Integrating Circularity into LCA: circularity with a life-cycle perspective

Julia Cilleruelo Palomero
LCA Consultant & Researcher

10 March 2026 | The Circularity and Life Cycle Assessment working group meeting on Circularity Measurements in LCA Software Tools, Swedish Life Cycle Center

About openLCA

- Free and open source project
- Developed by GreenDelta GmbH since 2007
- Constant development, continuous update releases

  - LCA, LCC, Social LCA
  - Carbon & Water footprint
  - Product Environmental Footprint
  - Environmental Product Declarations (EPDs)
  - **Circularity calculations**

2.6.0:

- System Dynamics (SD) simulation and modeling (experimental feature)
- Hestia import functionality with flow mapping selection and data preview
- Improved Jython/Python integration: CodeMirror 6 editor with code completion and run keymap
- Library signing (experimental)
- GLAD mapping file import support
- Allow results as default providers in processes with drag and drop support
- Allow adding multiple impact categories and flows to results at once
- Better provider names in Sankey diagram
- Improved process names in model graph
- Social aspects: allow deletion of a set of indicators under social aspects tab
- Fix: direct impacts of processes
- Fix: deletion of database repository
- Fix: library signing UI issues

2.5.0:

- Allow (EPD) results as default providers in processes
- Allow LCC for databases linked to libraries
- Copy/paste shortcuts in the navigator
- Import results of one EPD into a dedicated folder
- Fix: scale activity values in social aspects in library export
- Fix: project calculation fails with systems that have no impact contributions
- Fix: hidden icon within the JSON import
- Fix: incorrect “unlinked” icon for avoided products in model graph

2.4.1:

- Remove libraries from database (experimental).
- ILCD export: global parameters are only written to a process, when they are used in formulas of that process.
- Fix: corrected display of the connection state in the connection dialog of the graphical editor.
- Fix: flow editor page with regionalized characterization factors crashed sometimes.
- Fix: reference data no longer shows errors during database validation.
- Fix: copy datasets from the library.

Introducing the idea

Sustainable development

- LCA older in the field
- Circular Economy is getting more traction

- Circularity Indicators can quantify Circular Economy solutions
- -> BUT conceptual approach, usually not reflected in LCA data

WHAT HAPPENS IF WE LOOK AT CIRCULAR ECONOMY WITH A LIFE CYCLE PERSPECTIVE?

- We modified an LCA database to track circularity variables
- We enhanced the software to make circularity indicator calculations
- We investigated how does circularity look in an LCA dataset

Circularity Indicators

	Fully linear system	Fully circular system
MCI	0.1	1
CI	0	1

- **Material Circularity Indicator (MCI)**

$$MCI_P = 1 - LFI \cdot F(X) \quad ; \quad LFI = \frac{V + W}{2M + \frac{W_F - W_C}{2}} \quad ; \quad X = \frac{L}{L_{av}} \cdot \frac{U}{U_{av}}$$

$V = virgin\ material$
$W = waste$
$L = life\ duration$
$U = utility$

- **Circularity Index (CI)**

$$CI = \frac{recovered\ EOL\ material}{total\ material\ demand} \cdot \left(1 - \frac{energy\ required\ to\ recover\ material}{energy\ required\ for\ primary\ production}\right)$$

Ellen MacArthur Foundation, "Material Circularity Indicator (MCI) Methodology," 2019. [Online]. Available: https://emf.thirdlight.com/link/3jtevhlkbukz-90f4s4/@/preview/1?0. [Accessed 18 April 2023].
J. Cullen, "Theoretical Benchmark or Perpetual Motion Machine?," Journal of Industrial Ecology, 21, pp. 483-486, 2017.

Applying circularity to LCA

✓ Avoid double counting

Apply new **elementary flows to shadow** circularity information.

Across all the inventory.

