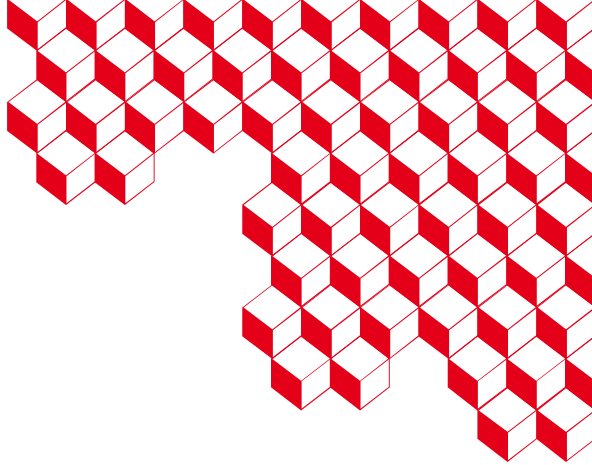


Tuto Brightway – Part 1

Téo Lavisse

PhD Student in CEA & GSCOP

01/10/2024

Program

1. Theory of BW

- A matrix approach
- Architecture
- Activities & exchanges
- Performing a LCA in BW

2. Practice

- Setup your project
- Database import
- LCA: simple, comparative, multi-category
- Data visualization (simple)
- Contribution analysis
- Uncertainties

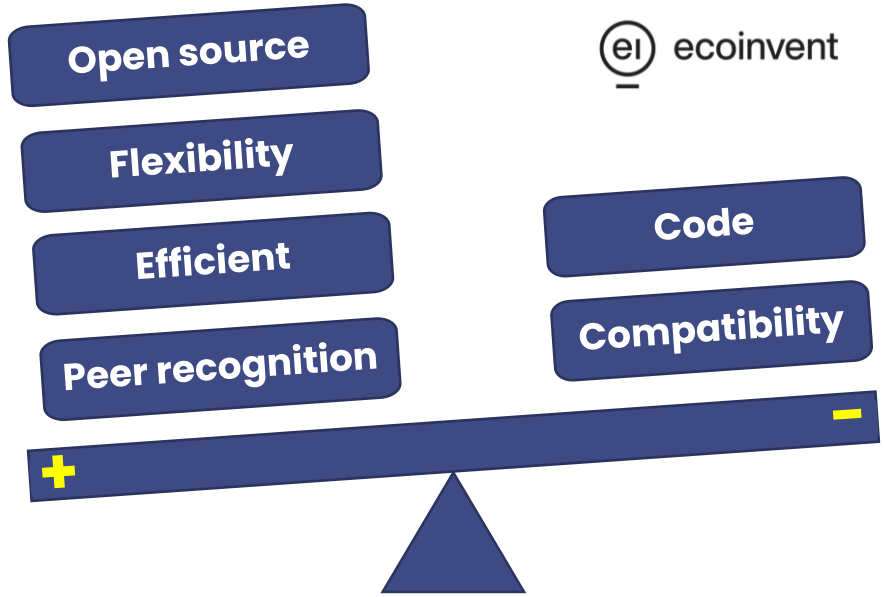
Bright what ?

Actors

Brightway

DÉPART DE SENTIER

PAUL SCHERRER INSTITUT PSI



Main contributors:

Chris Mutel (Ecoinvent, ex-PSI)

Tomas Navarrete Gutiérrez (LIST)

Romain Sacchi (PSI)

Bernhard Steubing (Leiden)

Adrian Haas (VSHN)

References:

