Tuto Brightway – Part 2

Téo Lavisse

PhD Student in CEA & GSCOP

01/10/2024

Program

1. Uncertainty in LCA : theory and methodology
2. How to do this in BW ?
3. Application part

1. Uncertainties in LCA

Principles and methodology

Uncertainty : definitions and key principles

Uncertainty	Variability
Experimental error due to: - Inaccurate measurements - Model assumptions - Lack of data	Variations **inherent** in the world - Spatial variability - Temporal variability - Variability in sources/objects
↓	↓
Uncertainty is present for any data used for the inventory and the impact assessment.	Variability is inherent and can only be assessed through sensitivity analysis

Soure : formation doctorale EcoSD, Advanced LCA Methodologies & Tools : Uncertainties & Impact Assessment, 2020

General methodology for assessing uncertainties in LCA

How does uncertainty/variability in the inputs **propagate through the model** to uncertainty/variability in the output?

1) Define goal and scope

2) Construction of the reference LCA

- *Identification of the input parameters*
- *Validation of the LCA*

3) Characterization of the uncertainties of the identified parameters

- *Variance ? Distribution type ?*

4) Estimation of the uncertainty of the final results

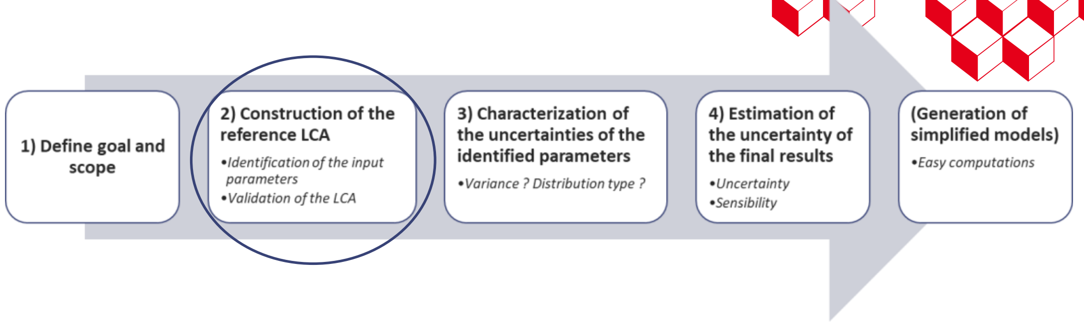
- *Uncertainty*
- *Sensibility*

(Generation of simplified models)

- *Easy computations*

Pérez-Lopez, P. *et al.* (2020) *INCER-ACV: Incertitudes dans les méthodologies d'évaluation des impacts environnementaux des filières de production énergétique par ACV*. ADEME, p. 65.
Jolivet, R. *et al.* (2021) 'lca_algebraic: a library bringing symbolic calculus to LCA for comprehensive sensitivity analysis', *The International Journal of Life Cycle Assessment*, 26(12), pp. 2457–2471. Available at: https://doi.org/10.1007/s11367-021-01993-z.

Types of uncertainty



Method → uncertainties related to methodological choices

ex : FU definition, boundary selection, objectives, goal and scope

Technical → uncertainties related to the data set

Ex : data quality of the LCI

Epistemic → uncertainties related to the knowledge of the system under study and its environment (regulation, market)

Ex : model simplification adding uncertainties, include aslo future events (regulations, market) that can influence the sudy

Leroy, Y. and Froelich, D. (2010) *A qualitative, quantitative or mixed approach to deal with uncertainty in Life Cycle Assessment of complex systems: towards a selective integration of uncertainty according to LCA objectives*

Identification of sources of uncertainty and variability

1) Define goal and scope
2) Construction of the reference LCA
- Identification of the input parameters
- Validation of the LCA

3) Characterization of the uncertainties of the identified parameters
- Variance ? Distribution type ?

4) Estimation of the uncertainty of the final results
- Uncertainty
- Sensibility

(Generation of simplified models)
- Easy computations

Main classification by Huijbregts (1998), with additional types by Björklund (2002)

Temporal variability
Temperature change with seasons

Spatial variability
Electricity mix depends on country

Variability between objects/sources
Differences btw individuals

Epistemological uncertainty
Lack of relevant knowledge

Model uncertainty
Functionnal unit, boundary

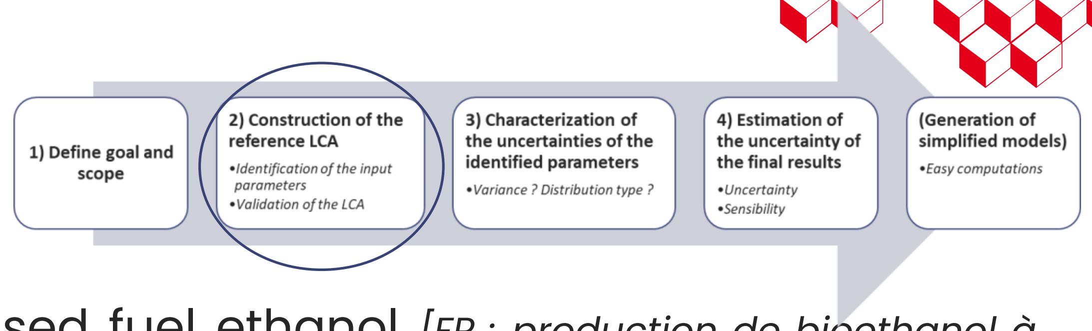
Methodological choices

Mistakes

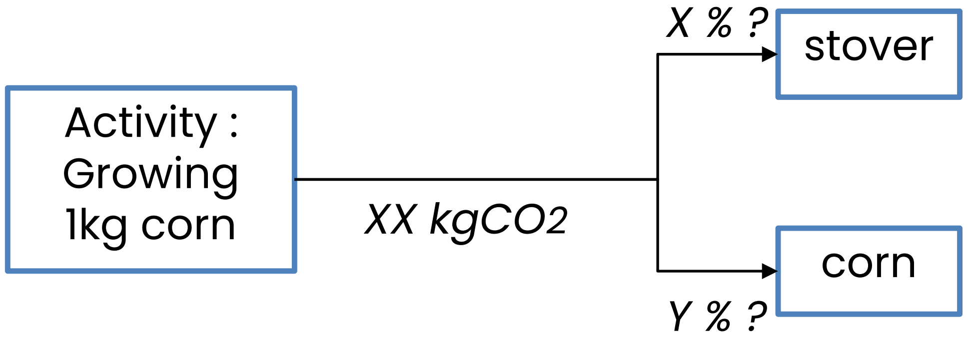
Lack of data

Rosenbaum, R.K., Georgiadis, S. and Fantke, P. (2018) 'Uncertainty Management and Sensitivity Analysis', in M.Z. Hauschild, R.K. Rosenbaum, and S.I. Olsen (eds) Life Cycle Assessment: Theory and Practice. Cham: Springer International Publishing, pp. 271–321. Available at: https://doi.org/10.1007/978-3-319-56475-3_11.
EcoSD, *Advanced LCA Methodologies & Tools : Uncertainties & Impact Assessment*, 2020
Björklund, A.: Survey of approaches to improve reliability in LCA. Int. J. Life Cycle Assess. 7, 64–72 (2002). doi:10.1007/BF02978849
Huijbregts, M.A.J.: Application of uncertainty and variability in LCA Part I: a general framework for the analysis of uncertainty and variability in life cycle assessment. Int. J. Life Cycle Assess. 3, 273–280 (1998). doi:10.1007/BF02979835

