓	○ involved processes (perimeter)
○ modelling choices	✓	○ modelling choices
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Consistent normalization approach

Starting point

- Based on Life Cycle Inventory database
- LCA matrix algebra

= Statistics from international agencies & institutions

= A structured collection and aggregation work

- involved processes (perimeter)

✓ involved processes (perimeter)

- modelling choices

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Consistent normalization approach

Illustrative example

LCI is only wheat & tomato…

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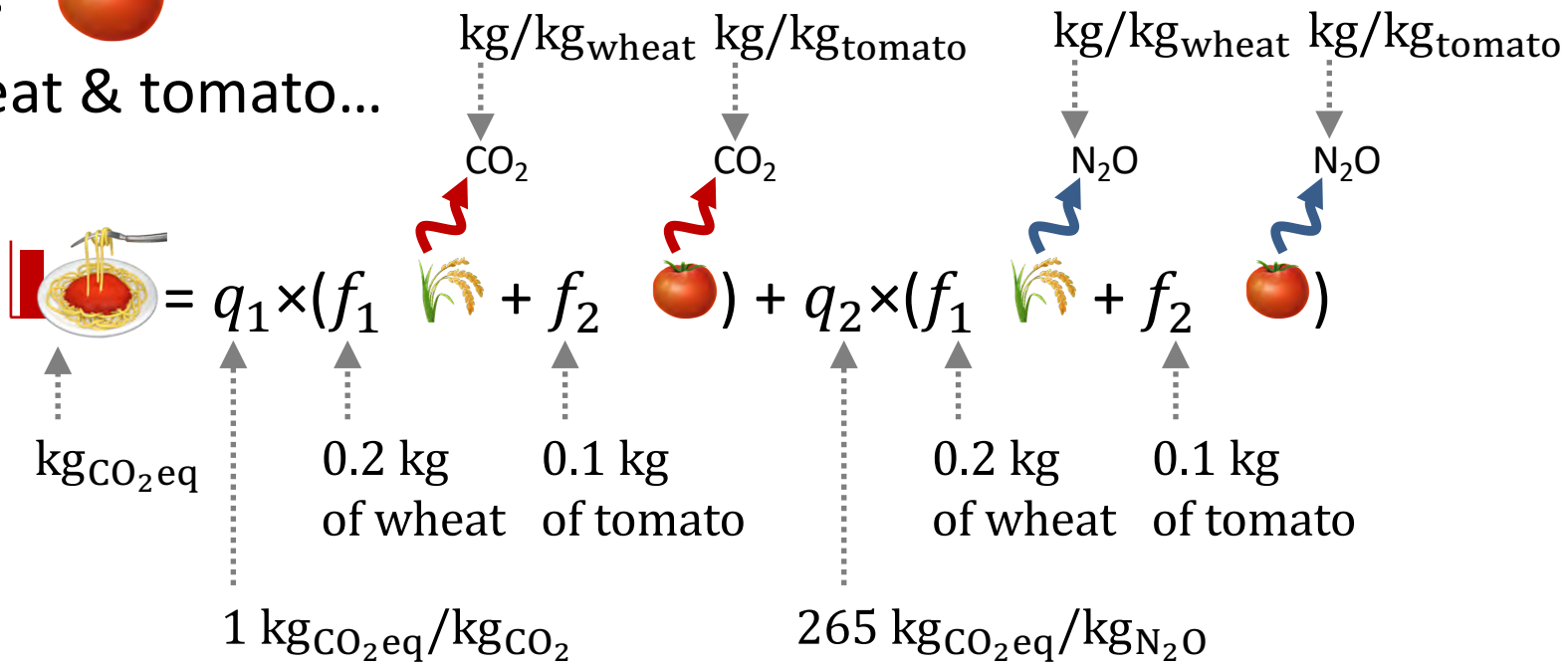
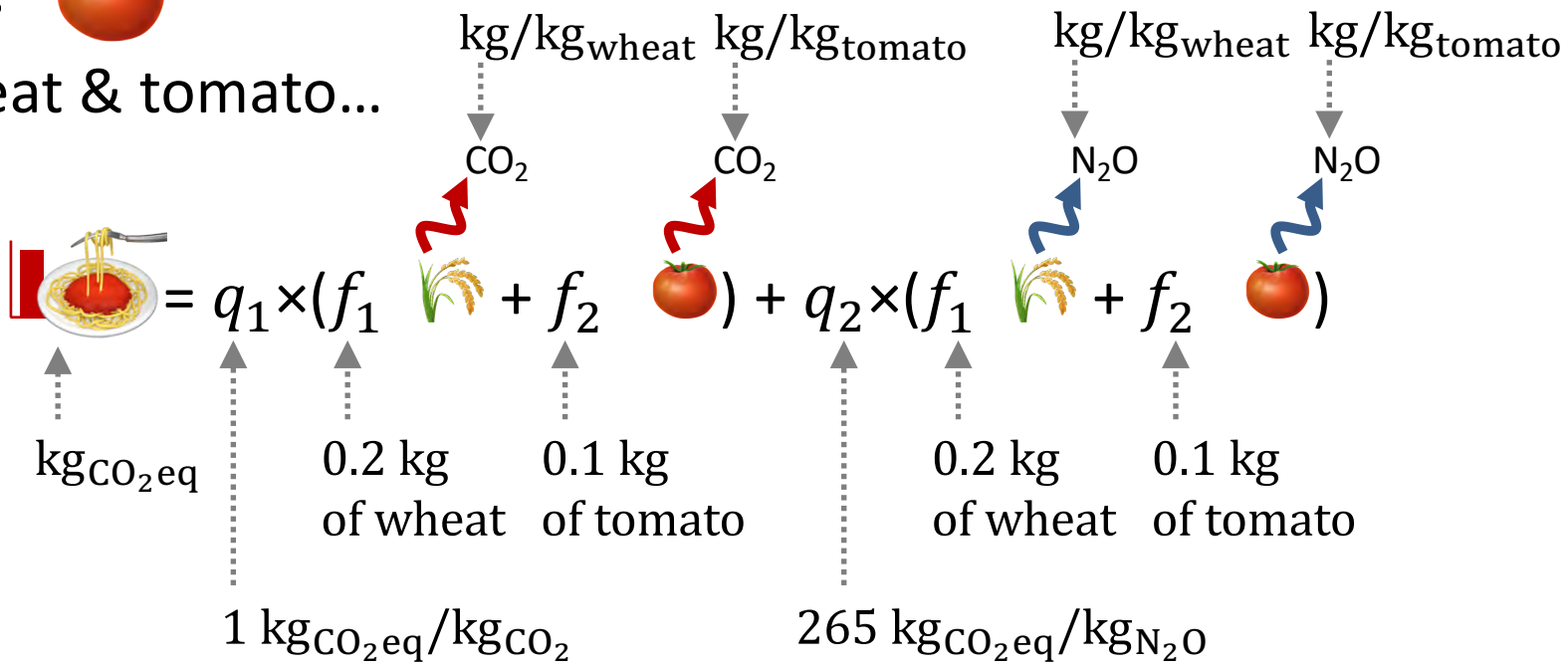
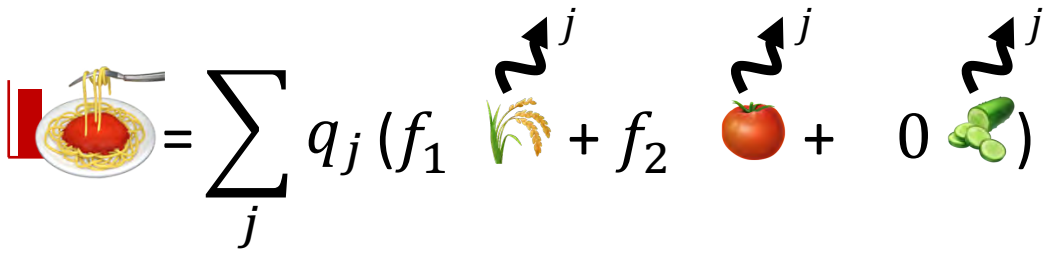


 & : pre-calculated interventions in the LCI database

Illustrative example

LCI is only wheat & tomato…





The “world” is composed of wheat, tomato & cucumber
(3 datasets in the LCI database)

Principle

- Based on Life Cycle Inventory database
- LCA matrix algebra

= Statistics from international agencies & institutions

= A structured collection and aggregation work

- involved processes (perimeter)
- modelling choices
- inventoried substances

✓ involved processes (perimeter)

✓ modelling choices

✓ inventoried substances

Consistent normalization approach

Principle

- Based on Life Cycle Inventory database
- LCA matrix algebra
- involved processes (perimeter)
- modelling choices
- inventoried substances

=

=

✓

✓

✓

- **Based on Life Cycle Inventory database**
- **LCA matrix algebra**
- involved processes (perimeter)
- modelling choices
- inventoried substances

Consistent normalization approach

Illustrative example

World (reference system) is only wheat, tomato and cucumber…

$$\text{🌍} = \sum_j q_j \left(f_1^{\text{REF}} \overset{j}{\rightsquigarrow} \text{🌾} + f_2^{\text{REF}} \overset{j}{\rightsquigarrow} \text{🍅} + f_3^{\text{REF}} \overset{j}{\rightsquigarrow} \text{🥒} \right)$$

- ✓No additional data required
- ~Exhaustivity of the data?
- ✗Unknown final demands…

Illustrative example

World (reference system) is only wheat, tomato and cucumber…

$$\blacksquare = \sum_j q_j \left(f_1^{\mathrm{REF}} \rightsquigarrow^{j} + f_2^{\mathrm{REF}} \rightsquigarrow^{j} + f_3^{\mathrm{REF}} \rightsquigarrow^{j} \right)$$

? ? ?