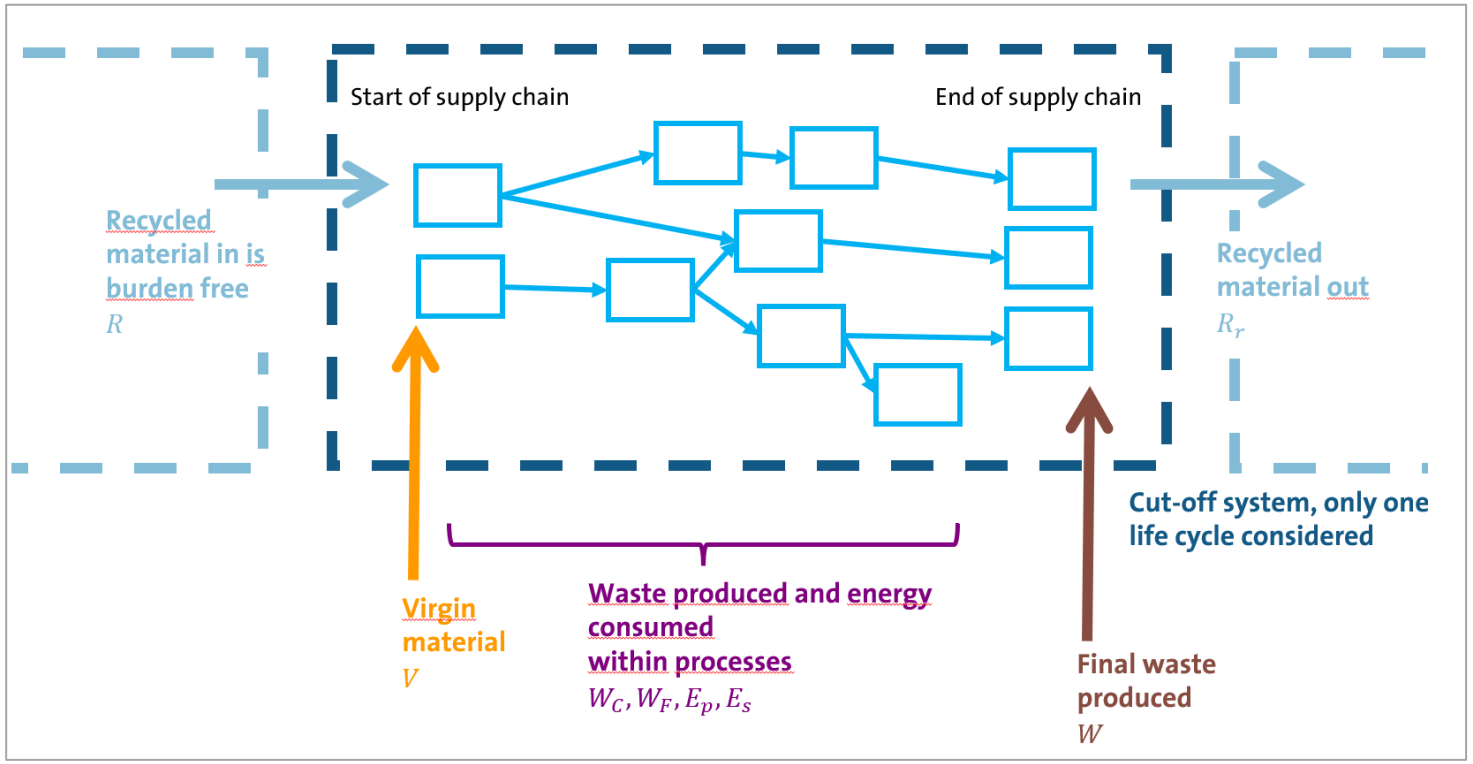


Figure 1: Circularity variables and their placing in an LCA database

Rest of variables can be calculated from these or from user input

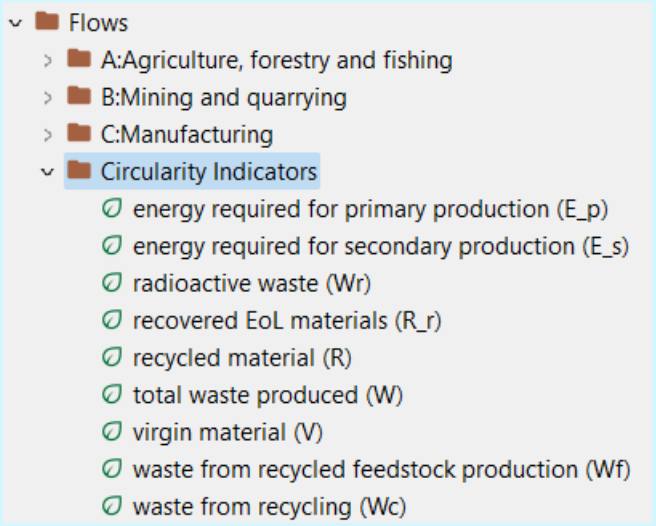
(applied to ecoinvent cut-off)

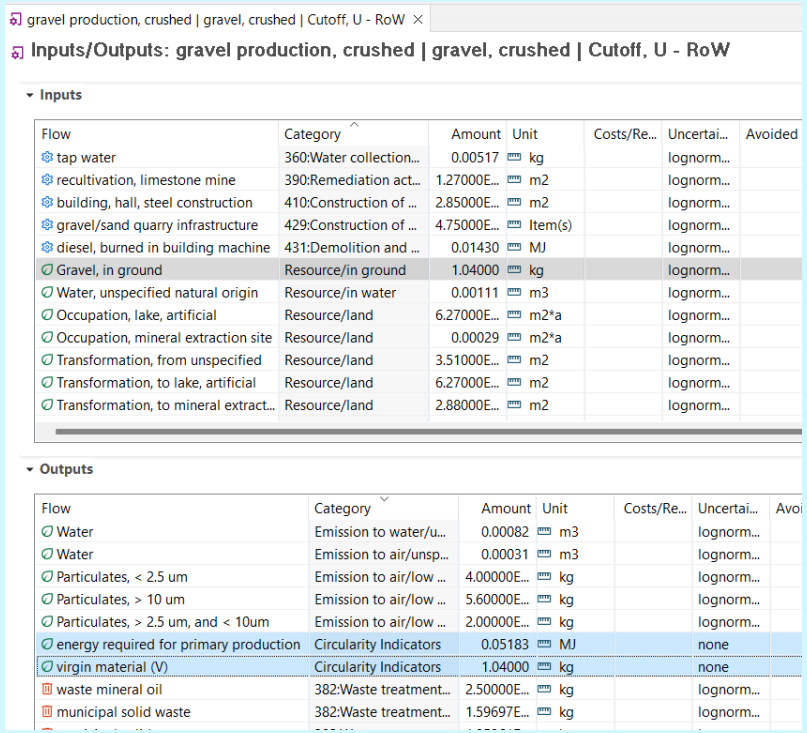
How to execute circularity in openLCA ?

- Ecoinvent database with **circularity traced in inventory**