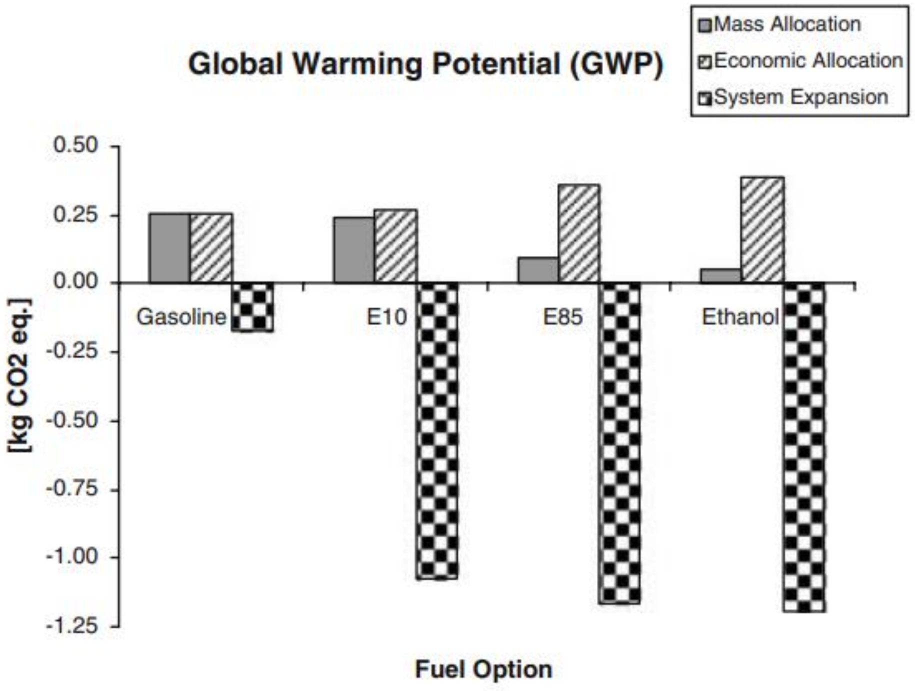
Example of uncertainty: allocation choice



Case of study: Coproduction of corn stover-based fuel ethanol *[FR : production de bioethanol à partir des tiges de maïs]*



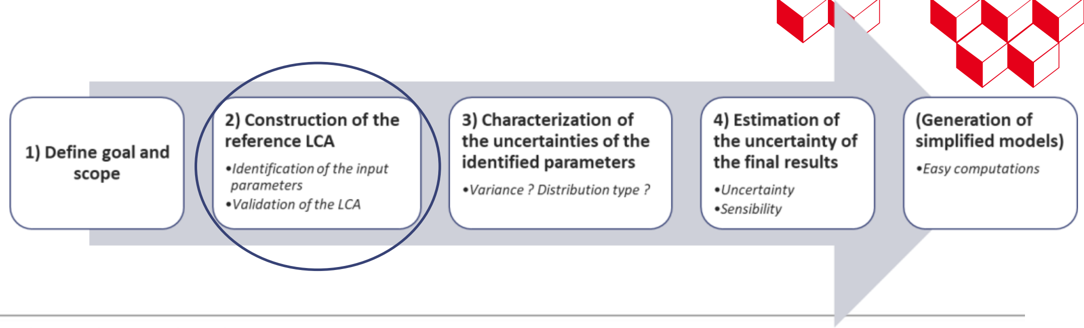
Allocation	Percentage	
	Stover (%) *[tiges]*	Corn (%) *[mais]*
Mass value	37.5	62.5
Economic value	11.8	88.2



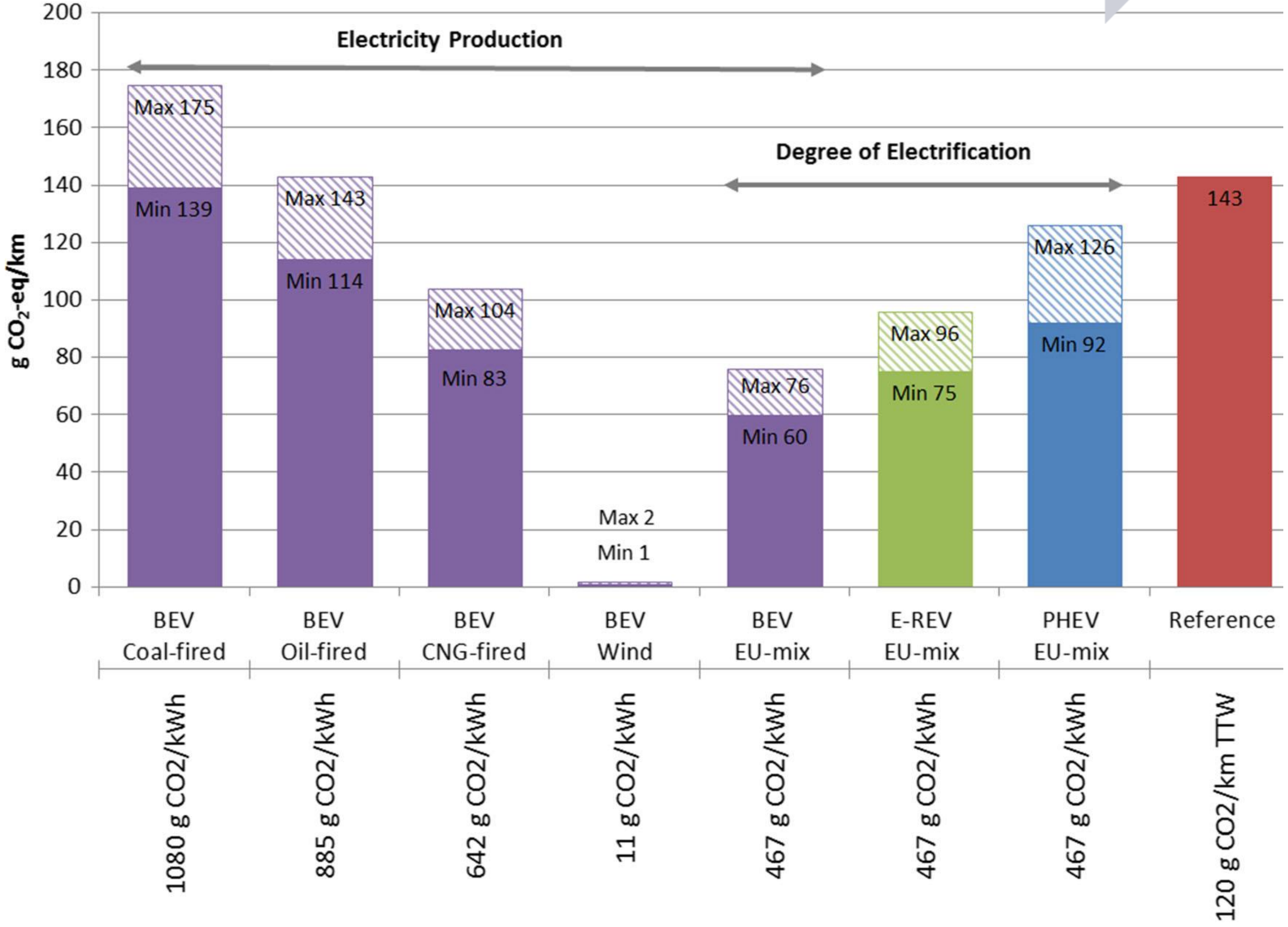
E10: 10% ethanol + 95% gasoline
E85: 85% ethanol + 15% gasoline