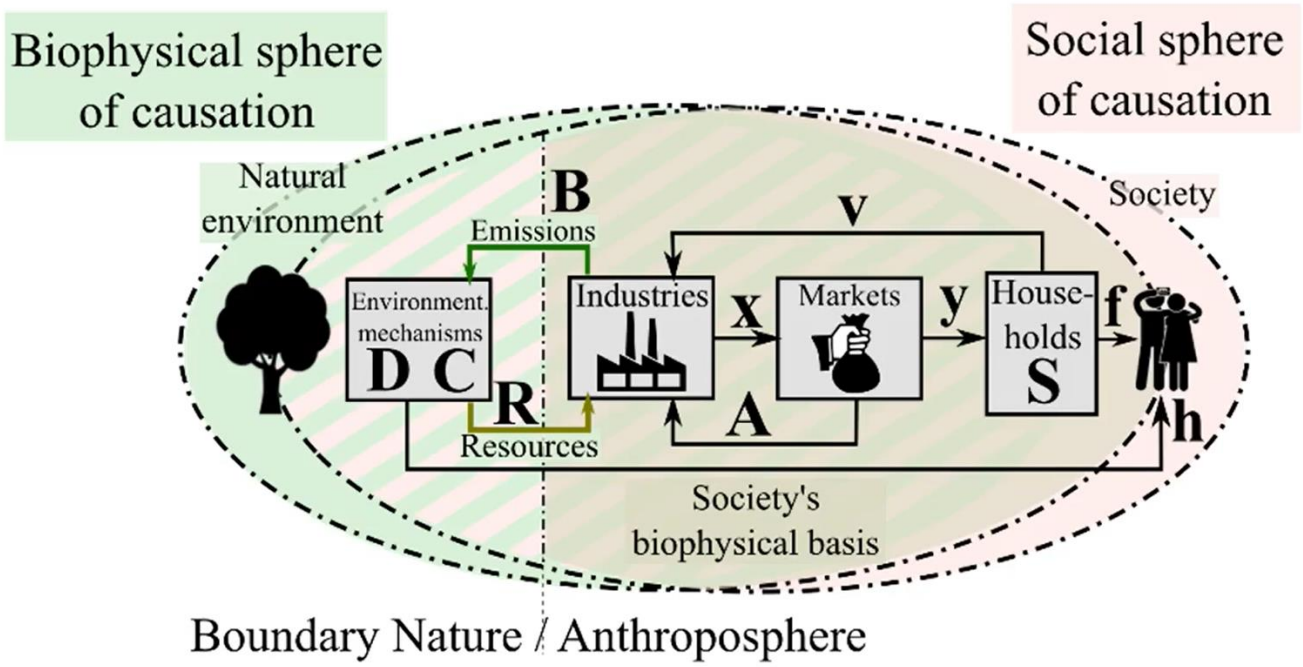
- **Society** → Départ de Sentier https://www.d-d-s.ch/
- **Article** → Mutel, Chris. (2017) *https://doi.org/10.21105/joss.00236*
- **Documentation** → *https://docs.brightway.dev/en/latest/ et le blog de développement de Cmutel : https://chris.mutel.org/*
- **Code** → *https://github.com/brightway-lca*
- **Tuto** (Notebook) a short selection :
  - *https://github.com/brightway-lca/brightway2/blob/master/notebooks/Getting%20Started%20with%20Brightway2.ipynb*
  - *https://github.com/maximikos/Brightway2_Intro/blob/master/BW2_tutorial.ipynb*
  - *https://github.com/PoutineAndRosti/Brightway-Seminar-2017/blob/master/Day%201%20AM/2%20-%20BW%20structure%20and%20first%20LCAs.ipynb*
  - *If unsolvable problems → https://stackoverflow.com/ with label 'Brightway" (very quick answer)*

1. Theory of BW

Theory of BW

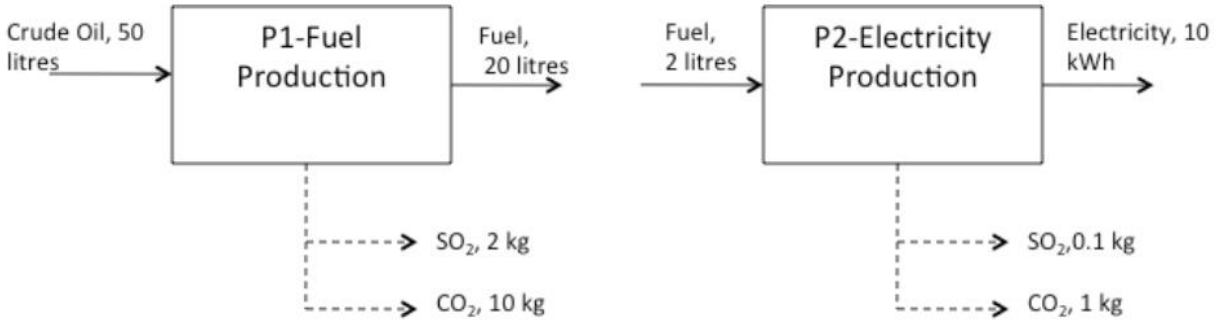
LCA in BW can be summed up by this equation (matrix vision) :

$$\boldsymbol{h = C \cdot B \cdot A^{-1} \cdot f}$$



To go further: Scott Matthews et al. « LCA Book ». In Life Cycle Assessment: Quantitative Approaches for Decisions That Matter. Carnegie Mellon University, 2014.
EcoSD, Advanced LCA Methodologies & Tools : Uncertainties & Impact Assessment, 2020
http://www.teaching.industrialecology.uni-freiburg.de/