- ✓No additional data required
- ~Exhaustivity of the data?
- ✗Unknown final demands…

Illustrative example

$$\text{🌍} = \sum_j q_j \left(f_1^{\text{REF}} \text{🌾}^j + f_2^{\text{REF}} \text{🍅}^j + f_3^{\text{REF}} \text{🥒}^j\right)$$

- The arithmetic mean

$$M_1\left(\text{🍅🥒}^j \; \mathbf{f}^{\text{REF}}\right) = \frac{\left(f_1^{\text{REF}} \text{🌾}^j + f_2^{\text{REF}} \text{🍅}^j + f_3^{\text{REF}} \text{🥒}^j\right)}{n}$$

- The mean instead of the sum

$$\text{🌍} = n \times \sum_j q_j \times M_1\left(\text{🍅🥒}^j \; \mathbf{f}^{\text{REF}}\right)$$

Illustrative example

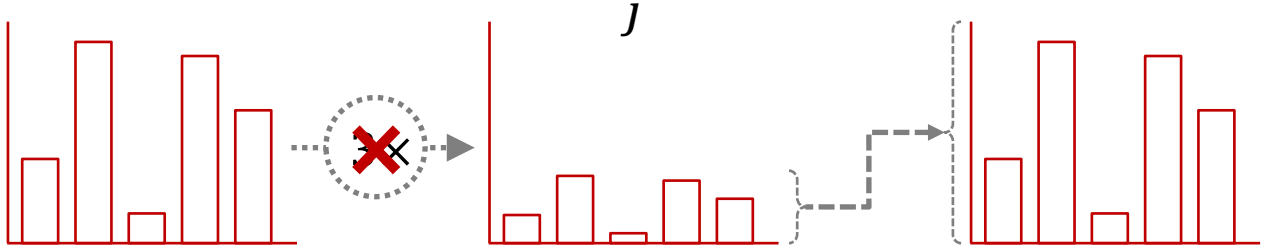
$$\text{🌍} = \sum_j q_j \left(f_1^{\text{REF}} \text{🌾}^j + f_2^{\text{REF}} \text{🍅}^j + f_3^{\text{REF}} \text{🥒}^j\right)$$

- The arithmetic mean

$$M_1\left(\text{🥒🍅}^j \; \mathbf{f}^{\text{REF}}\right) = \frac{\left(f_1^{\text{REF}} \text{🌾}^j + f_2^{\text{REF}} \text{🍅}^j + f_3^{\text{REF}} \text{🥒}^j\right)}{n}$$

- The mean instead of the sum

$$\text{🌍} = \cancel{n} \times \sum_j q_j \times M_1\left(\text{🥒🍅}^j \; \mathbf{f}^{\text{REF}}\right)$$



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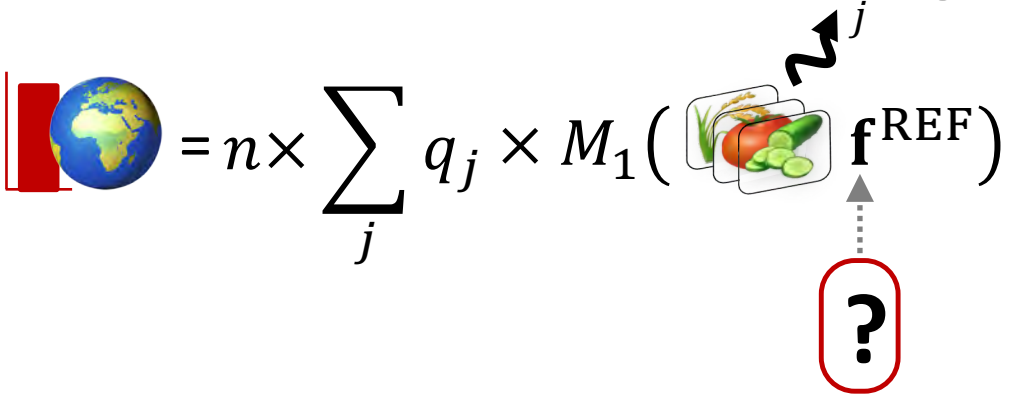
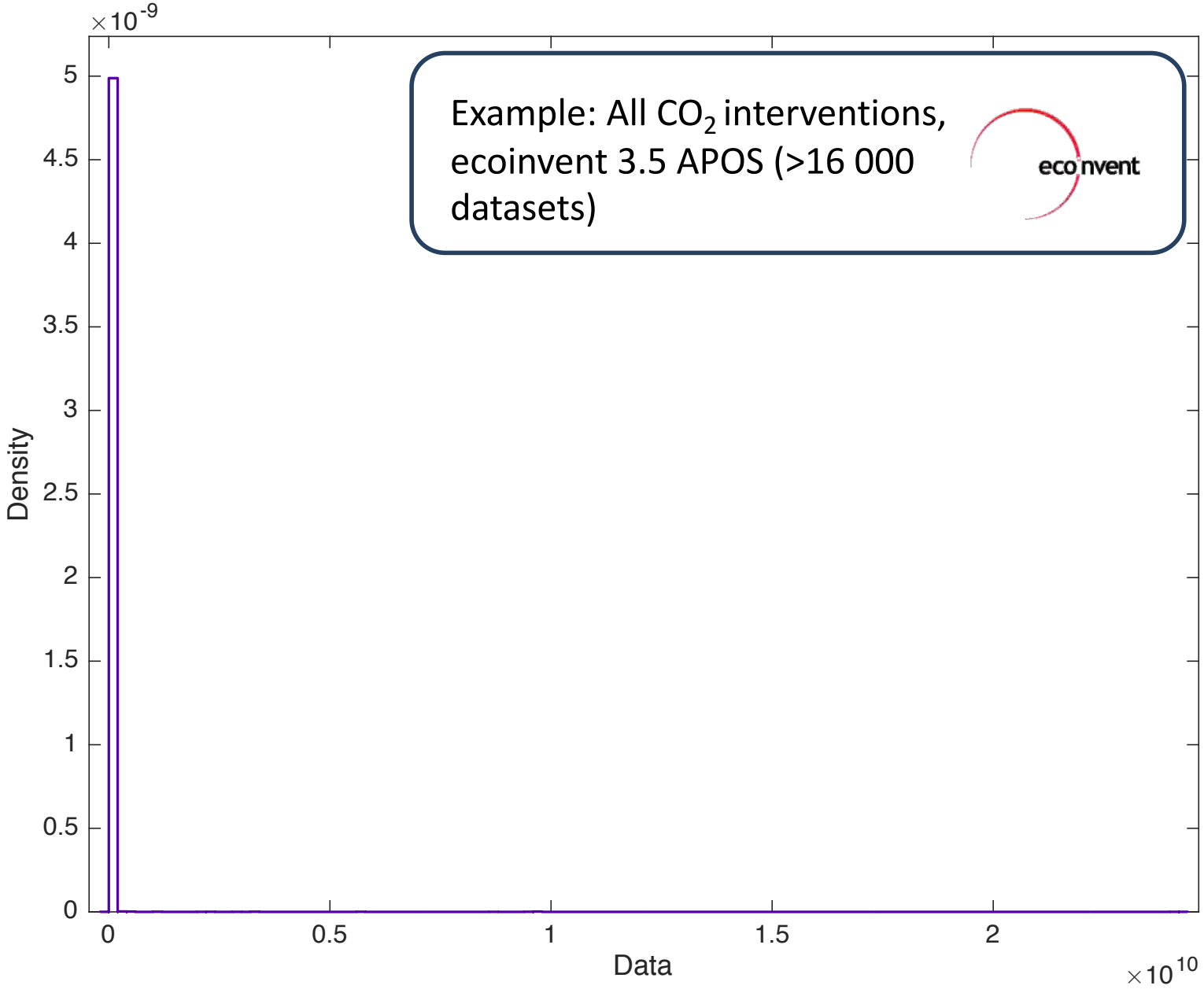
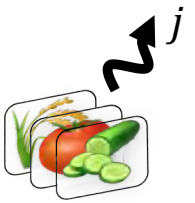