Luo et al, 2009, 'Allocation issues in LCA methodology: a case study of corn stover-based fuel ethanol'

Example of variability: Spatial variability



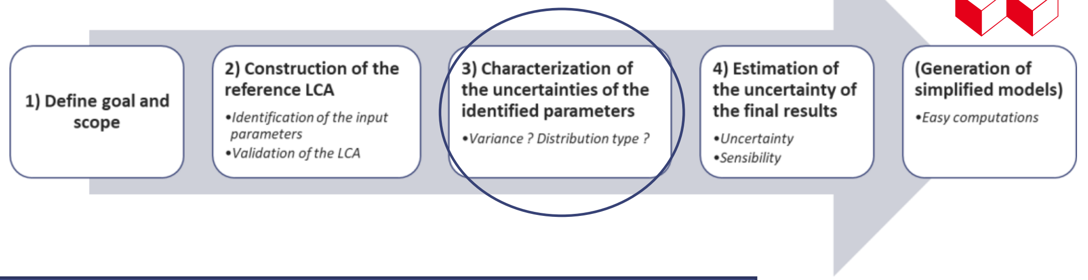
Case of study: Electricity production source to recharge a traction electric battery



BEV: Battery Electric Vehicle
PHEV: Plug-in Electric Vehicle

Source: Nordelöf, A. et al. (2014) 'Environmental impacts of hybrid, plug-in hybrid, and battery electric vehicles—what can we learn from life cycle assessment?', The International Journal of Life Cycle Assessment, 19(11), pp. 1866–1890. Available at: https://doi.org/10.1007/s11367-014-0788-0.

How to quantify uncertainties of my inventory ?



The probabilistic nature of uncertainty is represented by a **probability distribution**.
Probability is approximated by the **relative frequency** when enough values are sampled

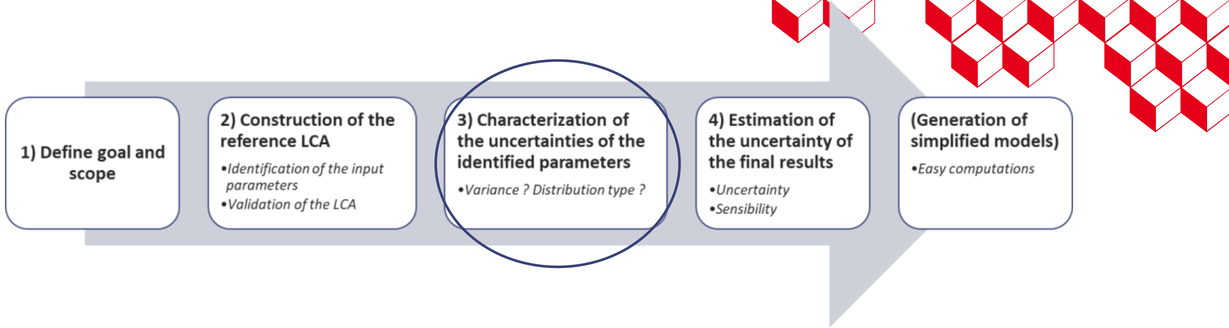
Example: In ecoinvent → use of the **Pedigree matrix** (also called DQI Data Qualitative Indicator)

→ a pedrigree matrix with 5 coefficients (X_1, X_2, X_3, X_4, X_5)
→ Asymetric lognormal distribution ssumed that is characterized by :
1) The median value μ
2) The geometric standard deviation $\sigma = \exp(\sqrt{(\sum_1^n \ln(X_i)^2 + (\ln(X_b))^2})$

Xi	1	2	3	4	5 (default)
Reliability	1	1,05	1,10	1,20	1,50
Completeness	1	1,02	1,05	1,10	1,20
Temporal correlation	1	1,03	1,10	1,20	1,50
Geographical correlation	1	1,01	1,02		1,10
Further technological correlation	1		1,20	1,50	2

Ciroth, A. *et al.* (2016) 'Empirically based uncertainty factors for the pedigree matrix in ecoinvent', *The International Journal of Life Cycle Assessment*, 21(9), pp. 1338–1348. Available at: https://doi.org/10.1007/s11367-013-0670-5.

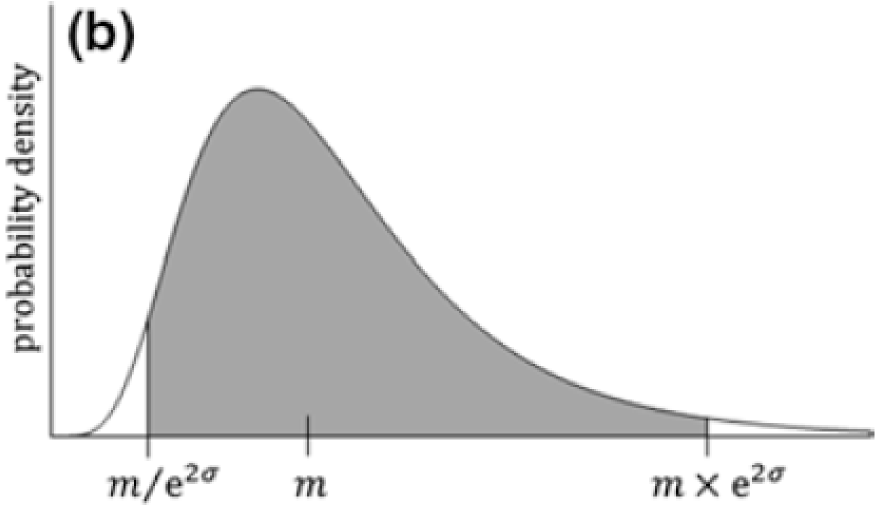
How to quantify uncertainties of my inventory ?



Why using lognormal in ecoinvent ?

- **Central limit theorem** : the arithmetic mean of a sufficiently large number of independent values will be approximately normally distributed
- Data must be **positive** (not possible with normal distribution)
- Lognormal shares similarities with normal distribution

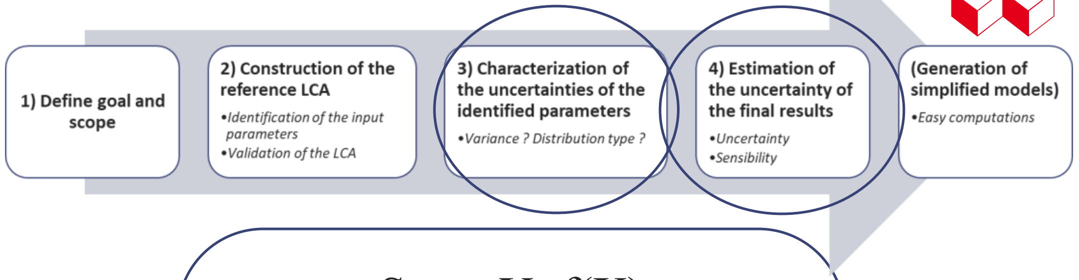
$$x \sim lognormal(\mu, \sigma) \Rightarrow \ln(x) \sim normal$$

