



WIR SCHAFFEN WISSEN – HEUTE FÜR MORGEN

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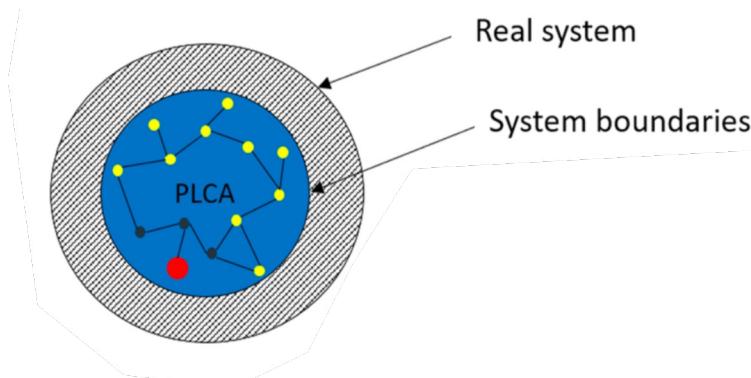
Hybrid Life-Cycle Assessment: Introduction and Implementations

Open Inventory Data Manipulation Autumn School (OIDMAS), Grosshöchstetten, October 2022

LCA and EEIOA

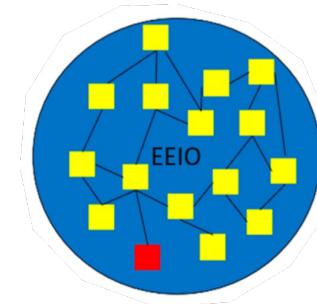
Process-Based Life-Cycle Assessment (PLCA)

Based on detailed description of value chains and exchanges with the environment. *“Precise, but lacks accuracy.”*

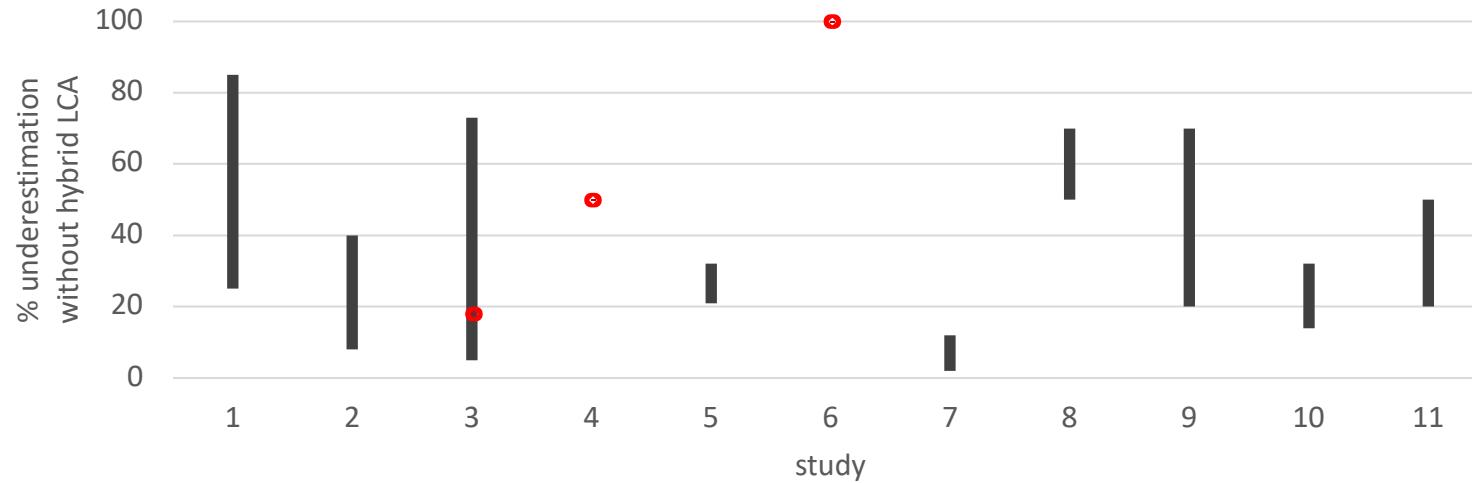


Environmentally-Extended Input-Output Analysis (EEIOA)

Based on national inventories and trade tables. *“More likely to cover true value, but lacks precision.”*



What's wrong with PLCA?



Studies using life-cycle assessment with a purely process-based inventory tend to show lower emissions than if they had used a hybrid approach. The underestimation ranges up to 100%.