- No change in the conclusions
- Unknown final demands

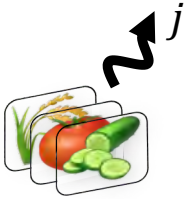
Distribution of data



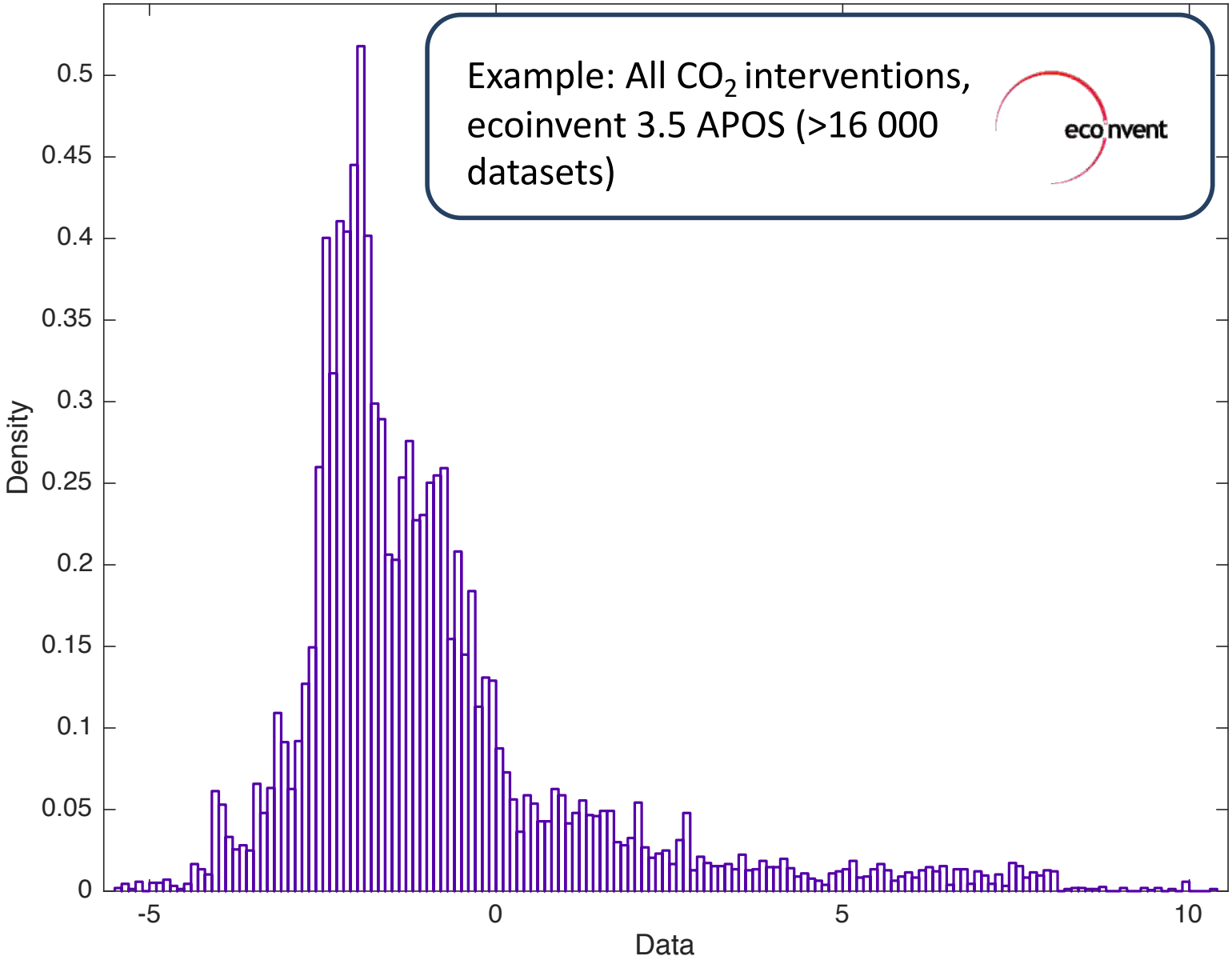
Example: All CO_2 interventions, ecoinvent 3.5 APOS (>16 000 datasets)



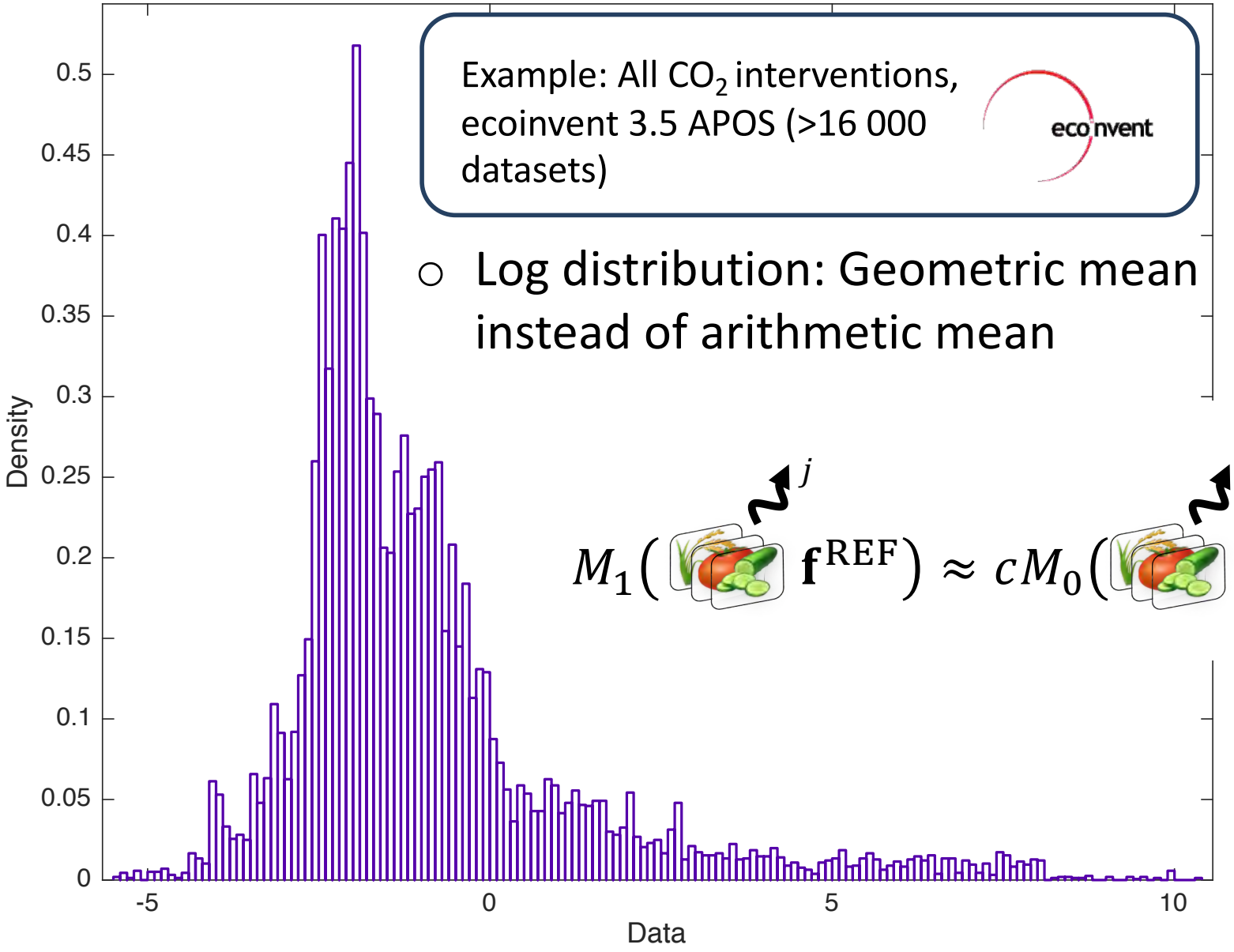
Distribution of data, log-scale



Example: All CO_2 interventions, ecoinvent 3.5 APOS (>16 000 datasets)



Distribution of data, log-scale



Example: All CO_2 interventions, ecoinvent 3.5 APOS (>16 000 datasets)

- Log distribution: Geometric mean instead of arithmetic mean

$$M_1\left(\mathbf{f}^{\mathrm{REF}}\right) \approx cM_0\left(\mathbf{f}^{\mathrm{REF}}\right)$$

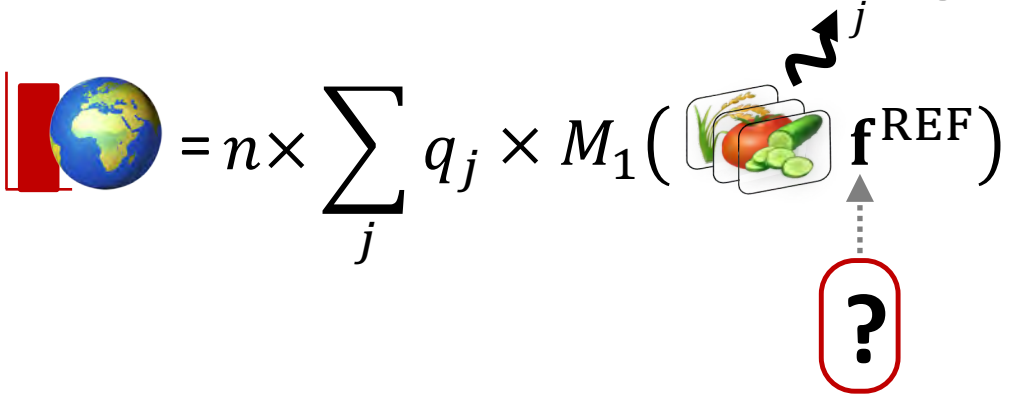
Geometric mean

$$M_0\left(\sim^{j}\ \mathbf{f}^{\mathrm{REF}}\right) = \sqrt[3]{\left(f_1^{\mathrm{REF}}\sim^{j} \times f_2^{\mathrm{REF}}\sim^{j} \times f_3^{\mathrm{REF}}\sim^{j}\right)}$$

$$M_0\left(\sim^{j}\ \mathbf{f}^{\mathrm{REF}}\right) = \sqrt[3]{\sim^{j} \times \sim^{j} \times \sim^{j}} \times \sqrt[3]{f_1^{\mathrm{REF}} \times f_2^{\mathrm{REF}} \times f_3^{\mathrm{REF}}}$$

$$M_0\left(\sim^{j}\ \mathbf{f}^{\mathrm{REF}}\right) = M_0\left(\sim^{j}\right) \times M_0\left(\mathbf{f}^{\mathrm{REF}}\right)$$

Illustrative example



- No change in the conclusions
- Unknown final demands

Illustrative example

$$\approx n \times \sum_j q_j \times c \times M_0(\text{}^{j}) \times M_0\left(\mathbf{f}^{\mathrm{REF}}\right)$$