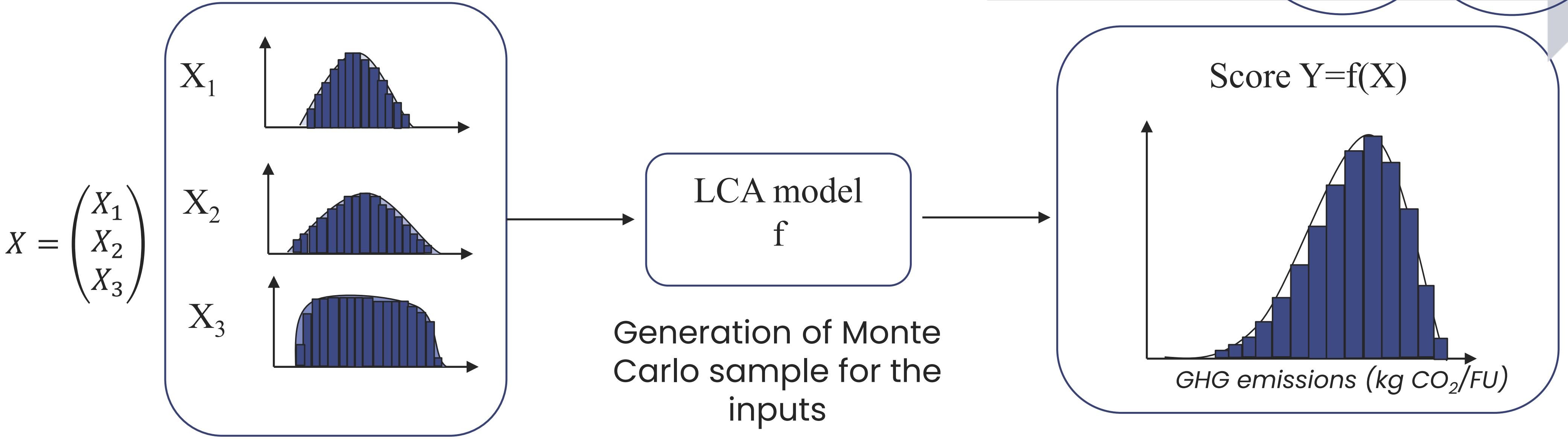


median $m = e^{\mu}$

Ciroth, A. *et al.* (2016) 'Empirically based uncertainty factors for the pedigree matrix in ecoinvent', *The International Journal of Life Cycle Assessment*, 21(9), pp. 1338–1348. Available at: https://doi.org/10.1007/s11367-013-0670-5.

Monte Carlo simulation





Uncertainty distribution for input parameters X_i

Generation of Monte Carlo sample for the inputs

No more static score but a distribution function

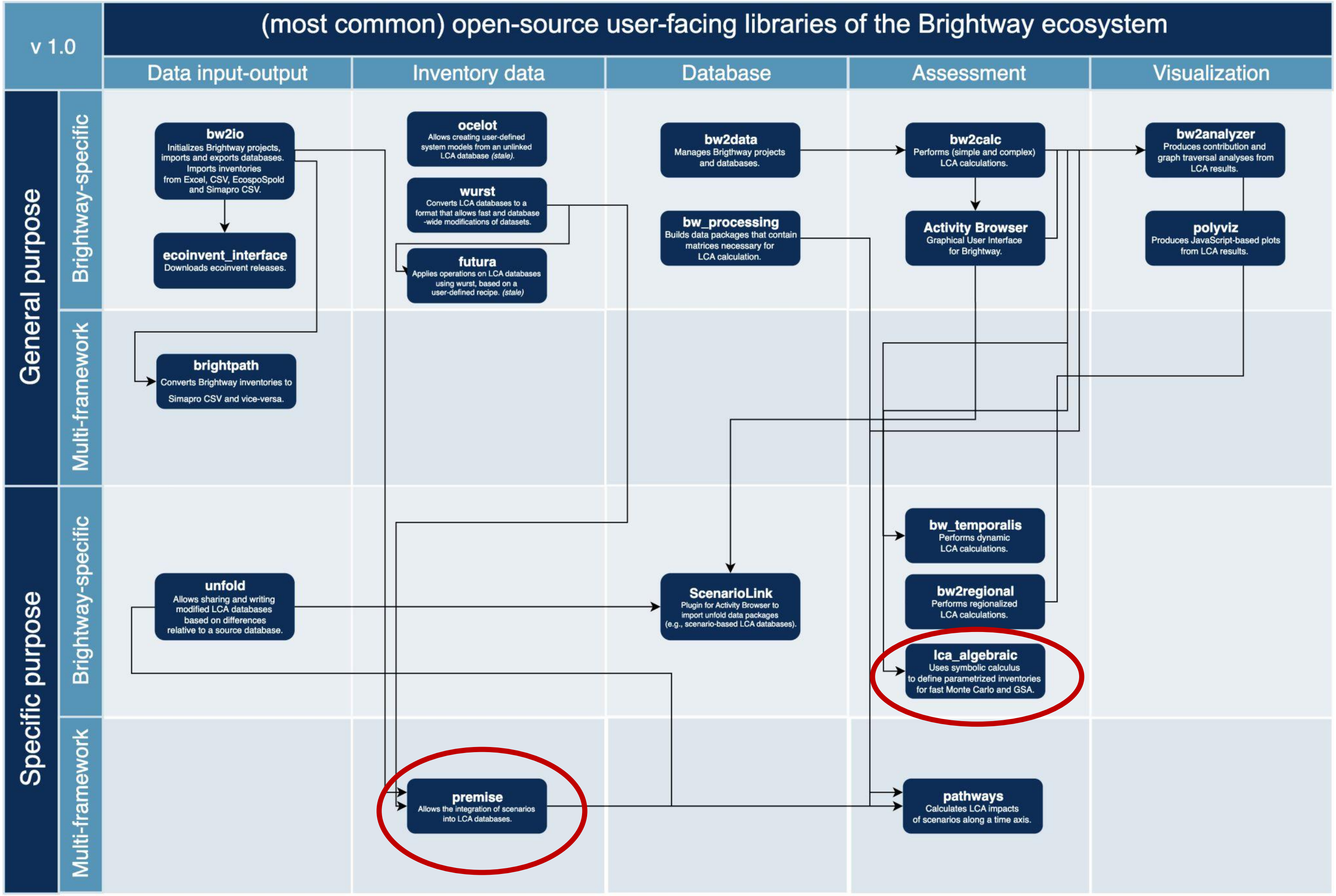
MC = class of algorithms that rely on **repeated random sampling** to compute the results of an equation and assess their **range of possible variability**

➔ No analytical but numerical solutions
➔ Powerful but time consuming !

Rosenbaum, R.K., Georgiadis, S. and Fantke, P. (2018) 'Uncertainty Management and Sensitivity Analysis', in M.Z. Hauschild, R.K. Rosenbaum, and S.I. Olsen (eds) Life Cycle Assessment: Theory and Practice. Cham: Springer International Publishing, pp. 271–321. Available at: https://doi.org/10.1007/978-3-319-56475-3_11.