LCIA: Mathematical Formulation

Life-Cycle Inventory (LCI):

$$\vec{g} = \hat{B}\vec{s} = \hat{B}\hat{A}^{-1}\vec{f}$$

where

\vec{g} ... inventory vector

\vec{s} ... scaling vector

\vec{f} ... final demand vector

\hat{B} ... inventory matrix

\hat{A} ... technology matrix

Life-Cycle Impact Assessment (LCIA):

$$\vec{h} = \hat{C}\vec{g} = \hat{C}\hat{B}\hat{A}^{-1}\vec{f}$$

where

\vec{h} ... impact vector

\hat{C} ... characterization matrix

EEIOA: Mathematical Formulation

Input-Output Analysis (IOA):

$$\vec{x} = \hat{A}\vec{x} + \vec{f} = (\mathbb{I} - \hat{A})\vec{f}$$

$$\vec{f} = (\mathbb{I} - \hat{A})\vec{x}$$

Environmentally-Extended IOA (EEIOA):

$$\vec{x}^{P^*} = \hat{D}^P(\mathbb{I} - \hat{A})^{-1}\vec{f}$$

where

\vec{x} ... total output of all sectors

\vec{f} ... total final demand ("exogenous demand")

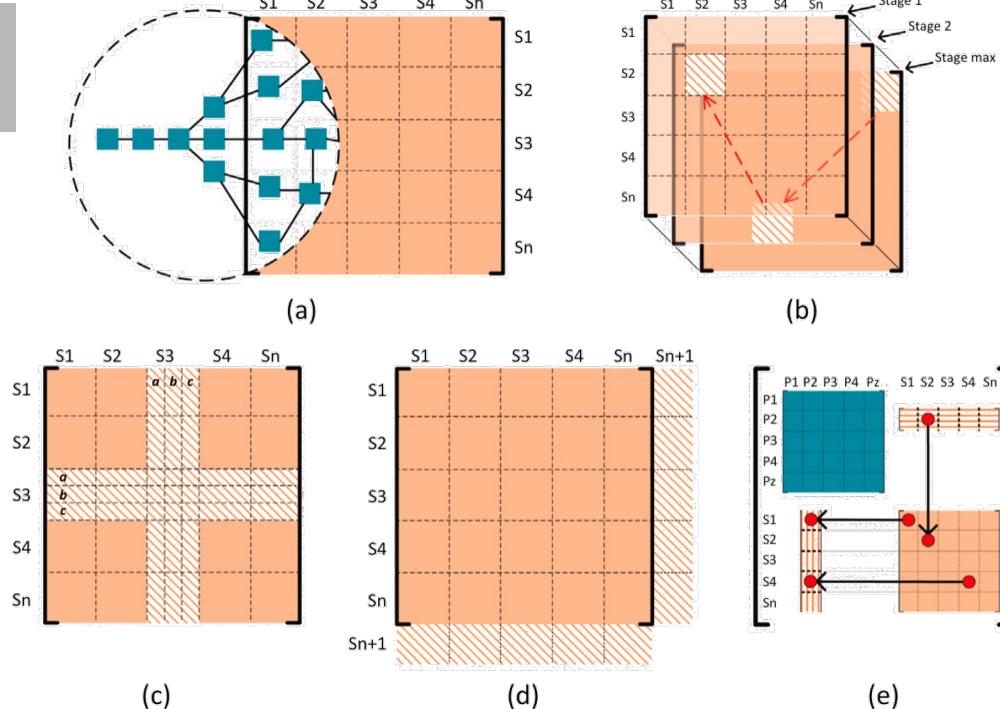
\hat{A} ... technical coefficient matrix ("intersectoral direct requirements")

\vec{x}^{P^*} ... pollution vector ("environmental burdens")