Theory of BW



Let's assume $Y = \begin{pmatrix} Y_1 \\ Y_2 \end{pmatrix}$ with Y_1 the final fuel production and Y_2 electricity production, and X= $\begin{pmatrix} X_1 \\ X_2 \end{pmatrix}$ is a scaling factor that represents the production capacity. We can write :

Equation can be rewrite with matrix :

$$\begin{cases} 20X_1 - 2X_2 = Y_1 \\ 0X_1 + 10X_2 = Y_2 \end{cases}$$

$$\boldsymbol{A \cdot X = Y \Leftrightarrow X = A^{-1} \cdot Y}$$

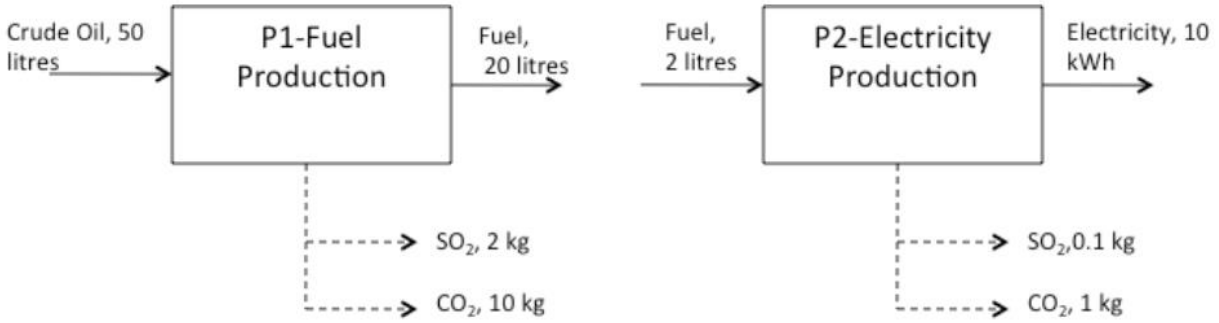
P1 P2

$$A = \begin{bmatrix} 20 & -2 \\ 0 & 10 \end{bmatrix}$$ ← Fuel ← Electricity

A is the **technosphere matrix**
→ *Rows = flows ; Columns = Activities*

$$A^{-1} = \begin{bmatrix} 0.05 & 0.01 \\ 0 & 0.1 \end{bmatrix}$$

Theory of BW



Exercise : If we want to produce 1000 kWh, how much fuel do I need ?

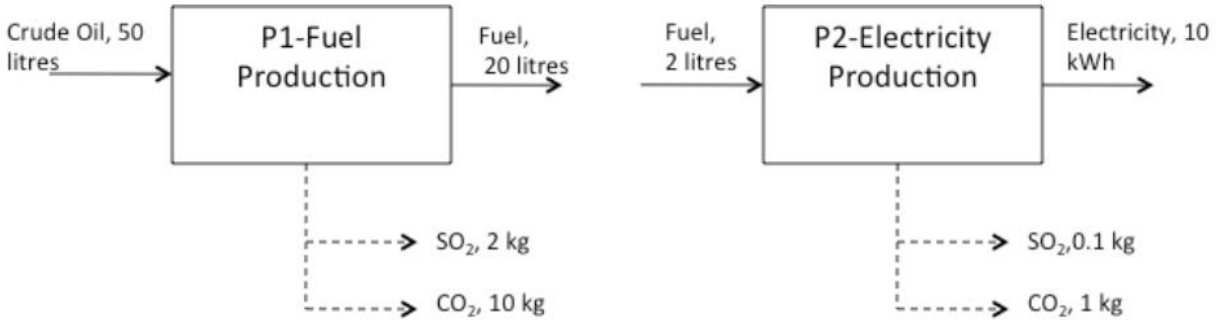
$$Reminder : \begin{cases} 20X_1 - 2X_2 = Y_1 \\ 0X_1 + 10X_2 = Y_2 \end{cases} (2)$$

Answer :

Produce 1000 kWh $\rightarrow \mathrm{Y} = \begin{bmatrix} 0 \\ 1000 \end{bmatrix} \Longrightarrow \mathrm{X} = \begin{bmatrix} 10 \\ 100 \end{bmatrix}$

*Which means I need to do **10× the P1-process** to do 100× the P2-process (to get 1000 kWh),*