- Can be **acquired through openLCA Nexus**, as a regular database would
- Counts with **extra functionality** for circularity calculations

How to execute circularity in openLCA ?

1. Include circularity elementary flows in your **foreground model.**

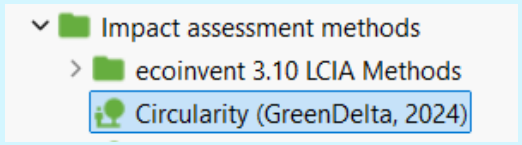


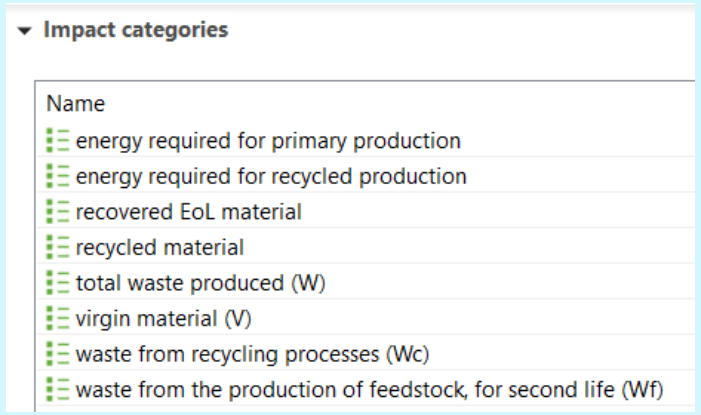


(example from ecoinvent dataset)

Note: the background datasets already trace circularity!