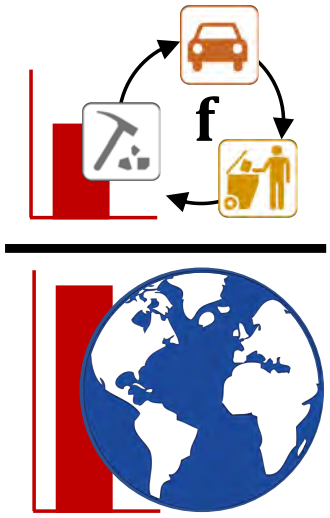
$$\approx n \times c \times M_0\left(\mathbf{f}^{\mathrm{REF}}\right) \sum_j q_j \times M_0(\text{}^{j})$$

$$\approx \cancel{n \times c \times M_0\left(\mathbf{f}^{\mathrm{REF}}\right)} \sum_j q_j \times M_0(\text{}^{j})$$

- No change in the conclusions
- **No final demands in the normalization references…**

Outline

- An expression of the result relative to the average component of the reference system instead of the sum of all the components.
- Consistency between system under study & normalization references
  - Same involved processes (perimeter)
  - Same modelling choices
  - Same inventoried substances
- No additional data collection

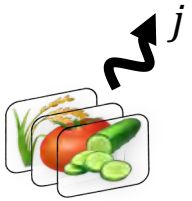


$$\frac{}{} = \frac{\sum_{i=1}^{m}\left[f_i \times \text{LCI}\right]}{\left(\prod_{i=1}^{m}\left(\text{LCI}\right)\right)^{\frac{1}{m}}}$$

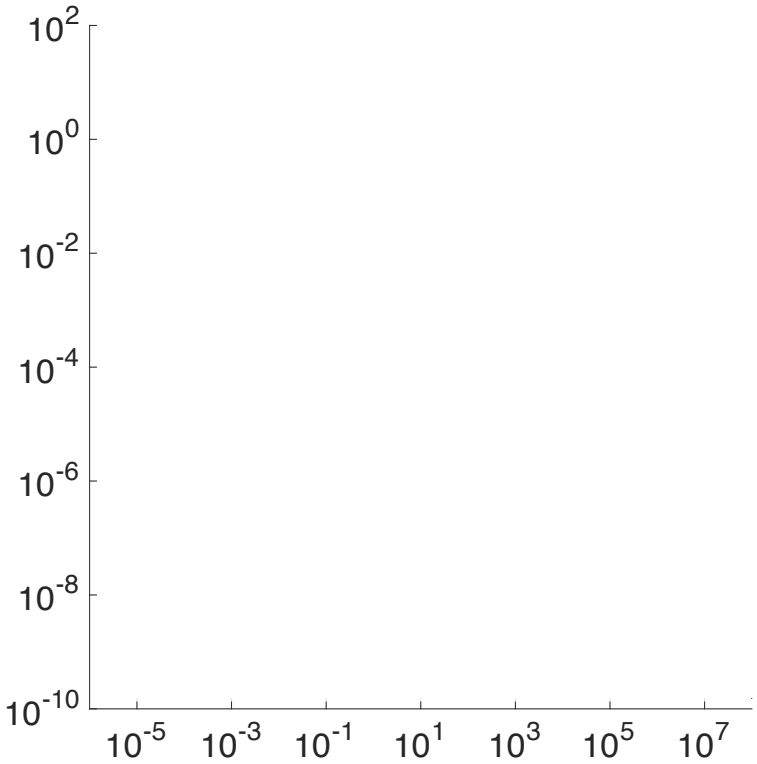
Application

- Ecoinvent 3.5
  - Long-term/no long-term emissions
  - 3 system models
    - At Point Of Substitution (APOS)
    - Cut-off
    - Consequential
- Geometric mean constraints (>0)
  - Approximated geometric mean
  - Pre-calculated inventories
- Comparison database-based vs literature based normalizations
- Available LCIA methods (provided by ecoinvent):
  - CML 2000, EDIP 2003, ILCD 2016, EF 2.0, ReCiPe midpoint 2008 (E,H&I versions), TRACI (first version)

Comparison



Database-based normalization references



Resource use, fossils
Land use
Climate change
Ecotoxicity, freshwater
Water use
Ionising radiation, human health
Eutrophication, terrestrial
Acidification
Phot. ozone form., human health
Eutrophication, marine
Eutrophication, freshwater
Resource use, minerals and metals
Human toxicity, non-cancer
Ozone depletion
Particulate matter
Human toxicity, cancer

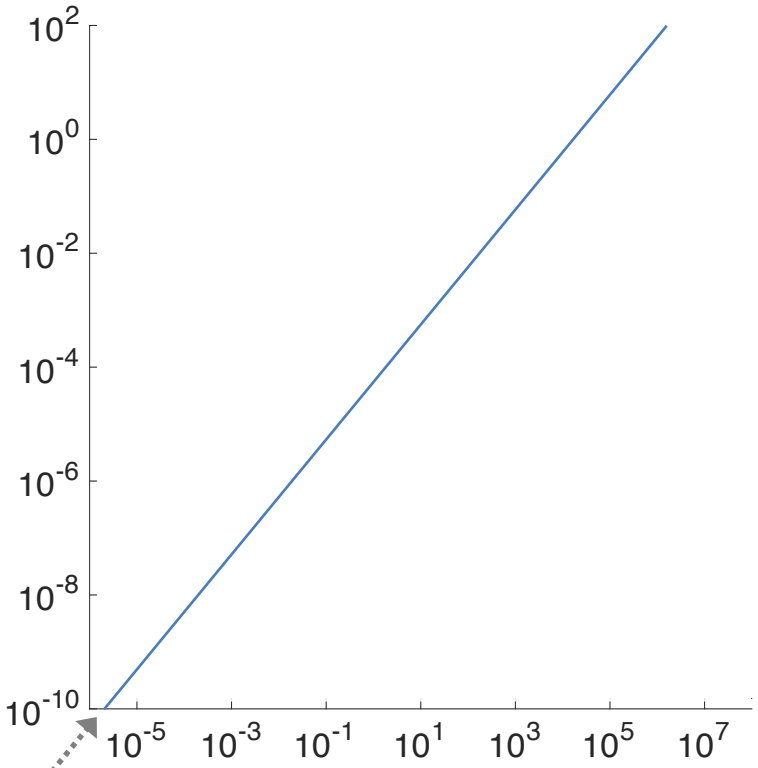
Literature-based normalization references

Comparison

$h_k^{\mathrm{REF},\widetilde{\mathbf{B}}}$

j

Database-based normalization references



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Literature-based normalization references

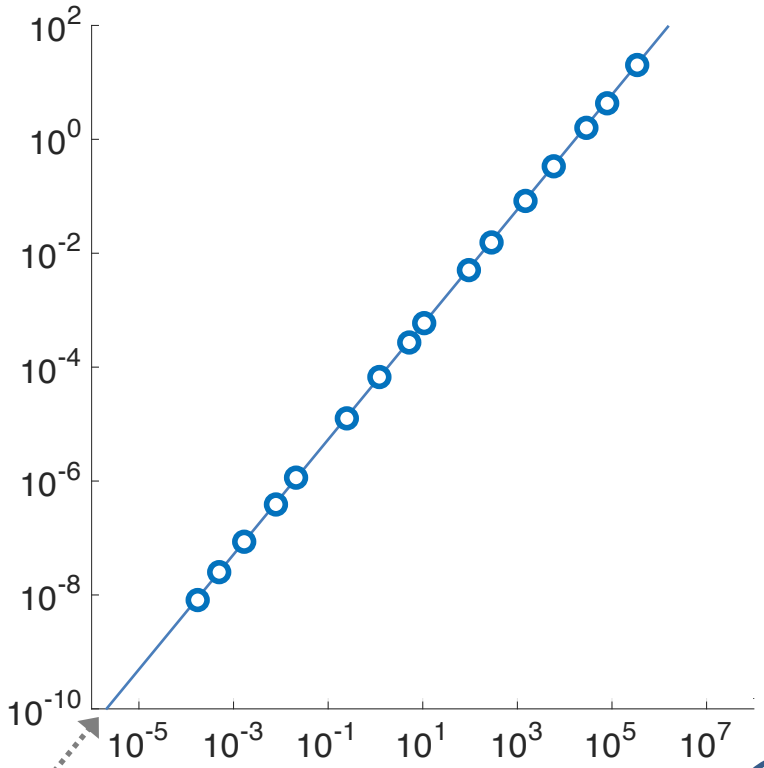
h_k^{REF}

$$h_k^{\mathrm{REF},\widetilde{\mathbf{B}}} = \frac{h_k^{\mathrm{REF}}}{n \times \mathrm{c} \times M_0(\mathbf{f}^{\mathrm{REF}})}$$

Comparison

$h_k^{\mathrm{REF},\widetilde{\mathbf{B}}}$ $\rightsquigarrow j$

Database-based normalization references



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$$h_k^{\mathrm{REF},\widetilde{\mathbf{B}}} = \frac{h_k^{\mathrm{REF}}}{n \times \mathrm{c} \times M_0(\mathbf{f}^{\mathrm{REF}})}$$