Theory of BW



If we add the **biosphere matrix B**, which represents the emissions for each process, we get **b, the life cycle inventory** (i.e. all elementary flows to meet the demand f)

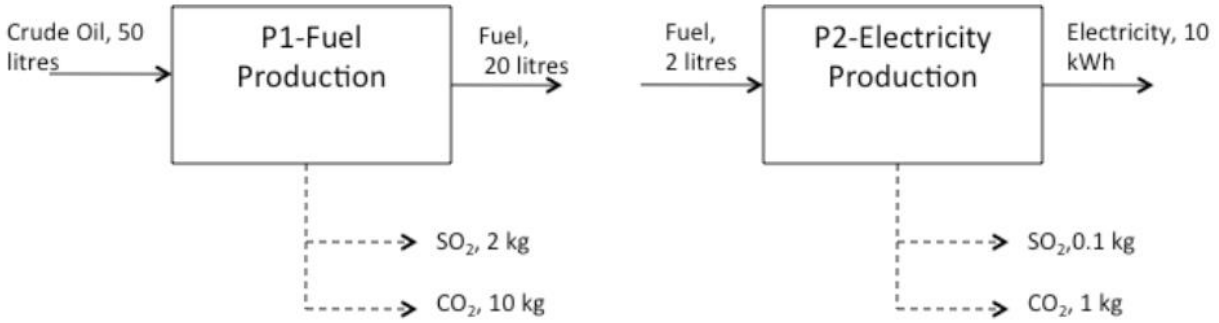
$$\mathbf{b} = B \cdot X = B \cdot A^{-1} \cdot Y$$

$$\text{with} : B = \begin{bmatrix} -50 & 0 \\ 2 & 0.1 \\ 10 & 1 \end{bmatrix}$$

$$A = \begin{bmatrix} 20 & -2 \\ 0 & 10 \end{bmatrix}$$

columns → **activities** (ie. the process)
rows → **intermediary flows** (for A) or **elementary flows** (for B).

Theory of BW



Exercise : What are the emissions that result from the production of 1000 kWh ?

Reminder :

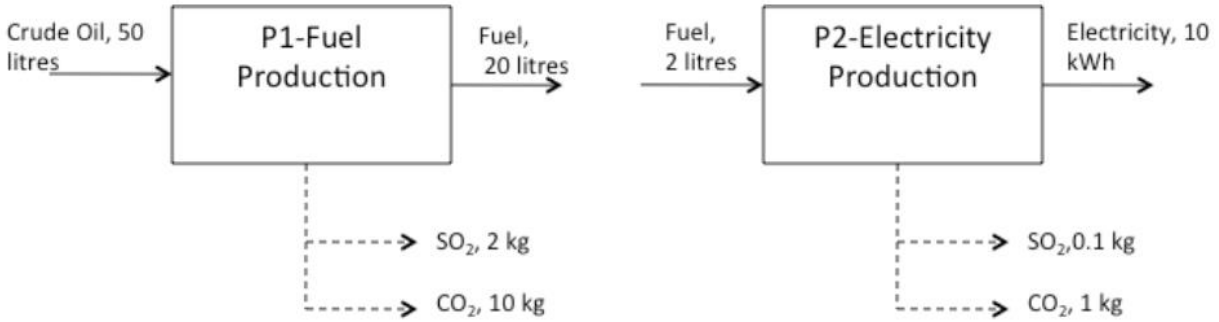
$$B = \begin{bmatrix} -50 & 0 \\ 2 & 0.1 \\ 10 & 1 \end{bmatrix}$$

Answer :

Produce 1000 kWh $\rightarrow \mathrm{Y} = \begin{bmatrix} 0 \\ 1000 \end{bmatrix} \Longrightarrow \mathrm{X} = \begin{bmatrix} 10 \\ 100 \end{bmatrix} \Longrightarrow \mathrm{b} = B \cdot X = B \cdot A^{-1} \cdot Y$

Numerical application : $b = \begin{bmatrix} -500 \\ 30 \\ 200 \end{bmatrix}$ *which means we will extract 500L of crude oil and emits 30kg* SO_2 *and 200kg* CO_2

Theory of BW



Knowing the LCI, we can add the **characterization matrix C**, that contains the characterization factor for each elementary flows

$$h = C \cdot B \cdot A^{-1} \cdot f$$

Flows	Life (years)	CF of GWP100 IPCC 2014 [2007]
CO_2	5 - 200	1 [1]
CH_4	12	28 [25]
N_2O	114	310 [298]
SF_6	3200	23 900 [22 800]