2. Calculate your model with the **Circularity LCIA Method**.
This already gives you information about circularity.





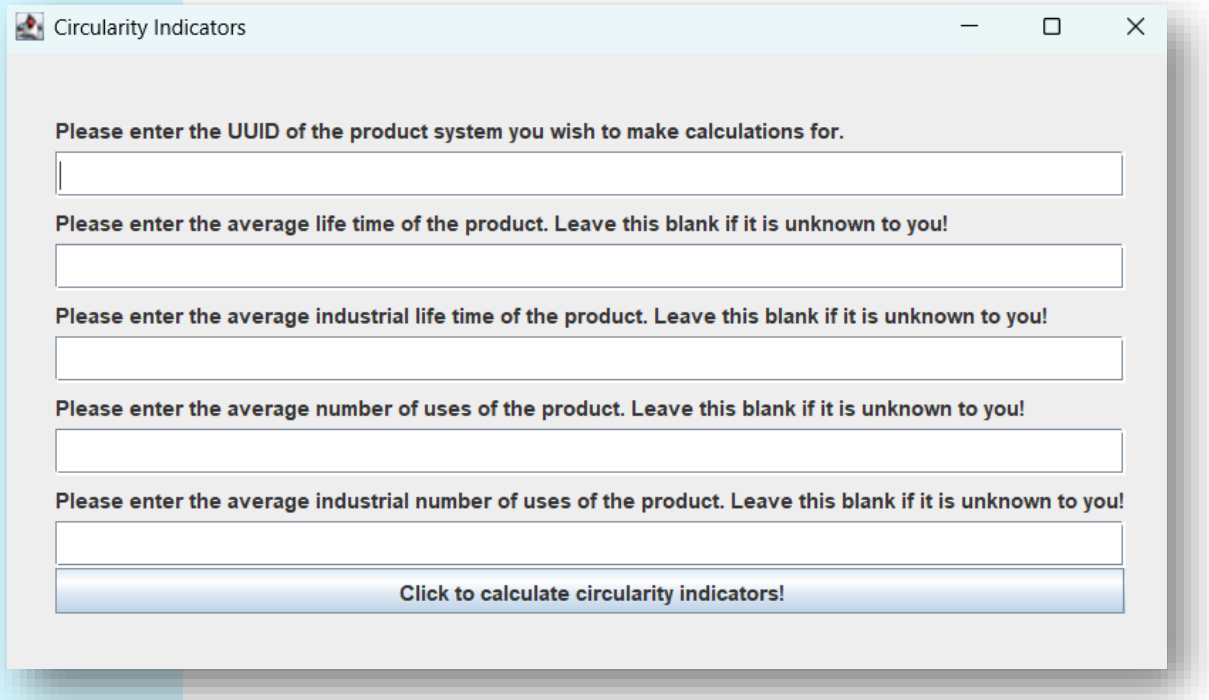
How to execute circularity in openLCA ?