Literature-based normalization references

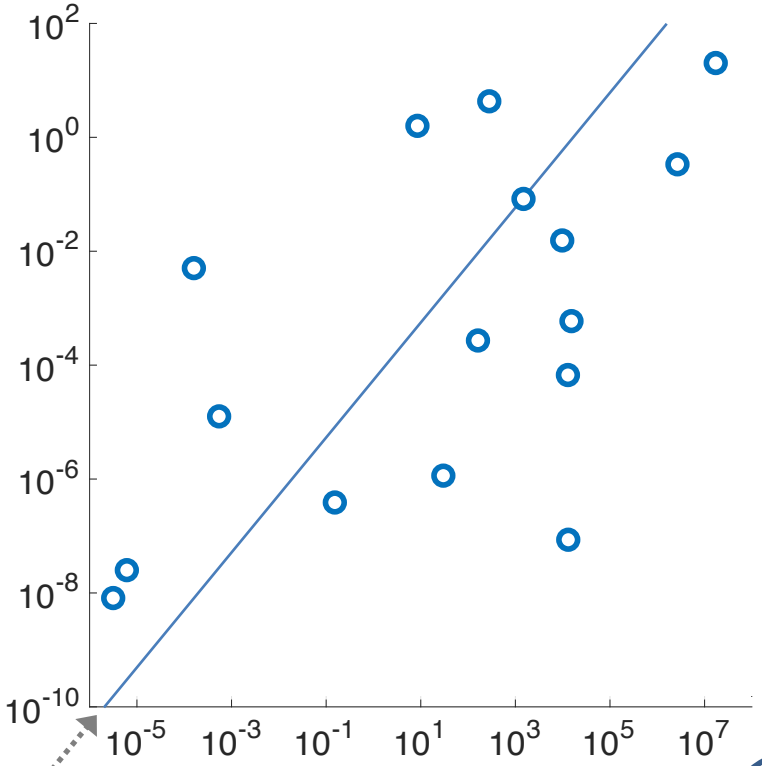
h_k^{REF}

- Perfect relation:
  - same representativeness of the reference sets
  - $M_1(\rightsquigarrow^{j} \mathbf{f}^{\mathrm{REF}}) \approx cM_0(\rightsquigarrow^{j} \mathbf{f}^{\mathrm{REF}})$

Comparison

$h_k^{\mathrm{REF},\tilde{\mathbf{B}}}$ $\rightsquigarrow j$

Database-based normalization references



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$$h_k^{\mathrm{REF},\tilde{\mathbf{B}}} = \frac{h_k^{\mathrm{REF}}}{n \times \mathrm{c} \times M_0(\mathbf{f}^{\mathrm{REF}})}$$

- Bad relation:
  - Something wrong…

Comparison

$h_k^{\mathrm{REF},\tilde{\mathbf{B}}}$ $\rightsquigarrow j$

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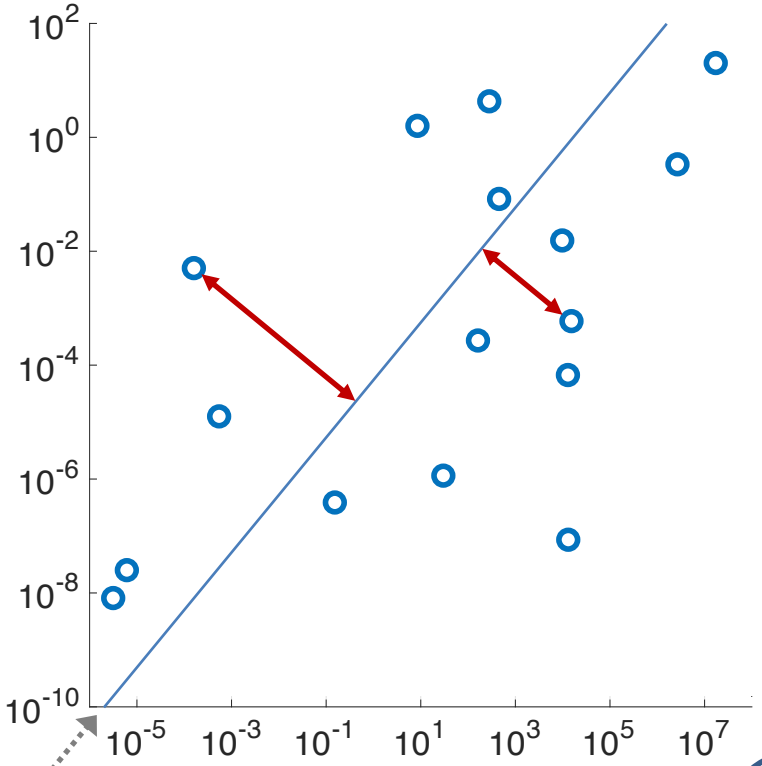

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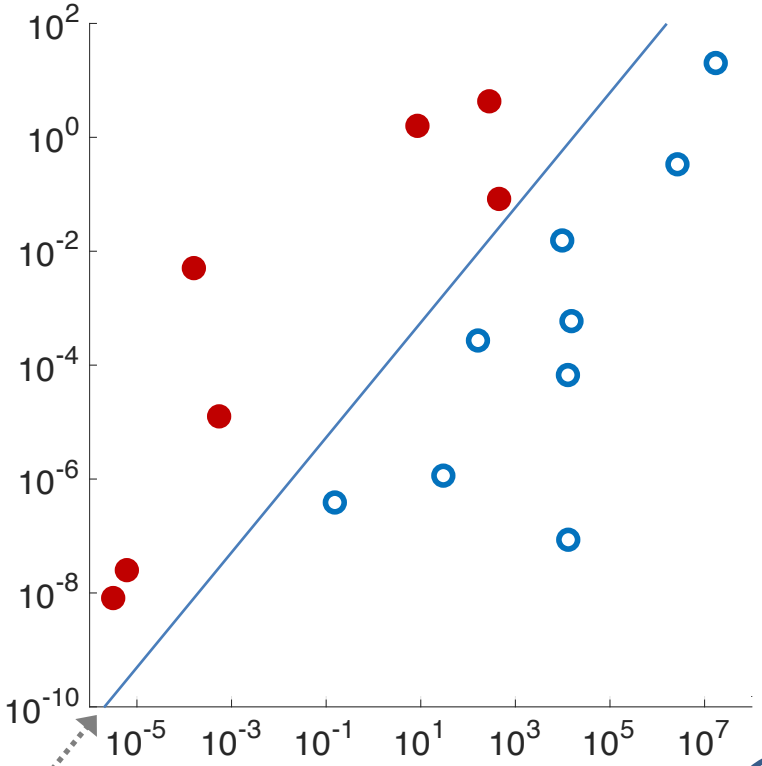
- Dispersion assessed by coefficient of variation (σ/μ, log-scale)

Comparison

$h_k^{\mathrm{REF},\tilde{\mathbf{B}}}$ $\rightsquigarrow j$

Database-based normalization references



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Literature-based normalization references

h_k^{REF}

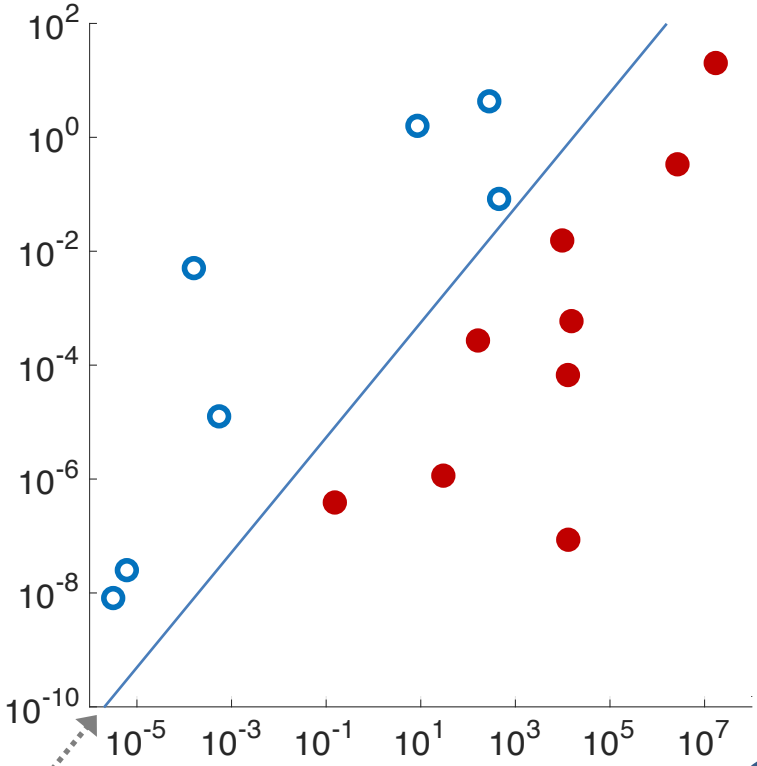
$$h_k^{\mathrm{REF},\tilde{\mathbf{B}}} = \frac{h_k^{\mathrm{REF}}}{n \times \mathrm{c} \times M_0(\mathbf{f}^{\mathrm{REF}})}$$