\hat{D}^P ... direct impact coefficient matrix

$(\mathbb{I} - \hat{A})^{-1}$... Leontief inverse

Hybridization: Different Methods



(a) Tiered

(b) Path Exchange

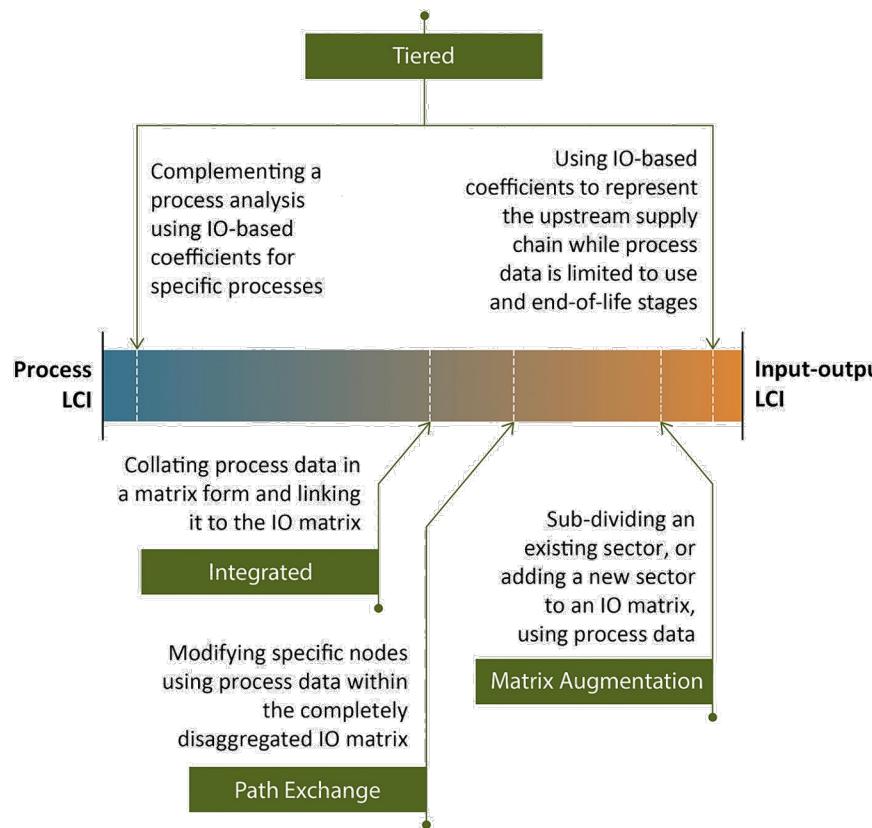
(c) Matrix Augmentation (sector disagg.)

(d) Matrix Augmentation (new sector)

(e) Integrated

- █ Input-output matrix
- █ Process data
- Process data system boundaries
- Modified section of the input-output matrix
- ← Link from process to input-output matrix
- ↔ Sector to sector transaction
- ||| Downstream cut-off matrix
- ||||| Upstream cut-off matrix

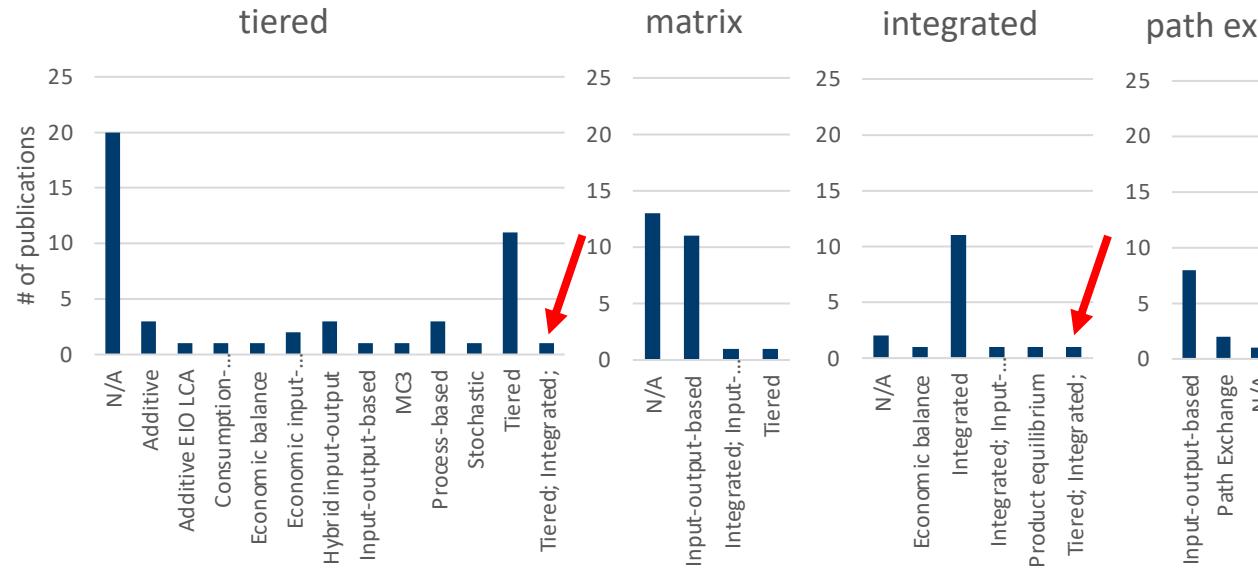
Hybridization: Different Methods



Different hybridization techniques:

1. 3 of 4 methods augment either the process data or the input/output data
2. 1 of 4 methods augments both data
3. attempt to solve different constraints of using either PLCA or EEIOA
4. vary in their success of solving the respective constraints
5. are implemented differently, depending on the practitioners

Methods: Terminology (or lack thereof)



There is still a lack of universally accepted nomenclature in defining different hybridization methodologies. Studies published up to 2015 show a wide range of definitions used by authors. Here, they are classified using Crawford et al. (2018).