2. How to do this in BW ?

Summary of main Brightway libraries



From R.Sacchi, 2024

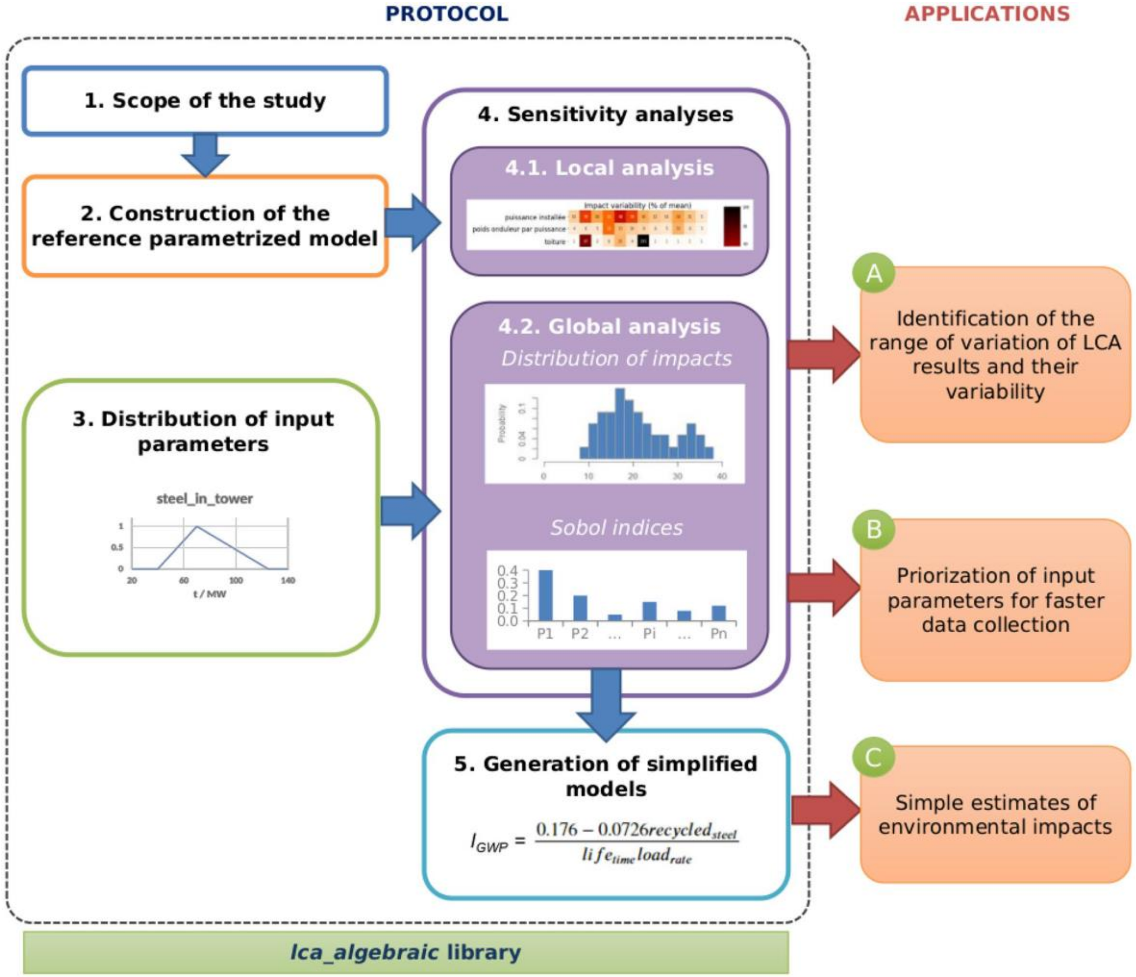
lca_algebraic, from INCER-ACV (ADEME, 2020)

lca_algebraic = **Open source library** based on BW2 and Sympy

Helper functions for compact & **declarative definition of parametric inventories**

Symbolic calculus (Sympy) brings :
- Parametric amounts
- Factorize background activities (super **fast**)
- **Automatic generation of simplified models**

- **Uncertainty** computations
- Identify **hotspots** parameters
- **Ecodesign tool**