3. Add extra variables through a pop-up window which displays results

>> The MCI includes variables that are usually outside the database inventory

$$X = \frac{L}{L_{av}} \cdot \frac{U}{U_{av}}$$

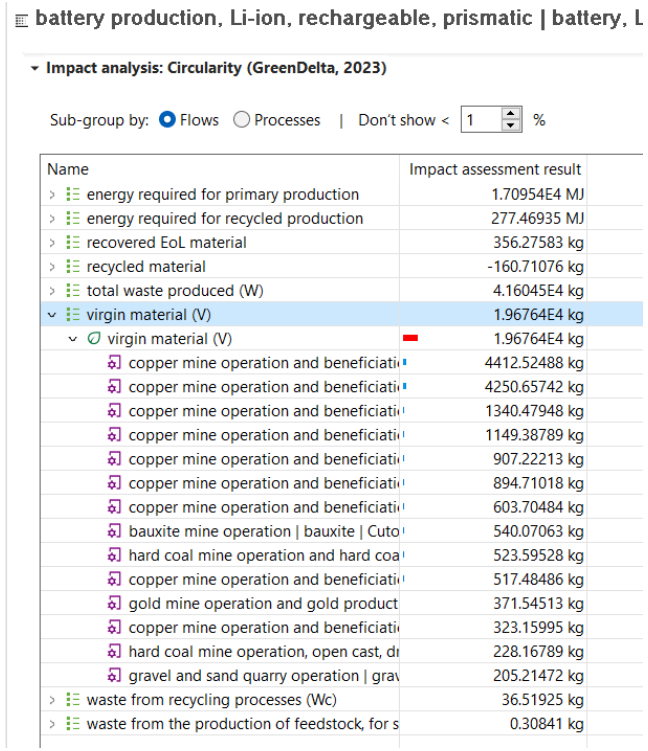
$L = life\ duration$
$U = utility$



Example

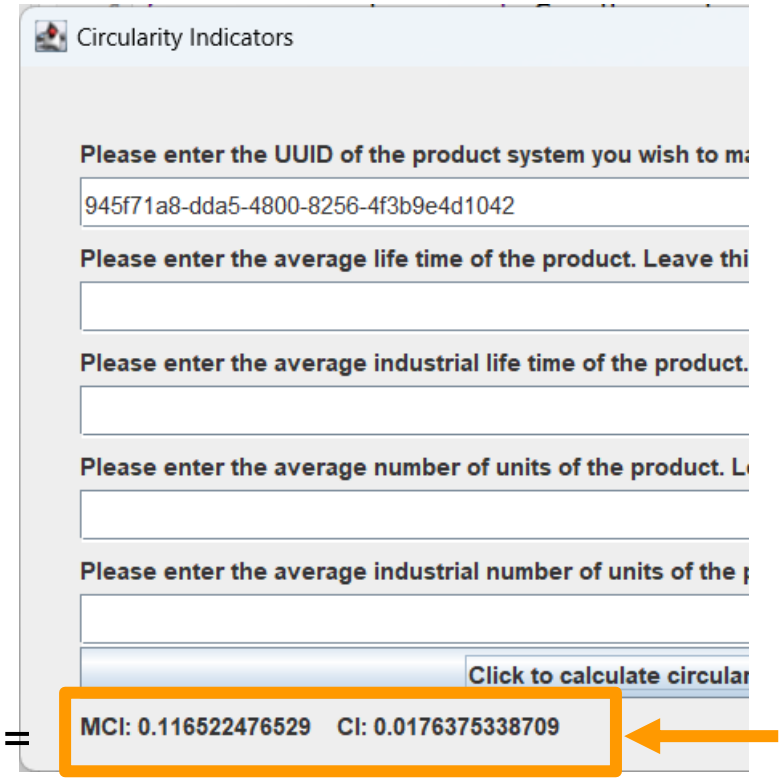
battery production, Li-ion, rechargeable, prismatic | battery, Li-ion, rechargeable, prismatic | Cutoff, U
FU = 1 item (**454kg**, EV battery)

Circularity Results



- **Material extracted** from Earth is **43x the weight of the battery**
- **356kg of recovered material**
  - 122kg from EoL treatment
  - 234kg from supply chain
- **1709MJ for primary production**
  - 38% anode supply chain
  - 38% cathode supply chain
  - 20% Al. supply chain