Method: “Matrix Augmentation Hybrid”, vers. 1

(also “input-output hybrid”)

Attempts to Solve:

Aggregation Error in EEIOA

Basic Idea:

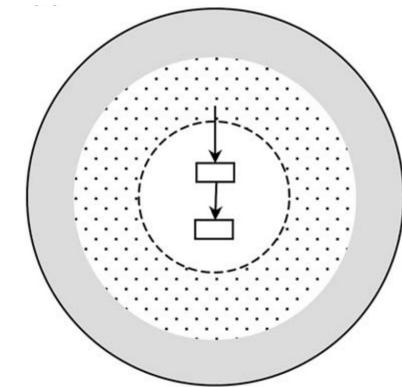
Split up a sector of the economy into sub-sectors corresponding to products (where process-information is available).

Required Assumption:

The technical coefficient matrix is unaffected by the introduction of the new sector.

Representation:

S1	S2	S3	S4	Sn
S1		a b c		
S2				
S3	g h c			
S4				
Sn				



Method: “Matrix Augmentation Hybrid”, vers. 2

(also “input-output hybrid”)

Attempts to Solve:

Aggregation Error in EEIOA

Basic Idea:

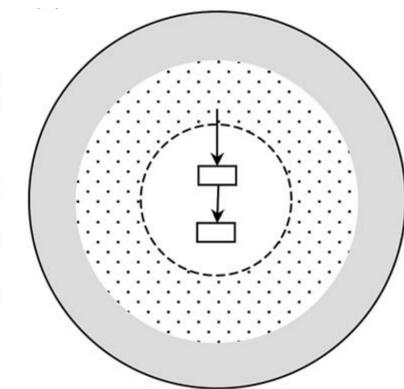
Represent a product (where process-information is available) as a new hypothetical sector of the economy.

Required Assumption:

The technical coefficient matrix is unaffected by the introduction of the new sector.

Representation:

S1	S2	S3	S4	Sn	Sn+1
S1					
S2					
S3					
S4					
Sn					
Sn+1					



Method: “Path Exchange Hybrid”

Attempts to Solve:

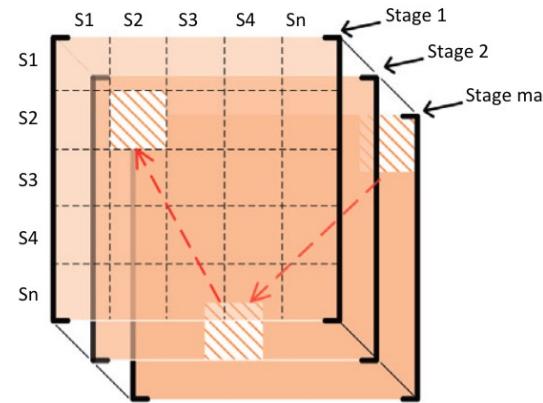
Aggregation Error in EEIOA

Basic Idea:

Structural Path Analysis (SPA):

$$(\mathbb{I} - \hat{A})^{-1} = \mathbb{I} + \hat{A} + \hat{A}^2 + \hat{A}^3 + \dots$$

Representation:



Method: “Tiered Hybrid”

Attempts to Solve:

Aggregation Error in PLCA

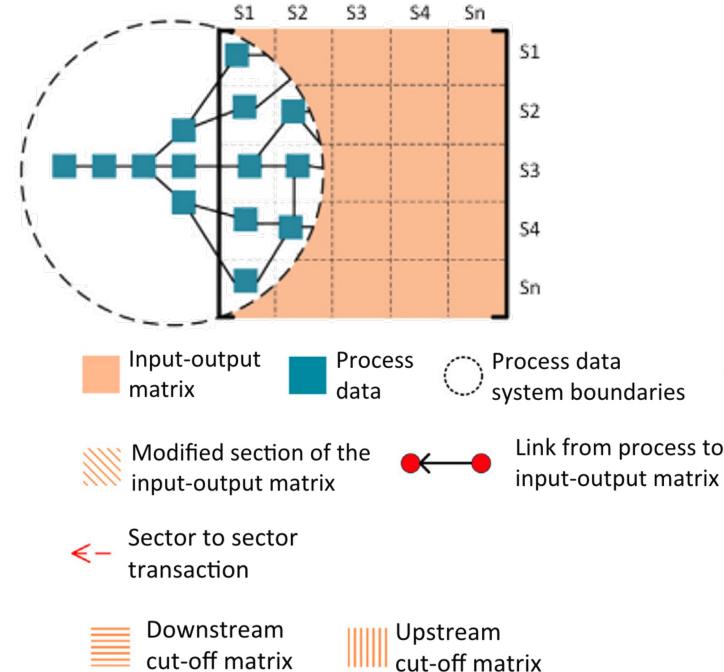
Basic Idea:

PLCA for use & disposal phase & several important upstream processes. The remaining input requirements from EEIOA.

Main Issues:

Double counting of commodity flows. No interaction between PLC and IO inventories.