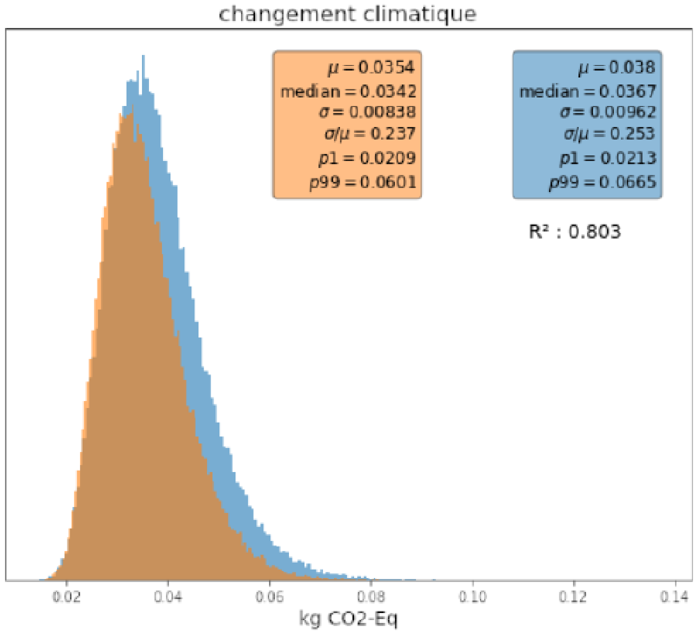


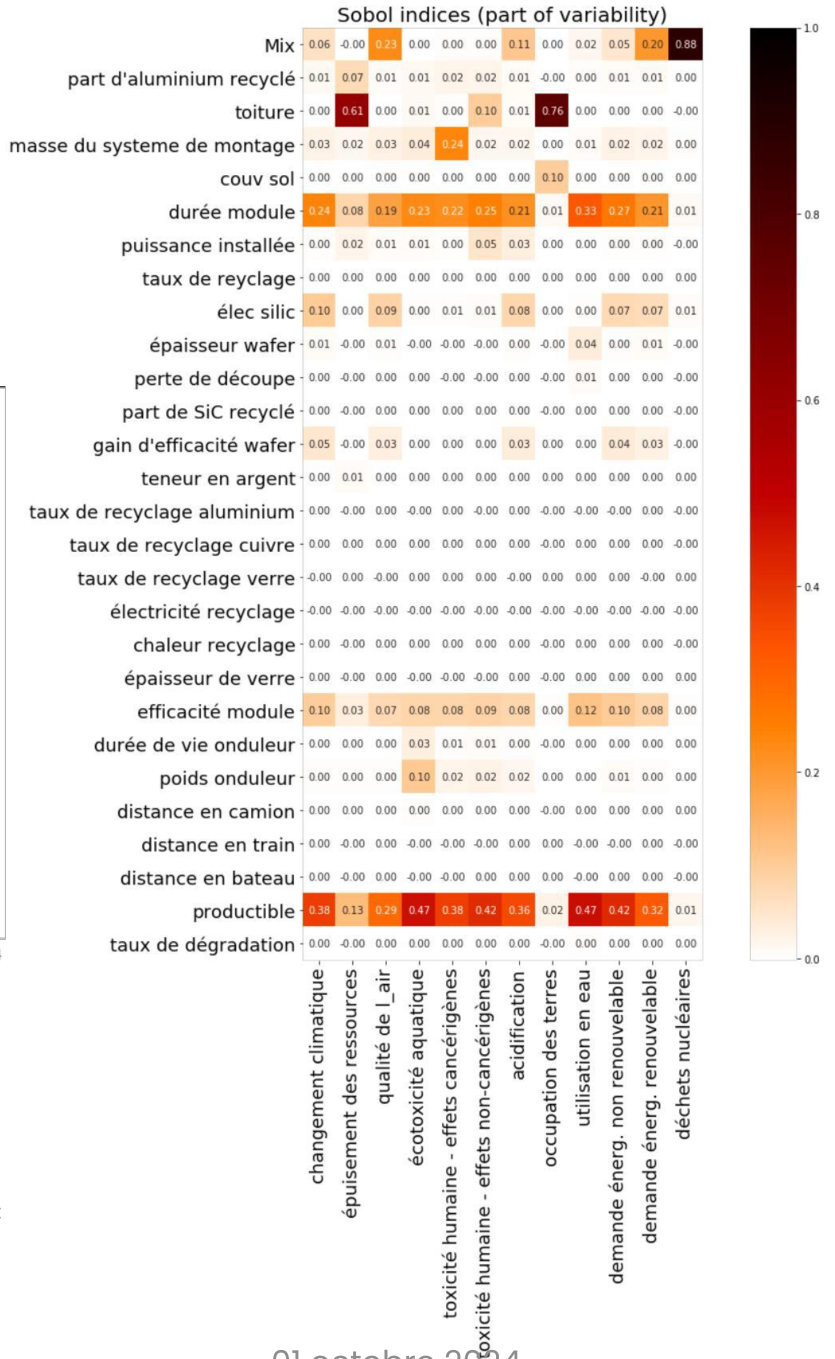
Pérez-Lopez, P. *et al.* (2020) *INCER-ACV: Incertitudes dans les méthodologies d'évaluation des impacts environnementaux des filières de production énergétique par ACV*. ADEME, p. 65.
Jolivet, R. *et al.* (2021) 'lca_algebraic: a library bringing symbolic calculus to LCA for comprehensive sensitivity analysis', *The International Journal of Life Cycle Assessment*, 26(12), pp. 2457–2471. Available at: https://doi.org/10.1007/s11367-021-01993-z.

lca_algebraic: application to wind turbines and PV systems

$$I_{cc} = \frac{A + B + C + 0.567}{(\eta_{module} \cdot Productible(1 + 0.994 \cdot life_{module})}$$

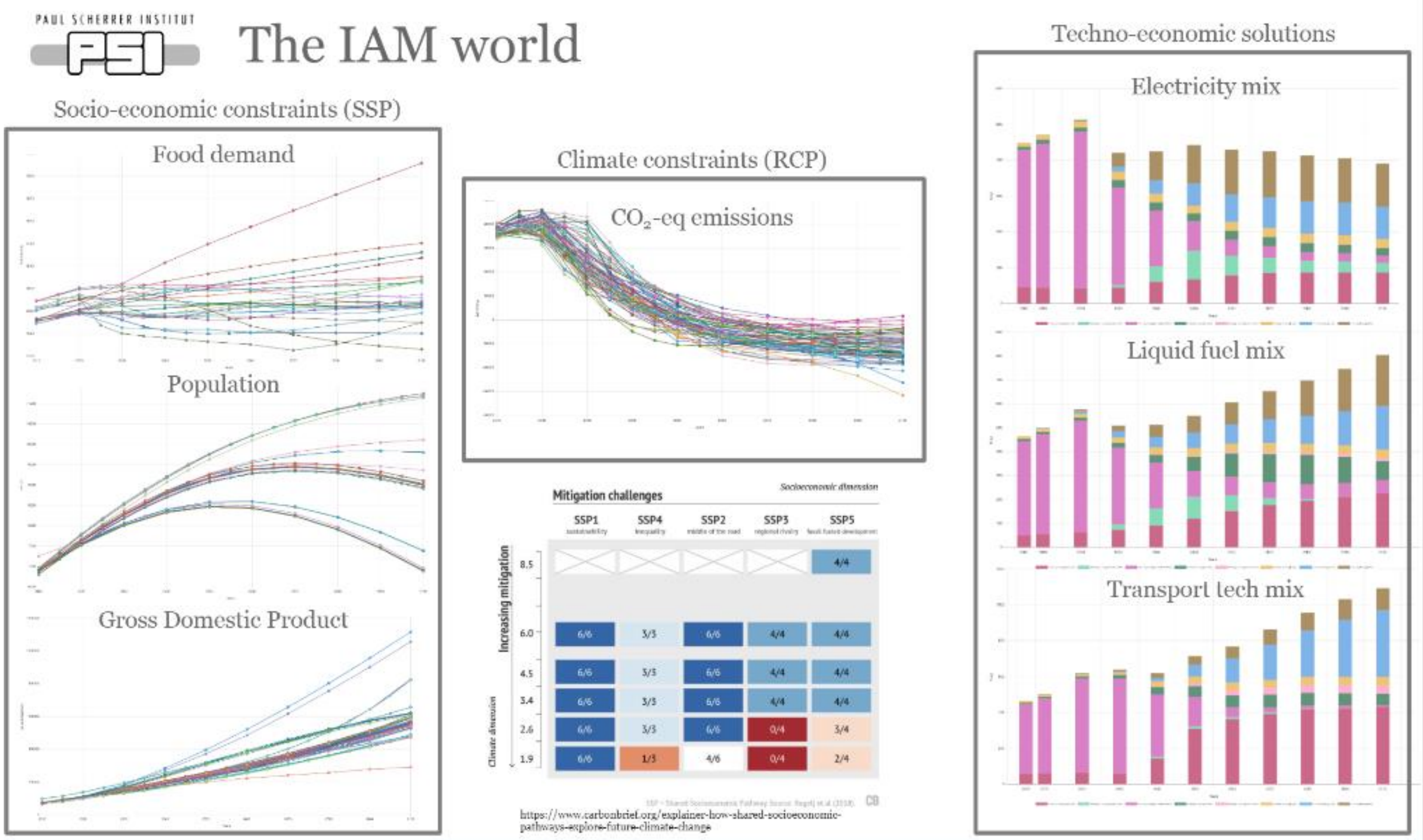
Développement d’outils de visualisation performants : http://viewer.webservice-energy.org/lca-wind-dk/