Linear System =



Example

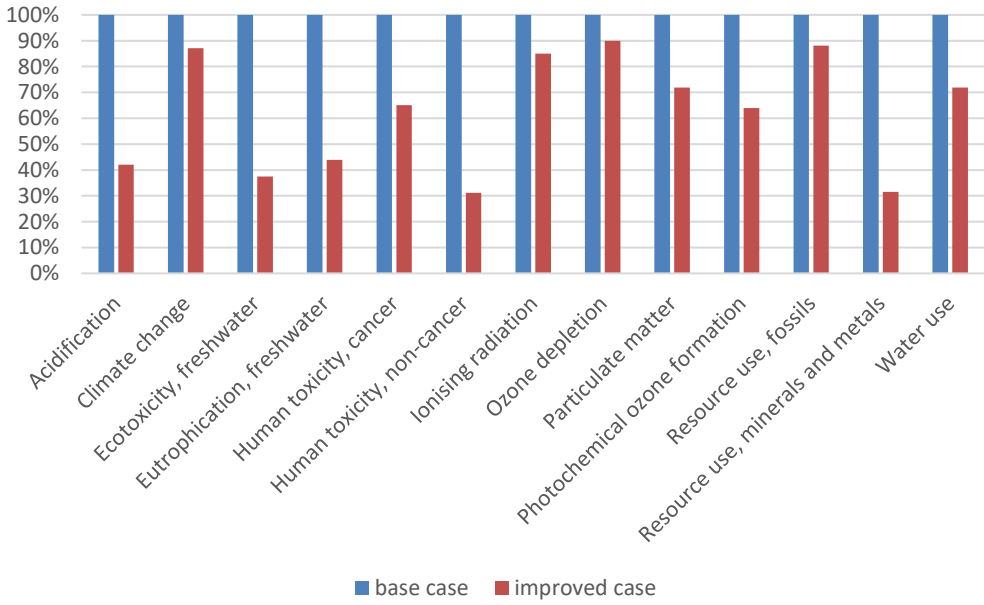
VIRGIN MATERIAL -> We saw that copper was a hotspot from the big amounts of “Gangue, in ground” extracted in copper mining.

Improved case: use 50% copper from recycled sources

Circularity Indicators

	Base case	Improved case		
Name	**Impact assessment result**		**Unit**	**% decrease**
energy required for primary production	17095.4	14242.8	MJ	17
energy required for recycled production	277.5	115.3	MJ	58
recovered EoL material	356.3	327.1	kg	8
recycled material	-160.7	-168.9	kg	-5
total waste produced (W)	41604.5	15815.8	kg	62
virgin material (V)	19676.4	7292.6	kg	63
waste from recycling processes (Wc)	36.5	27.8	kg	24
waste from the production of secondary feedstock, (Wf)	0.3	0.3	kg	10
MCI (from LCA)	**0.11652**	**0.13807**		
CI (from LCA)	**0.01764**	**0.04355**		

LCA normalised results (EF3.1)



Development of the Circularity Package

Project by GreenDelta GmbH

- TRIPLELINK research project – EIT Raw Materials
- PRIMUS EU Project – HORIZON

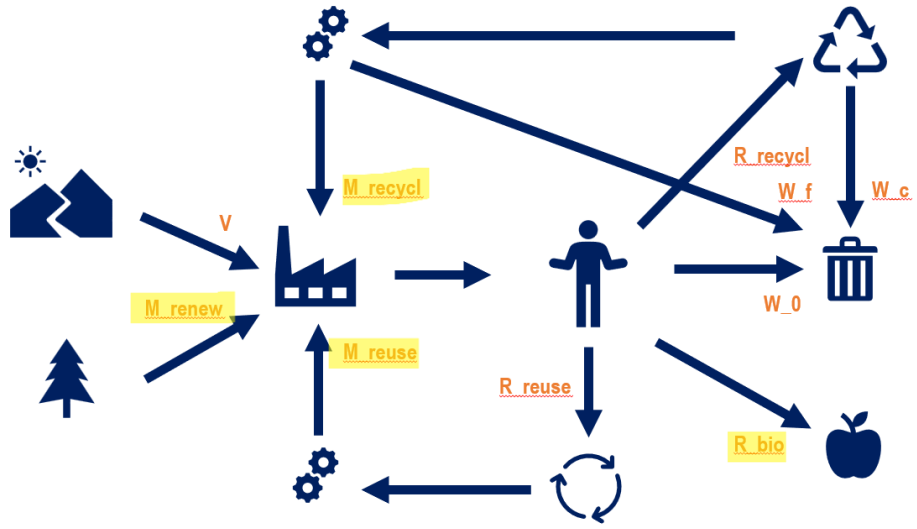
J. Cilleruelo Palomero, L. Freboeuf, A. Ciroth, and G. Sonnemann, “Integrating circularity into Life Cycle Assessment: Circularity with a life cycle perspective,” *Cleaner Environmental Systems*, vol. 12, Art. no. 100175, 2024. [Online]. Available: https://doi.org/10.1016/j.cesys.2024.100175