Representation:



Method: “Integrated Hybrid”

(also “tiered hybrid”, if used without downstream cutoff)

Attempts to Solve:

Aggregation Error in PLCA

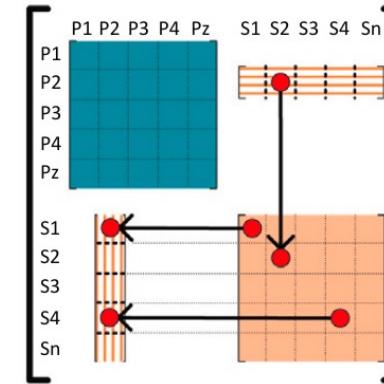
Basic Idea:

Connect the technology matrix to the input-output table via “up/downstream cutoffs”.

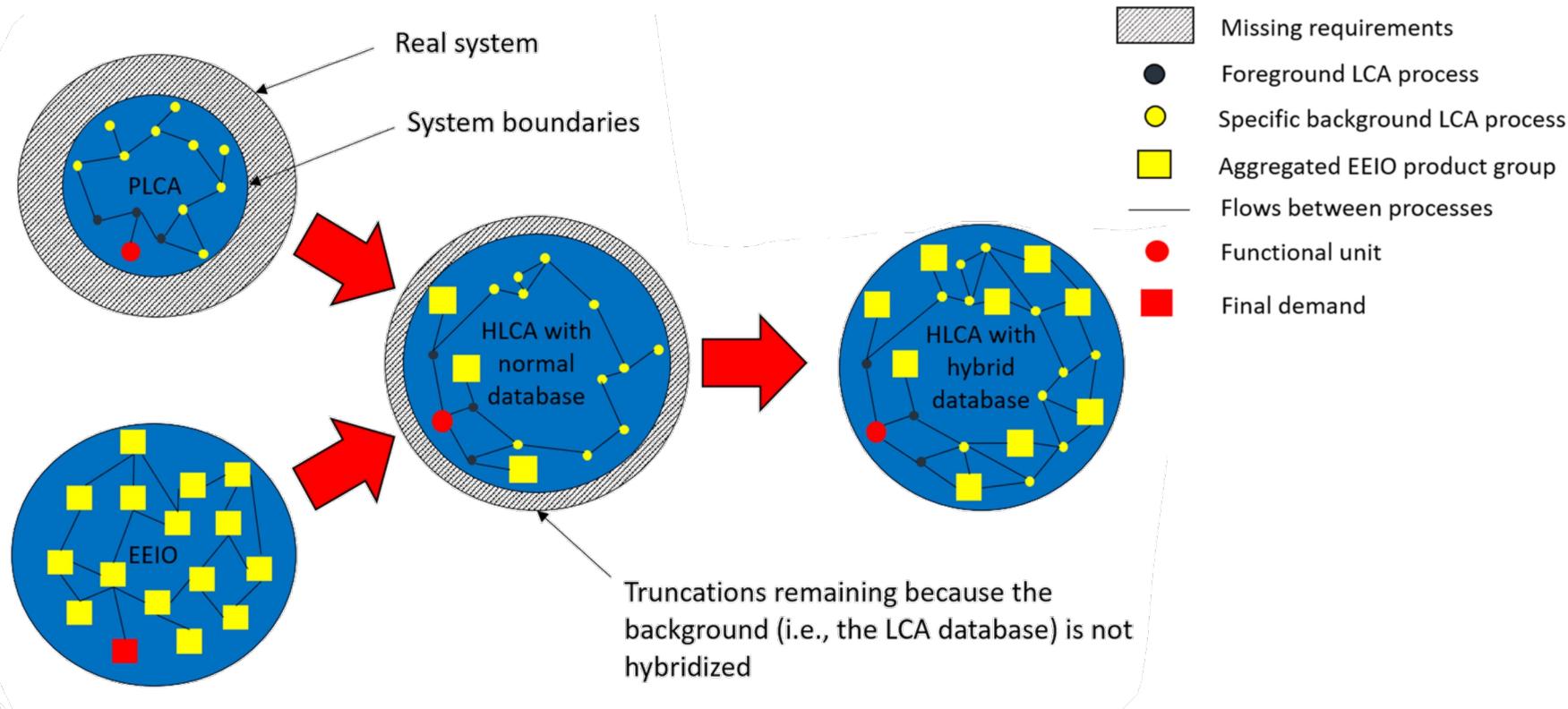
Main Issues:

Double counting of commodity flows.
Nomenclature differences of datasets.