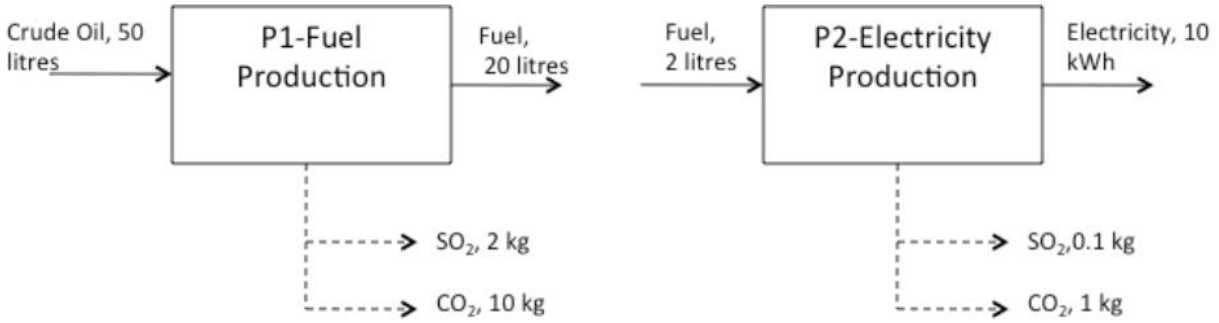
1kg CH_4 emitted → same effect as 28 kg of CO_2 over a 100 years.
➔ Unit of GWP is kg CO2 eq

GWP (IPCC 2014)

$$C = \begin{bmatrix} 1 \\ 28 \\ 310 \\ (\dots) \end{bmatrix}$$

← CO_2
← CH_4
← N_2O
← others

Theory of BW



Exercise : What would be the GWP 100 for 1000 kWh with P2 with the method IPCC 2014 ?
(*assuming only CO2 has effect on climate change during the process)*

Reminder :

$$C = \begin{bmatrix} 1 \\ 28 \\ 310 \\ \dots \end{bmatrix}$$

Answer :

Produce 1000 kWh →: $b = \begin{bmatrix} -500 \\ 30 \\ 200 \end{bmatrix}$

Assuming only CO2 has effect on climate change during the process, we have

$h = C \cdot b = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} \cdot \begin{bmatrix} -500 \\ 30 \\ 200 \end{bmatrix} = 200$ *kg CO2eq pour 1000 kWh*

Theory of BW

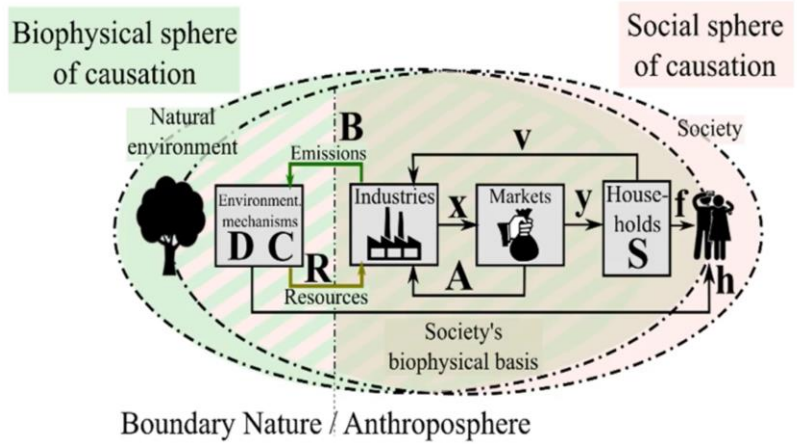
Go back to our main equation :

s = supply array, what is needed to supply my functional unit

$$h = C \cdot B \cdot A^{-1} \cdot f$$

b = life cycle inventory, all the elementary flows to meet my demand

h represents the characterized impacts for one impact category



Nomenclature:

f = final demand vector *[p×1]*

A = technosphere matrix *[p×q]*

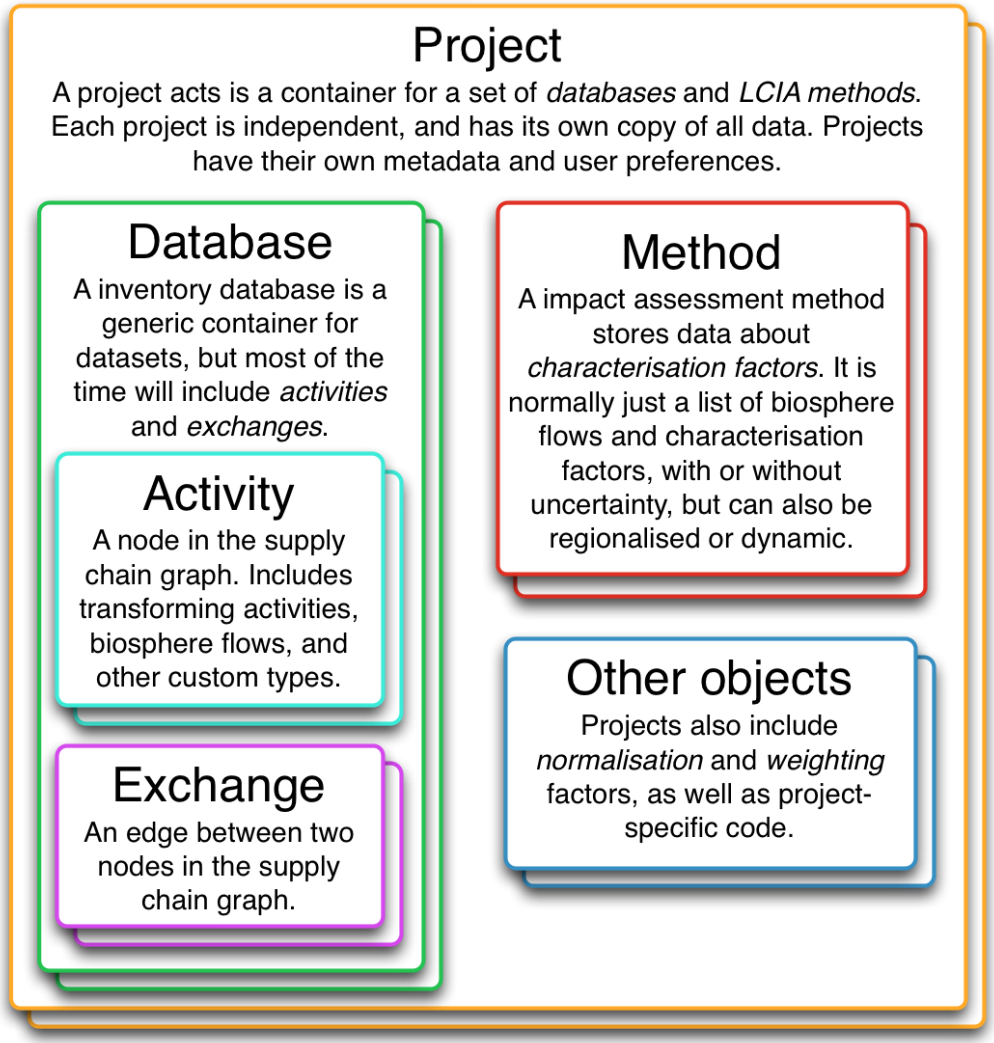
B= biosphere matrix *[r×q]*

C = characterization matrix *[p×q]*

h = characterised inventory matrix *[1]*

columns → **activities/**process *[q]*
rows → **intermediary flows** for A *[p]* or **elementary flows** for B *[r]*

Architecture



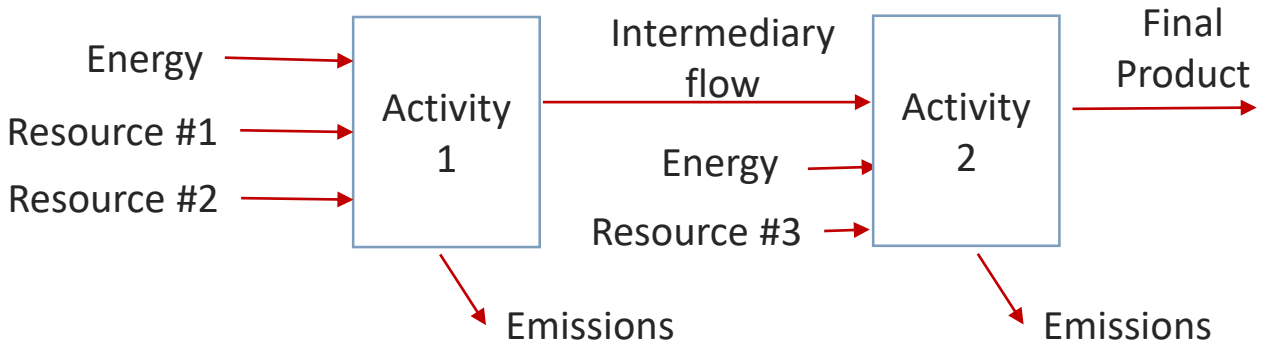
- Data in Brightway2 is structured in a hierarchy.
- At the top level, we have **projects**.
  → contains **database** and LCIA **methods**
  → totally independent of other projects
  → saved as subdirectories in the file system
- The database contain the activities connected with exchanges