- Literature-based probably underestimates the impacts

Comparison

$h_k^{\mathrm{REF},\tilde{\mathbf{B}}}$ → j

Database-based normalization references



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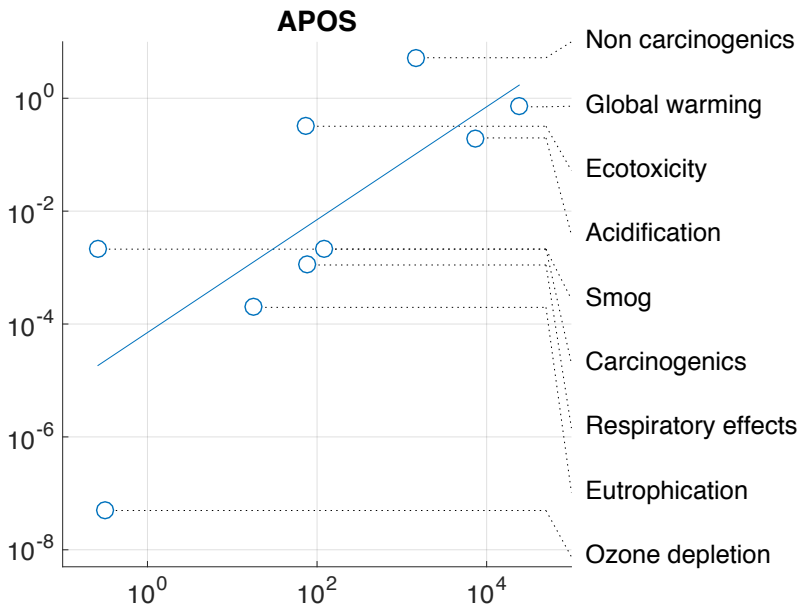
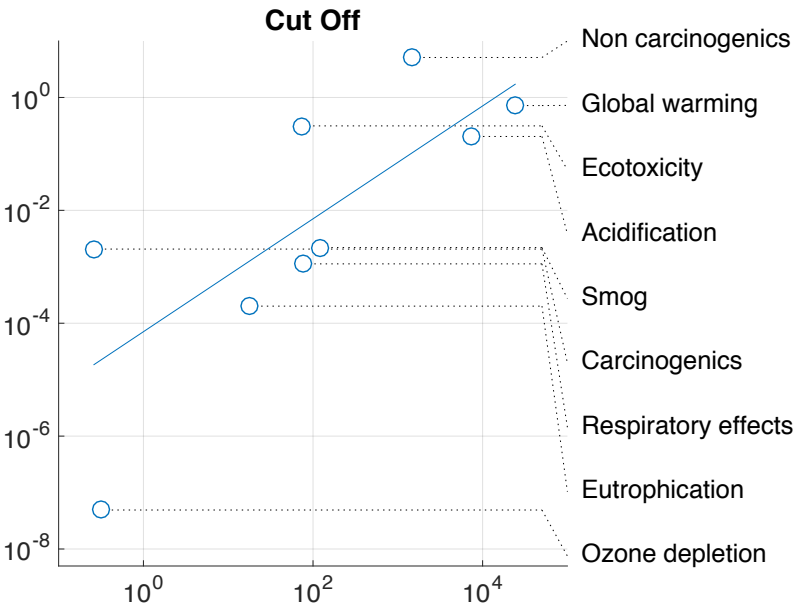
- Inventories are probably missing in the database

TRACI


APOS
Non carcinogenics
Global warming
Ecotoxicity
Acidification
Smog
Carcinogenics
Respiratory effects
Eutrophication
Ozone depletion
10^{0}
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{0}
10^{2}
10^{4}


Cut Off
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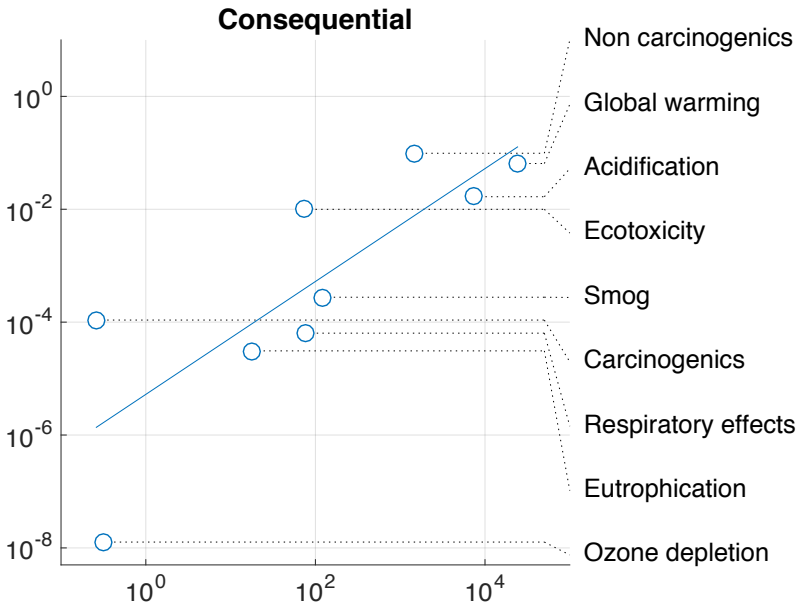
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Ozone depletion
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10^{-2}
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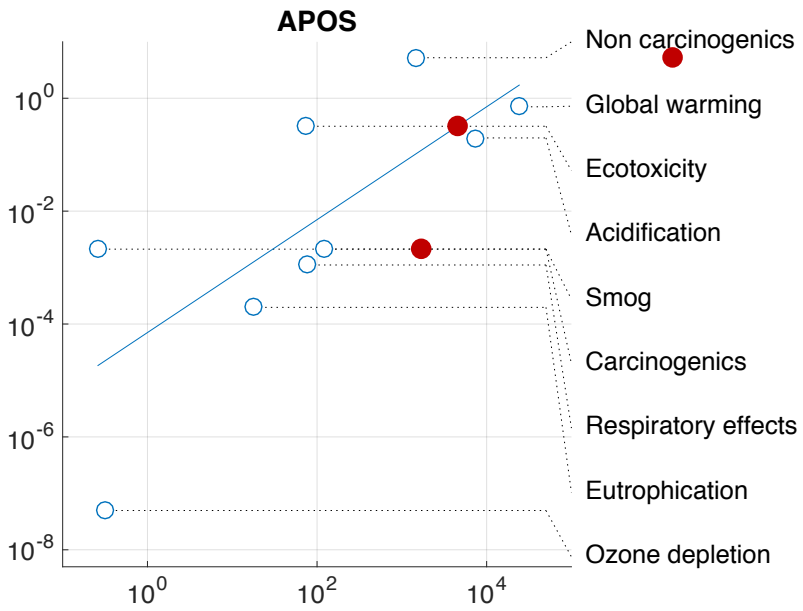
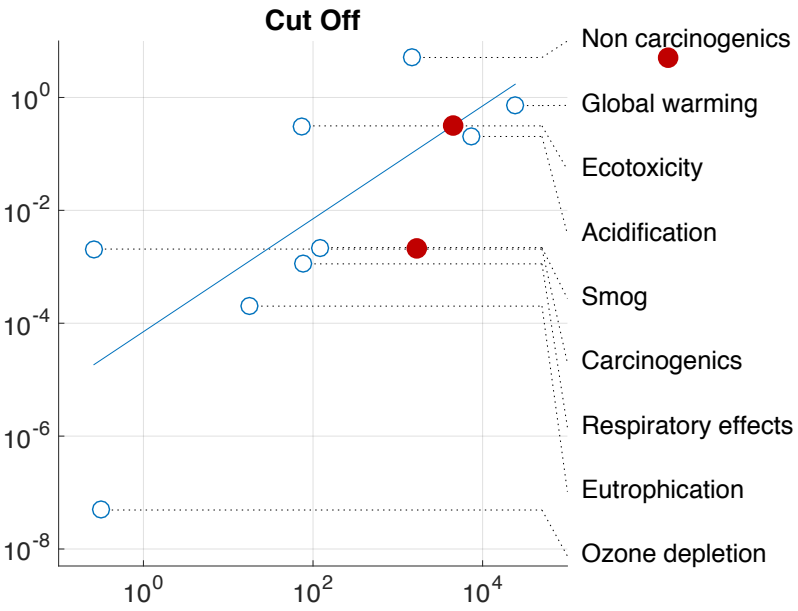
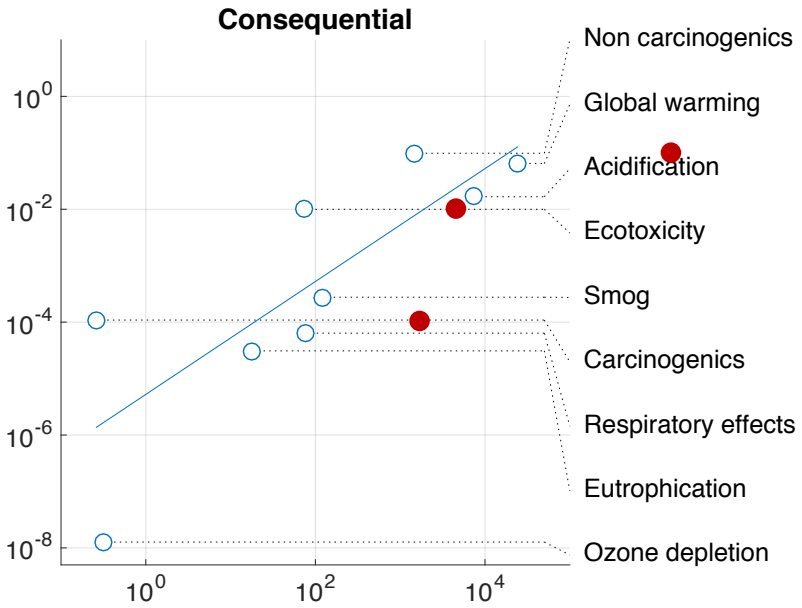
10^{-6}
10^{-8}
10^{0}
10^{2}
10^{4}

TRACI

Kim et al. 2013. The Importance of Normalization References in Interpreting Life Cycle Assessment Results. J. Ind. Ecol. 17, 385–395.