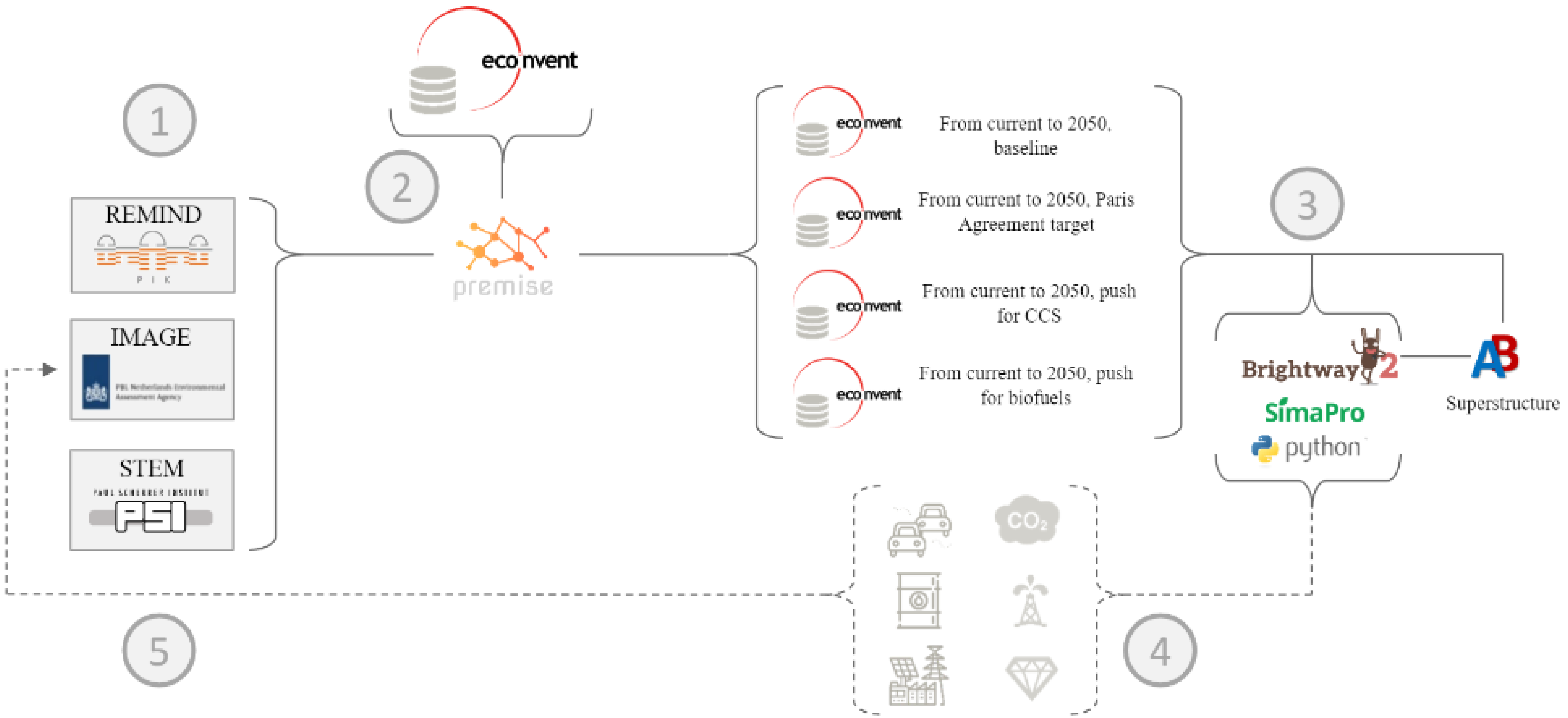
Pérez-Lopez, Paula, Raphaël Jolivet, Isabelle Blanc, Romain Besseau, Mélanie Douziech, Benoit Gschwind, Scarlett Tannous, et al. 2020. « INCER-ACV : Incertitudes dans les méthodologies d’évaluation des impacts environnementaux des filières de production énergétique par ACV ». ADEME.

premise : prospective LCA on BW



Source : Romain Sacchi, Autum School Open inventory data manipulation (Depart de Sentier)

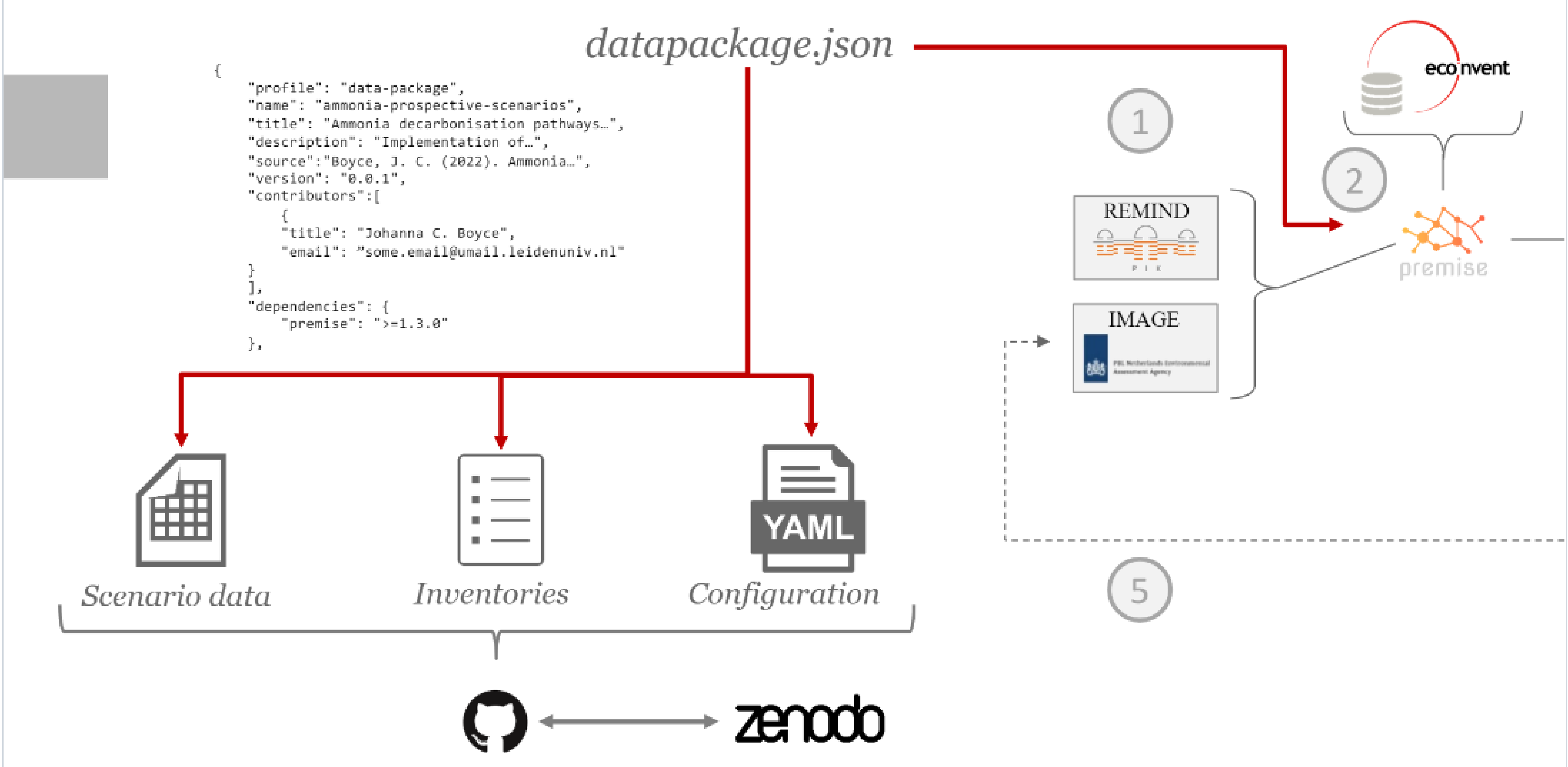
premise : prospective LCA on BW



Source : *Romain Sacchi, Autum School Open inventory data manipulation (Depart de Sentier)*

premise : prospective LCA on BW

Community for user-defined scenarios : https://github.com/premise-community-scenarios



Source : Romain Sacchi, Autum School Open inventory data manipulation (Depart de Sentier)

carculator : When, where and how can the electrification of passenger cars reduce greenhouse gas emissions ?

carculator is an open-source, comprehensive **and transparent LCA tool for passenger cars**.