NB : BW and Activity Browser share the same projects/databases

Activities & exchanges

Activities = **nodes** in the database
- → include transforming and **market/product activities** (technoshere or intermediary flows)
- → but also **biosphere flows** (biosphere flows)

Exchanges = **edges between two nodes** → inputs or outputs of several types :
- **biosphere** : consumption of resource or emissions,
- **technosphere** process,
- **production** : output amount



Linking activity datasets within and between databases requires a **unique identifier or a code** = a string of numbers and letters

```
In [7]: activity[0], activity[1]
Out[7]: ('ecoinvent 3.2 cutoff', 'ab2f7a551a06a59de9191065128233e4')

In [8]: activity == ('ecoinvent 3.2 cutoff', 'ab2f7a551a06a59de9191065128233e4')
Out[8]: True
```

LCA in BW

1. Translate the functional unit into a demand array
2. Find the right parameter arrays, and ask matrix builder for matrices
3. Solve the linear system As=F
4. Multiply the result by the LCIA CFs, if a LCIA method is present

FU → {activity : amount}

↓

Select a characterization method

↓

Produce A and B matrices and solves As=f

↓

Compute the impacts .lcia

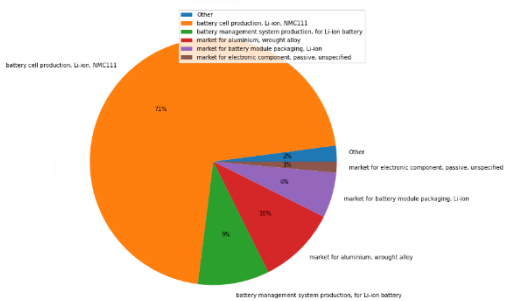
↓

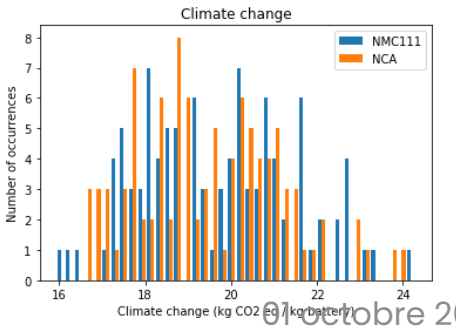
Analysis : contribution, MC, sensitivity…

```
[11]: NMC111_pack=[NMC111_pack for NMC111_pack in eidb if
                   'market for battery, Li-ion, NMC111, rechargeable, prismatic' in str(NMC111_pack)][0]
      fu_NMC={NMC111_pack.key:1}
      fu_NMC

[11]: {('ecoinvent 3.8_cutoff_ecoSpold02', 'bb7113838446330b7ffd1d91f72a1201'): 1}
```

```
[14]: list_methods = [method for method in bw.methods if "CML v4.8 2016"
                      in str(method) and not "no LT" in str(method)]
      list_methods[1]

[14]: ('CML v4.8 2016', 'climate change', 'GWP 100a')
```

```
[16]: lca = bw.LCA(fu_NMC, list_methods[1])
      lca.lci()
      lca.lcia()
      print("La fabrication d'1kg de pack NMC111 émet {:f}{}"
            .format(lca.score,bw.Method(list_methods[1]).metadata['unit']))

      La fabrication d'1kg de pack NMC111 émet 16.739185kg CO2-Eq
```