EF 2.0

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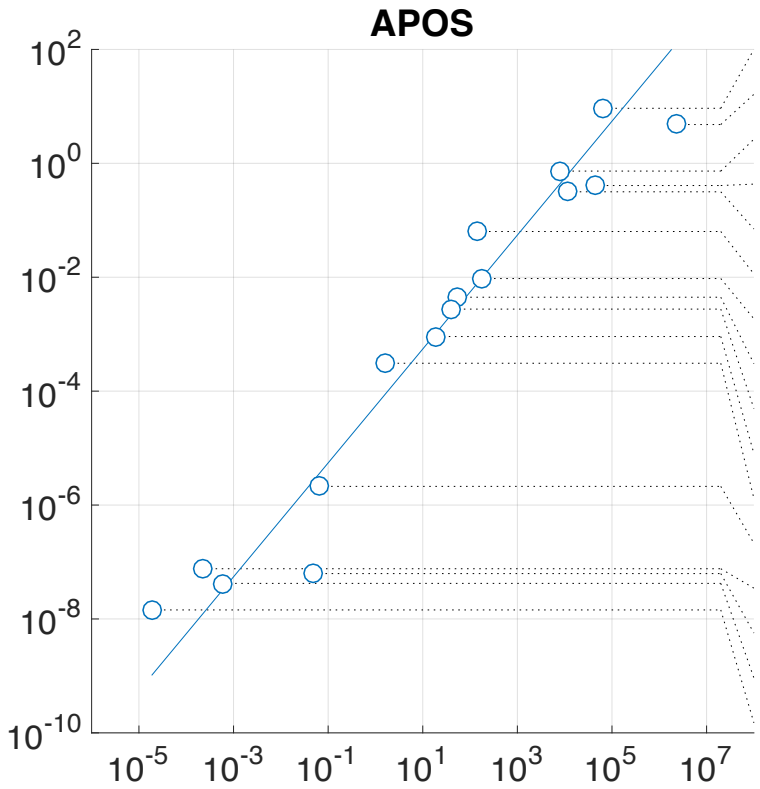
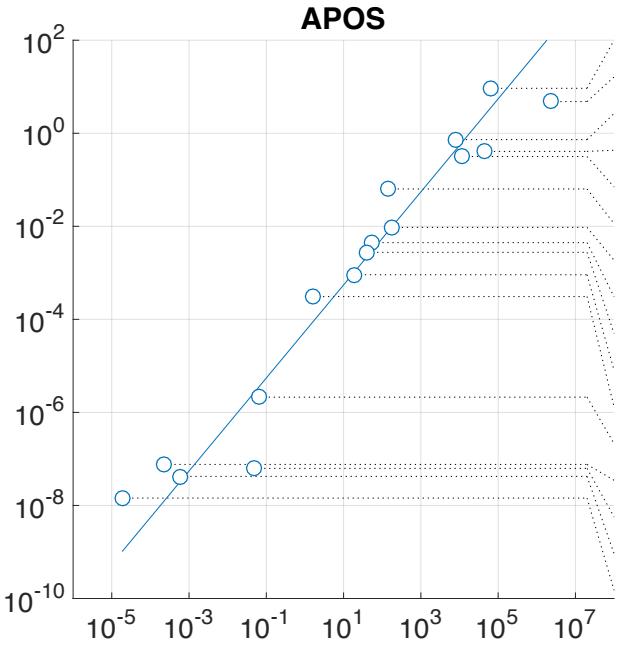


PEF

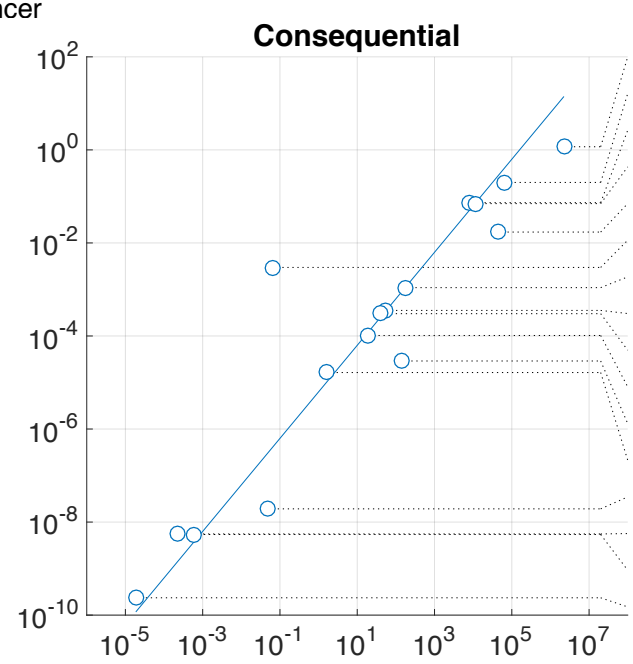
Literature-based normalization references

EF 2.0



Resource use, fossils
Land use
Climate change
Ecotoxicity, freshwater
Water use
Ionising radiation, human health
Eutrophication, terrestrial
Acidification
Phot. ozone form., human health
Eutrophication, marine
Eutrophication, freshwater
Resource use, minerals and metals
Human toxicity, non-cancer
Ozone depletion
Particulate matter
Human toxicity, cancer

PEF



Land use
Resource use, fossils
Climate change
Water use
Ecotoxicity, freshwater
Resource use, minerals and metals
Eutrophication, terrestrial
Acidification
Phot. ozone form., human health
Eutrophication, marine
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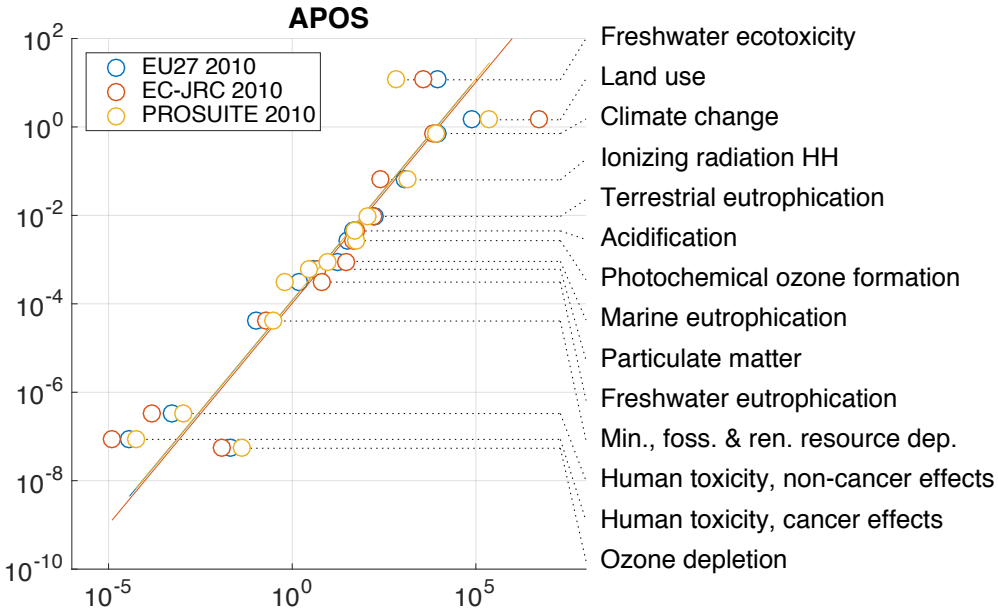
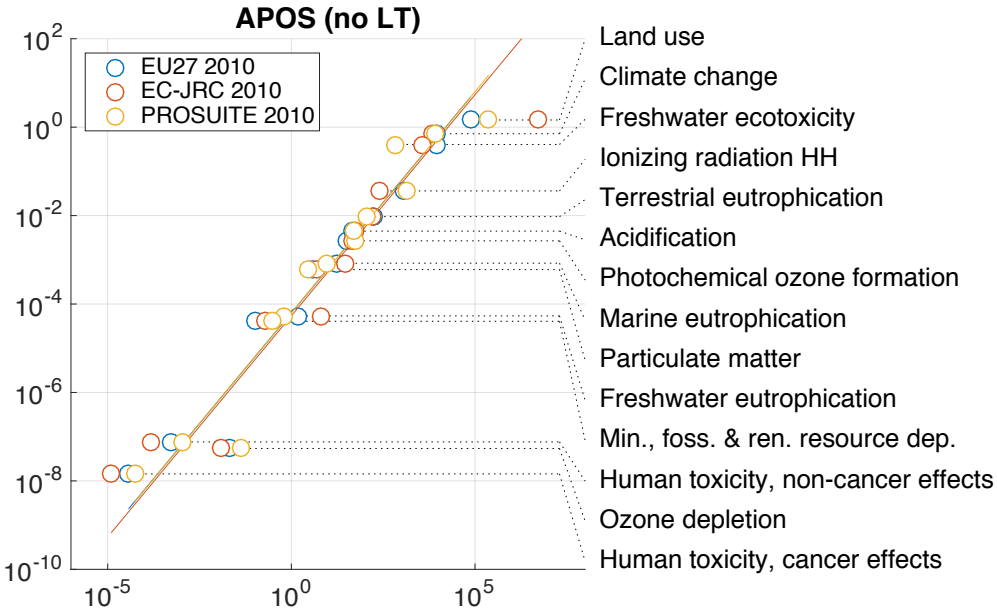
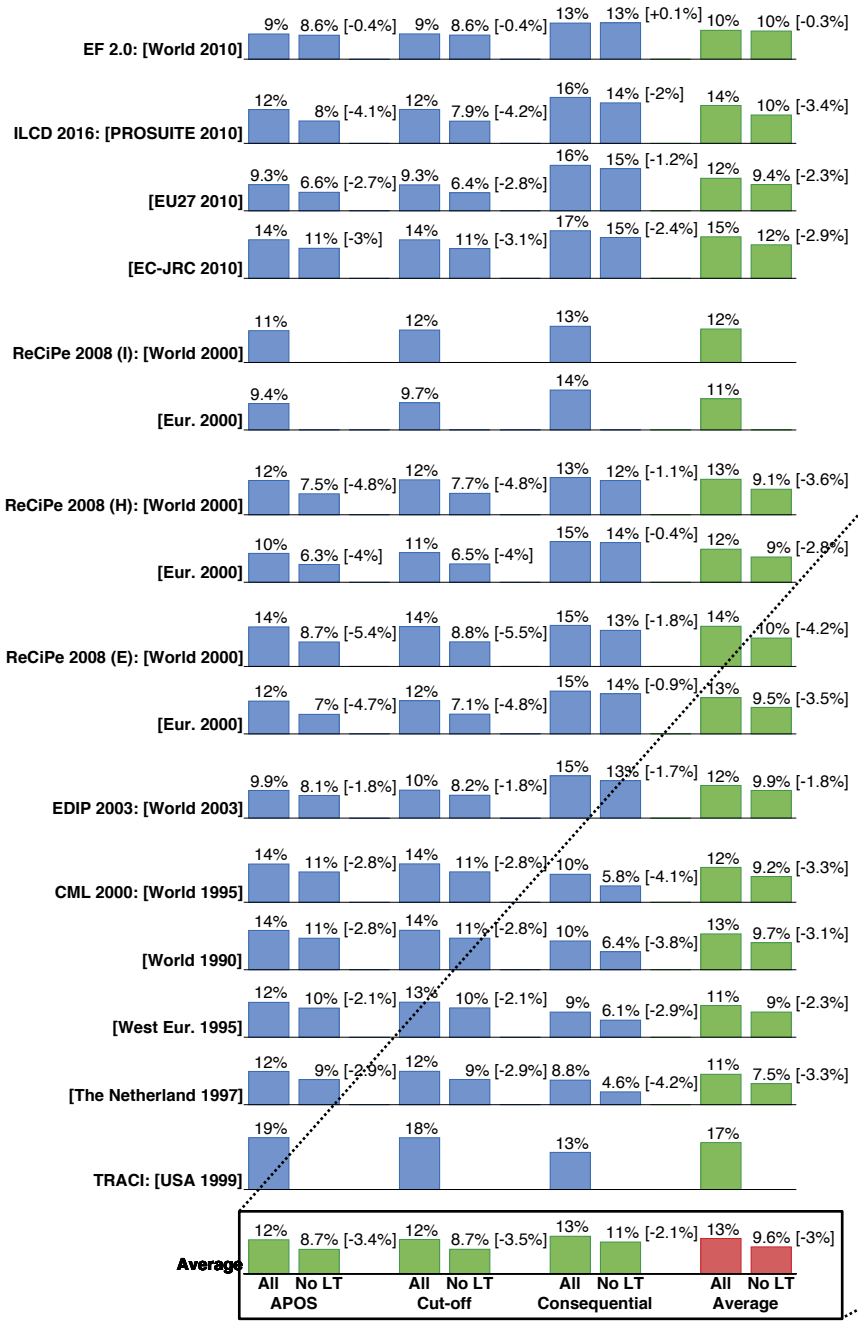
Human toxicity, non-cancer
Particulate matter
Human toxicity, cancer