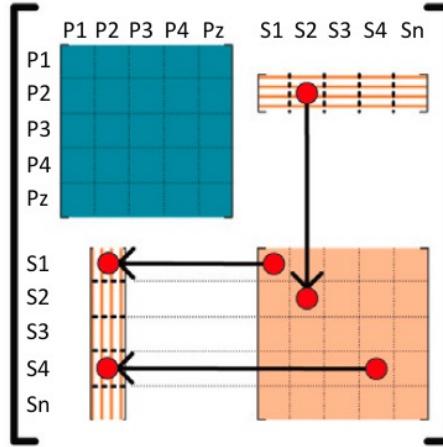
Representation:



Integrated Hybrid: Overview (1/2)



Integrated Hybrid: Overview (2/2)



$$\hat{x}^{P^*} = \begin{bmatrix} \hat{D}^P & 0 \\ 0 & \hat{D}^P \end{bmatrix} \begin{bmatrix} \hat{A} & \hat{X} \\ \hat{Y} & \mathbb{I} - \hat{A} \end{bmatrix}^{-1} \begin{bmatrix} \vec{f} \\ 0 \end{bmatrix}$$

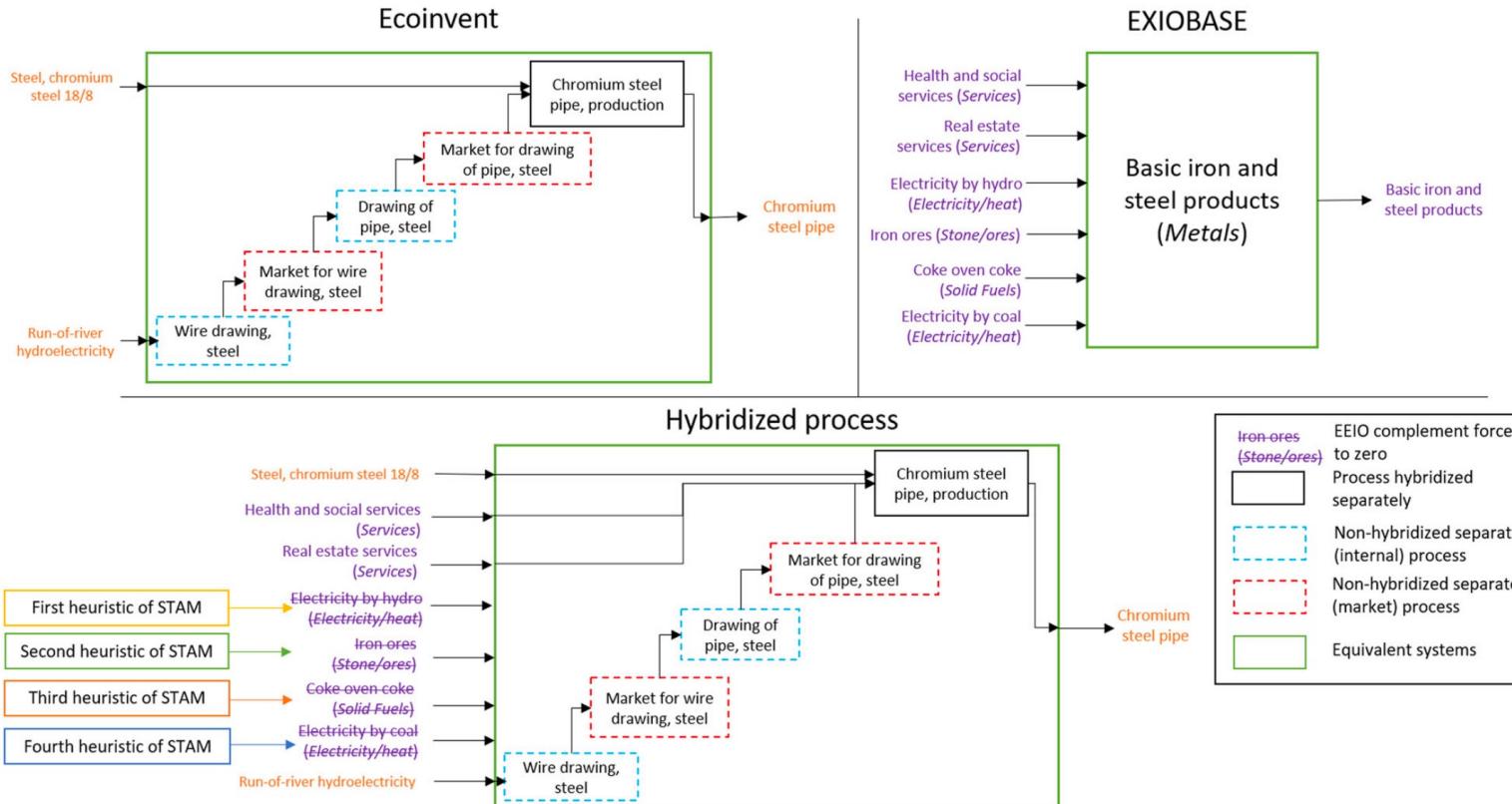
where

\hat{X} ... downstream cutoff matrix

\hat{Y} ... upstream cutoff matrix

- Input-output matrix ■ Process data ○ Process data system boundaries ← Sector to sector transaction
- Modified section of the input-output matrix ← Link from process to input-output matrix ■ Downstream cut-off matrix ■ Upstream cut-off matrix