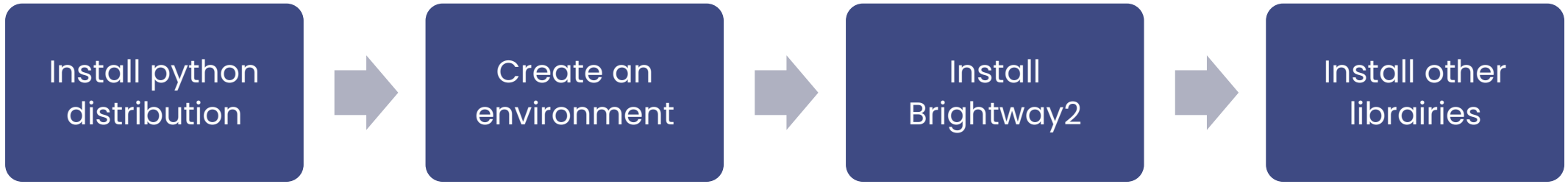
2. Practice

Installation

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

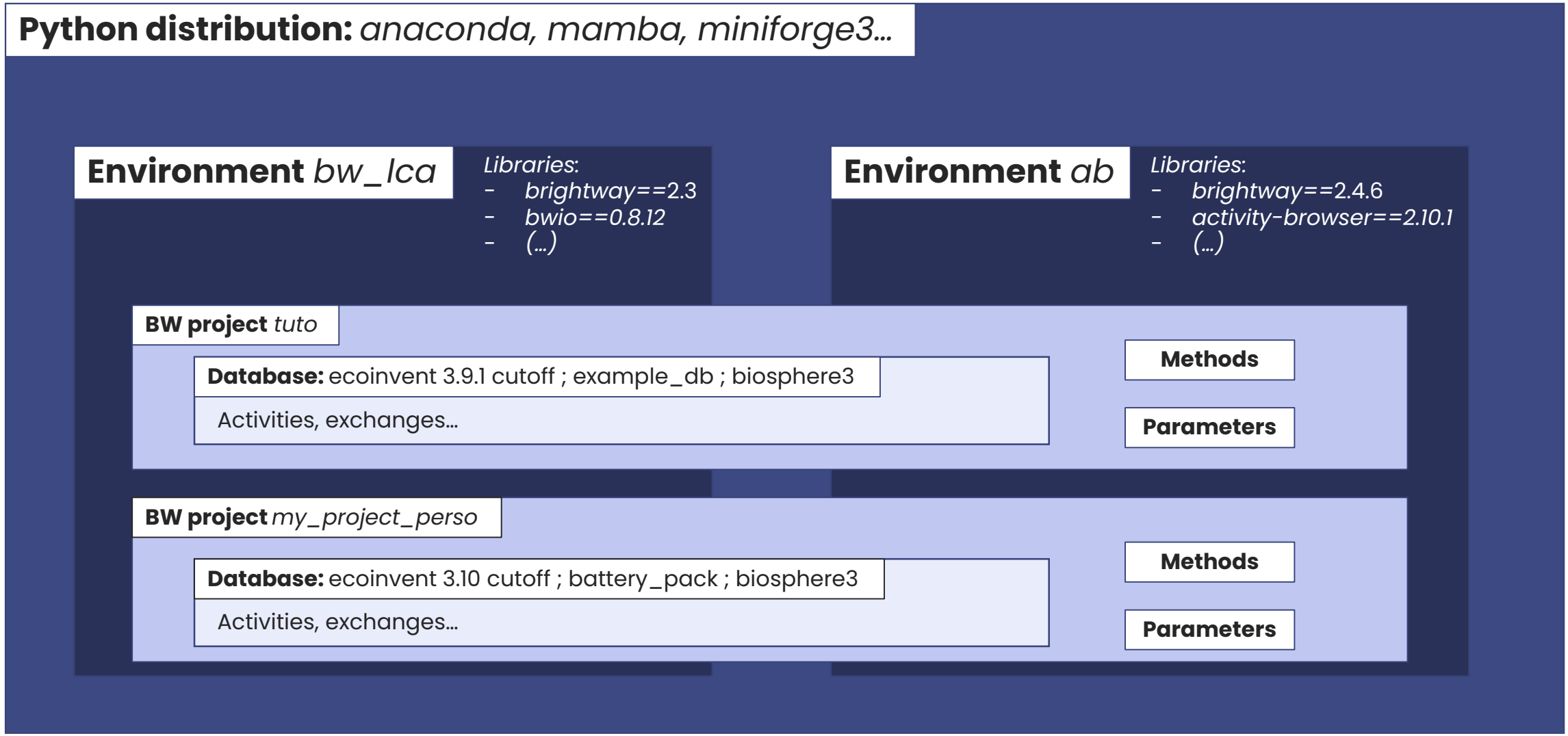
- Collaborative tool whose evolution and improvement are open to all
- Installation guide
- Tutorial
- Practical examples
- Open-access code

Installation a bit tricky, but here are the main steps



- 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



Practical part

Setup :

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

Open Jupyter :

- ✓ Open a anaconda/miniconde console
- ✓ Run *conda 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_beginner_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