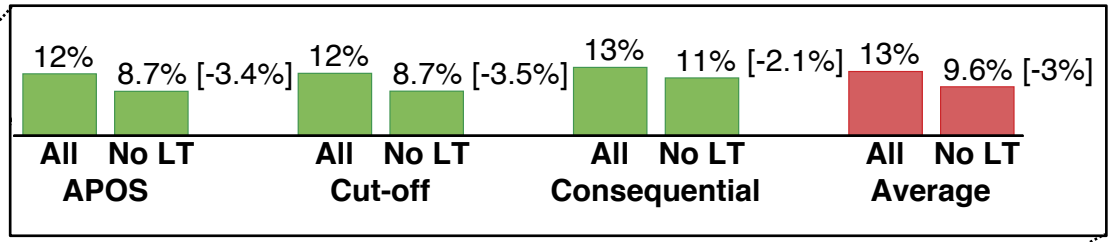
ILCD 2016


APOS
EU27 2010
EC-JRC 2010
PROSUITE 2010
Freshwater ecotoxicity
Land use
Climate change
Ionizing radiation HH
Terrestrial eutrophication
Acidification
Photochemical ozone formation
Marine eutrophication
Particulate matter
Freshwater eutrophication
Min., foss. & ren. resource dep.
Human toxicity, non-cancer effects
Human toxicity, cancer effects
Ozone depletion


APOS (no LT)
EU27 2010
EC-JRC 2010
PROSUITE 2010
Land use
Climate change
Freshwater ecotoxicity
Ionizing radiation HH
Terrestrial eutrophication
Acidification
Photochemical ozone formation
Marine eutrophication
Particulate matter
Freshwater eutrophication
Min., foss. & ren. resource dep.
Human toxicity, non-cancer effects
Ozone depletion
Human toxicity, cancer effects

Coefficients of variation

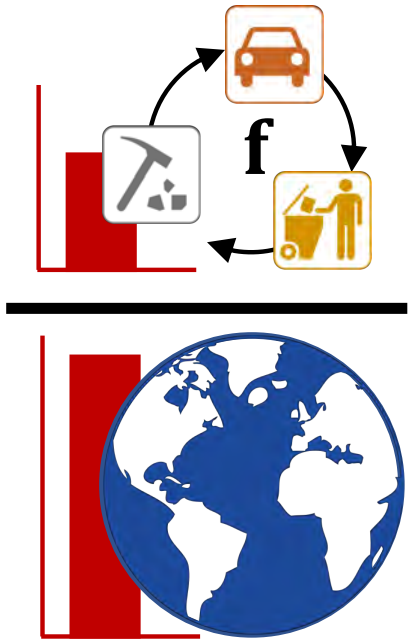




for environmental life cycle sustainability assessment elsa

Take-home message

- Normalization with consistency system / reference:
  - Normalization set for all impacts, without external data
  - Same data for both (inventories and system models)
  - System under study and normalization on the same "planet"
- A tool to check (by comparison)
  - If the LCI database is complete
  - If the external flows quantification for normalization reference seems exhaustive
- With ecoinvent and current normalization sets:
  - A good match..
  - Importance of the system model
  - "European feature" of the database



$$= \frac{\sum_{i=1}^{m} \left(f_i \times \text{LCI} \right)}{\left(\prod_{i=1}^{m} \left(\text{LCI} \right) \right)^{\frac{1}{m}}}$$

Thank you

research group for environmental life cycle & sustainability assessment

elsa

Helias A., Esnouf A. , Finkbeiner M. Consistent normalization approach for Life Cycle Assessment based on inventory databases. Under review

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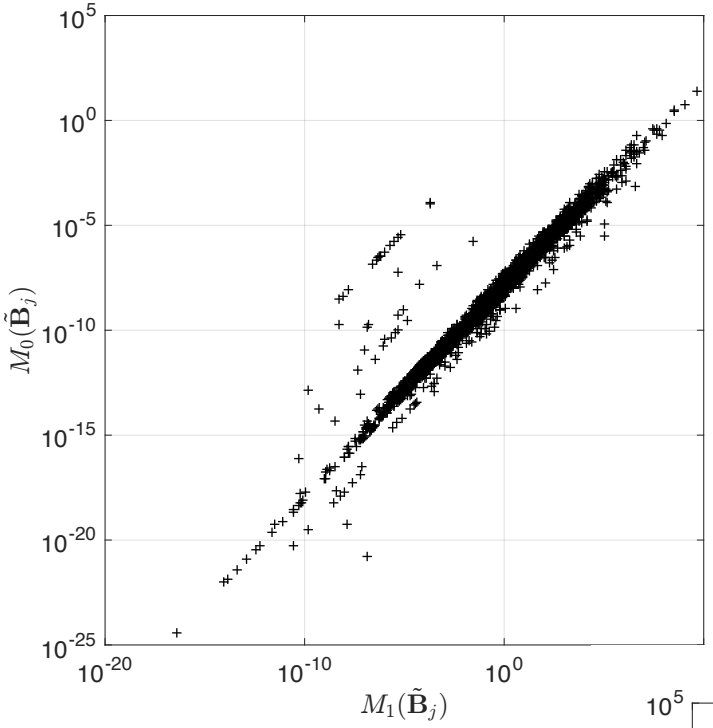
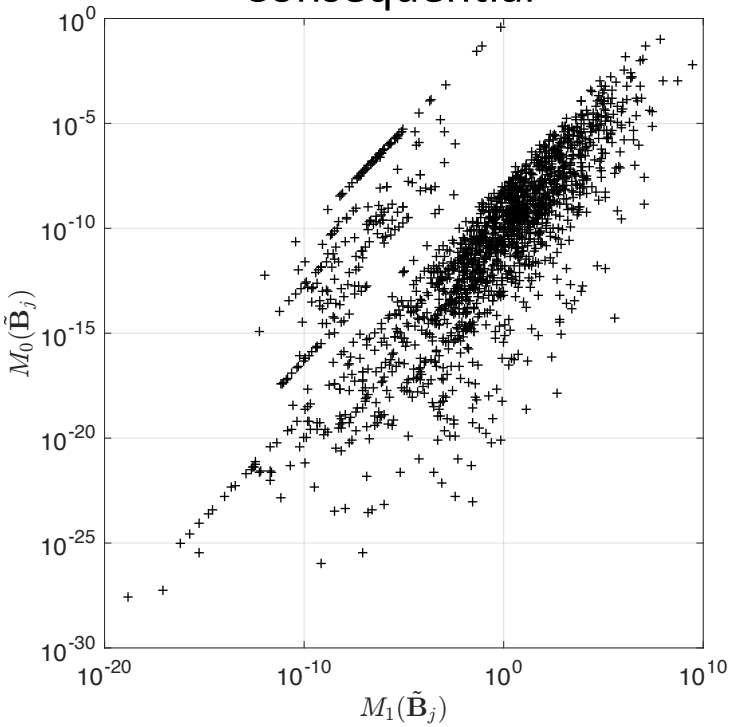


Consequential



Cut-off