Integrated Hybrid: Double Counting



Tools

pylcaio

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

Developed initially by Dr. Maxime Agez

<https://craig.org/index.php/project/pylcaio>

<https://github.com/OASES-project/pylcaio>

Originally developed at:



POLYTECHNIQUE
MONTRÉAL
UNIVERSITÉ
D'INGÉIERIE



Improved through:

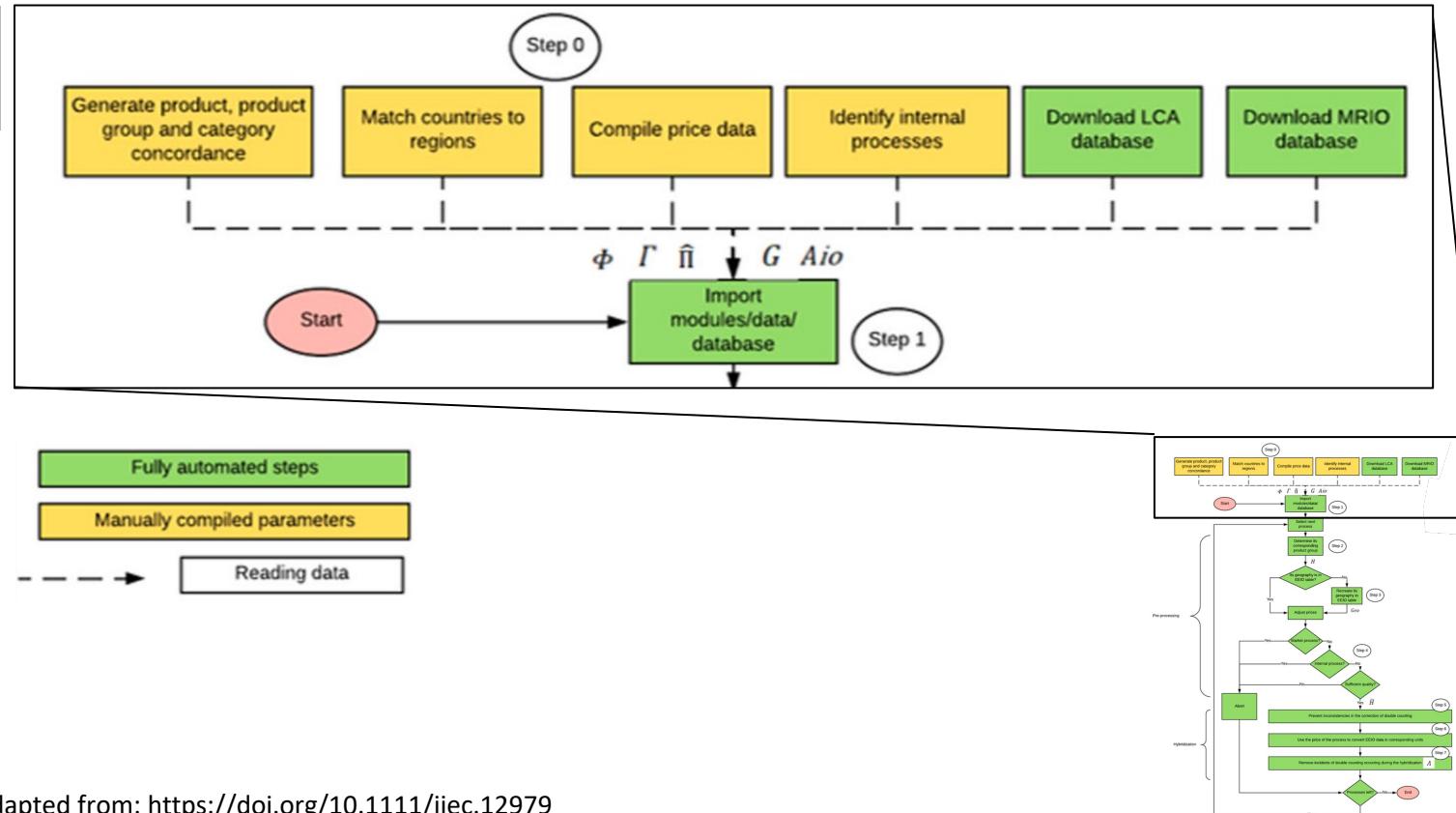


Sustainable Economy
National Research
Programme

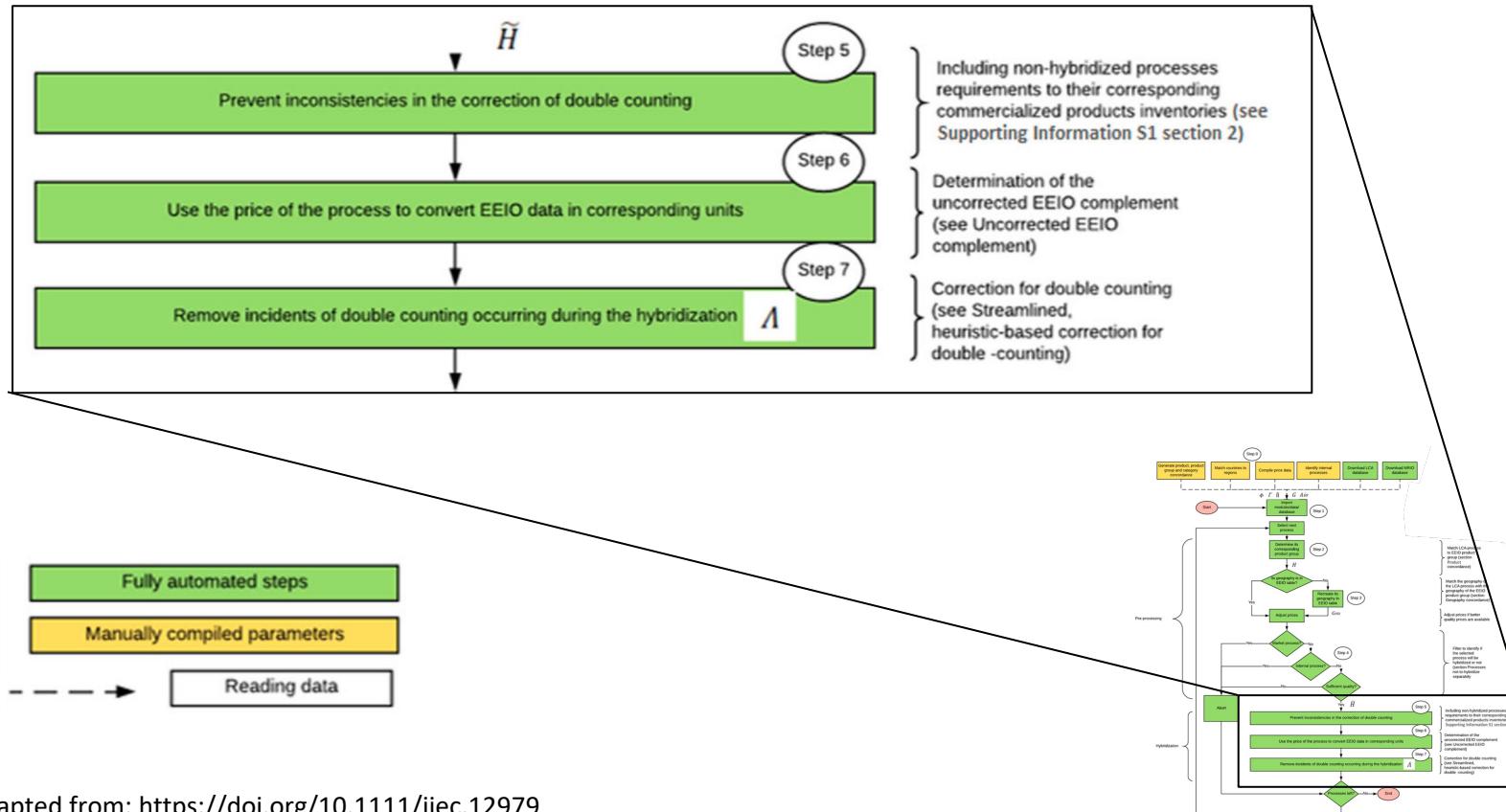


Oases

pylcaio diagram (1/2)



py1caio diagram (2/2)



Walkthrough Example

Now it's your turn!

Literature

OVERVIEW

Crawford et al., 2018 “Hybrid life cycle inventory methods”

<https://doi.org/10.1016/j.jclepro.2017.10.176>

Suh et al., 2005 “Methods for Life Cycle Inventory of a product”

<https://doi.org/10.1016/j.jclepro.2003.04.001>

INTEGRATED HYBRID METHODOLOGY (**pylcaio**)

Agez et al., 2020 “Hybridization of complete PLCA and MRIO databases”

<https://doi.org/10.1111/jiec.12979>

Agez et al., 2018 “Lifting the veil on the correction of double counting”

<https://doi.org/10.1016/j.jclepro.2017.10.176>

Links

- Presentations and Tutorials
 - <https://github.com/Depart-de-Sentier/Autumn-School-2022>
- Development Environment for the Autumn School
 - <http://autumn.brightway.dev/>
- pylcaio
 - <https://github.com/CIRAIIG/pylcaio>
 - <https://github.com/OASES-project/pylcaio>
- Brightway
 - <https://github.com/brightway-lca>
 - <https://2.docs.brightway.dev/>

Wir schaffen Wissen – heute für morgen

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