→ python library + online tool

It allows for an **economic** and **environmental** evaluation of **different types of cars** under **several driving and energy supply scenarios**. Results partly rely on the background inventory data of [ecoinvent v3.6](), and the implementation of impact assessment methods therein.

https://carculator.psi.ch/

https://github.com/romainsacchi/carculator

Sacchi, R. *et al.* (2022) 'When, where and how can the electrification of passenger cars reduce greenhouse gas emissions?', *Renewable and Sustainable Energy Reviews*, 162, p. 112475. Available at: https://doi.org/10.1016/j.rser.2022.112475.

pylcaio: Hybridization to combine LCA with other databases

An object class to hybridize lifecycle assessment (LCA) and environmentally extended input-output (EEIO) databases.

https://ciraig.org/index.php/fr/project/pylcaio-2/
https://github.com/MaximeAgez/pylcaio

➔ Create your own LCA-IO hybrid database

➔ Automates hybridization and correction for double-counting with two available methods (STAM and binary)

➔ The resulting hybrid-ecoinvent database can be exported to brightway2 and the GUI activity-browser

brightway2-regional : Regionalization

brightway2-regional is a separate library that extends the Brightway LCA framework to do regionalized LCA calculations.

https://github.com/brightway-lca/brightway2-regional

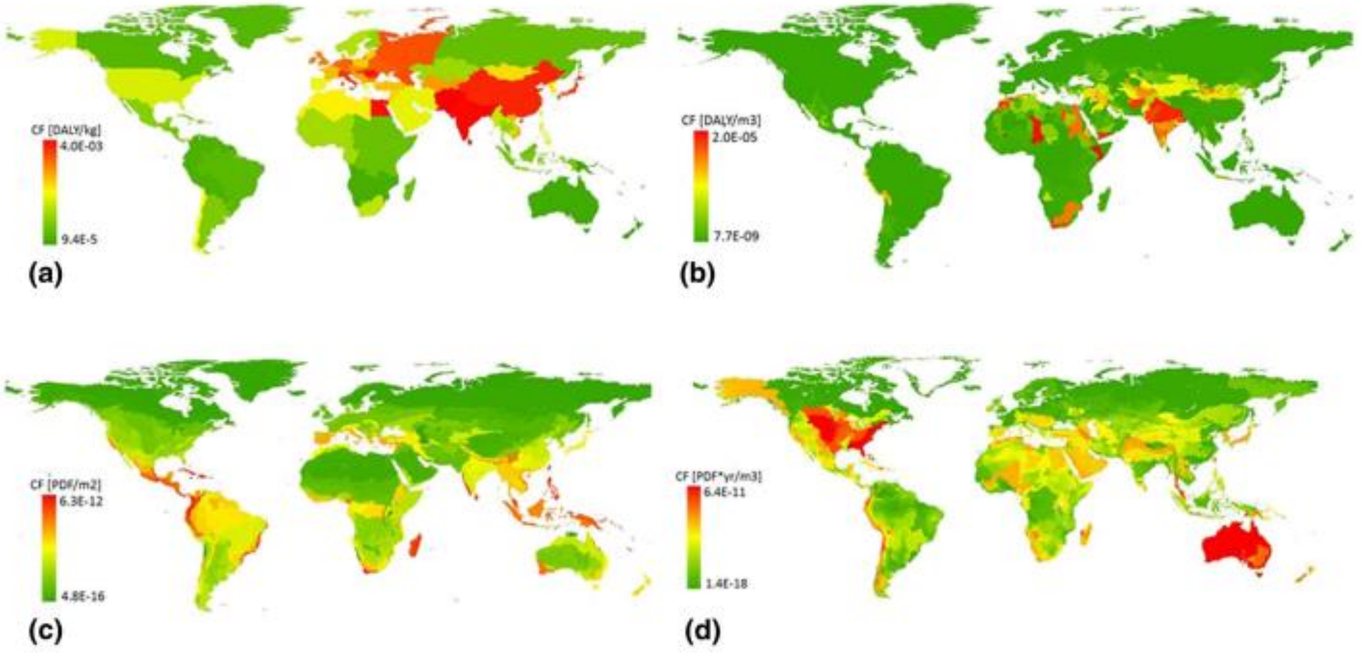


FIGURE 2 Example maps for characterization factors (CF) for (a) human health impacts of particulate matter (PM2.5) emissions (DALY/kg), (b) human health impacts of water consumption (DALY/m^3), (c) impacts on ecosystem quality from land occupation by annual crops (PDF/m^2), and (d) impacts on ecosystem quality from water consumption (PDF yr/m^3)

F. Verones et al., “LC-IMPACT: A regionalized life cycle damage assessment method,” Journal of Industrial Ecology, vol. 24, no. 6, pp. 1201–1219, Dec. 2020, doi: [10.1111/jiec.13018](https://doi.org/10.1111/jiec.13018).

3. Practice

Installation

All resources and documentation can be found in open-source on Github and official website:

- Collaborative tool whose evolution and improvement are open to all
- Installation guide
- Tutorial
- Practical examples
- Open-access code

<u>Installation a bit tricky, but here are the main steps</u>

Install python distribution → Create an environment → Install Brightway2 → Install other librairies

- Procedure detailed on https://docs.brightway.dev/en/latest/content/installation/index.html
- A simplified installation can be set up while executing the .bat file which create a dedicated environment bw_lca and install libraries all at once, in a compatible and stable version (see README.md for the detailed instructions)

Installation

Python distribution: *anaconda, mamba, miniforge3…*

Environment *bw_lca*

Libraries:
- *brightway==2.3*
- *bwio==0.8.12*
- *(…)*

Environment *ab*

Libraries:
- *brightway==2.4.6*
- *activity-browser==2.10.1*
- *(…)*

BW project *tuto*

Database: ecoinvent 3.9.1 cutoff ; example_db ; biosphere3

Activities, exchanges…

Methods

Parameters

BW project *my_project_perso*

Database: ecoinvent 3.10 cutoff ; battery_pack ; biosphere3

Activities, exchanges…

Methods

Parameters

Practical part

Setup :

- ✓ Create a working directory on your computer (*/Documents/tuto_bw/* for instance)
- ✓ Clone the repository or copy/Paste *tutoBW_advanced_TL.ipynb* in your working directory

Open Jupyter :

- ✓ Open a anaconda/miniforge prompt
- ✓ Run *mamba activate bw_lca* (replace bw_lca with the environment name where bw is installed)
- ✓ Open a Jupyter interface: run *jupyter lab* or any compatible IDE (VScode…)
- ✓ A web (localhost) window open with Jupyter interface
- ✓ Dig into your folder to reach your working directory
- ✓ Open up the Notebook *tutoBW_advanced_TL.ipynb*
- ✓ Best practice: when over, go in *File/Shut down* to properly turn off the server. (or you can also *Ctrl + C* in the console to force it to stop)

Thank you for your attention

Teo Lavisse

3rd year PhD Student

CEA Liten & GSCOP

teo.lavisse@cea.fr