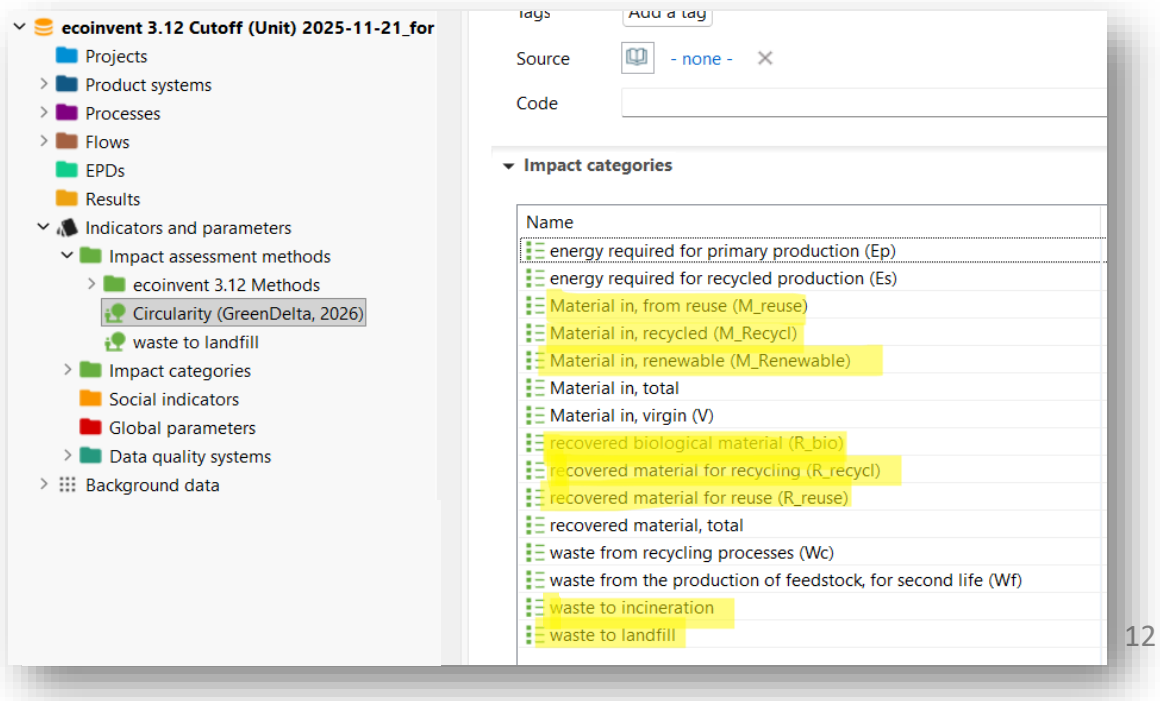
Future development

- Next release soon
- Ecoinvent 3.12 cut-off

- Incorporation of ISO 59000-series indicators

- Third party verified





Summary

- Circularity indicators are usually not calculated taken into account supply chains.

- The Circularity Package for openLCA allows to calculate an LCA model also with the circularity indicators MCI and CI.
- Circularity variables are also available, where the next update includes ISO 59000.

- The supply chain is taken into account.

...Any questions?

Julia Cilleruelo Palomero

LCA Consultant and Researcher
cilleruelo@greendelta.com

GreenDelta GmbH
Alt-Moabit 130, 10557 Berlin, Germany
www.greendelta.com

Extra slides

Implementation in ecoinvent

Variables required for circularity indicator calculations, and their respective location in the ecoinvent database:

Found in database

Internal calculation

User input

Circularity Variable		MCI	CI	Circularity Package	Location in ecoinvent database
Virgin material	V	x		x	Elementary flows with names "*Material name*, in ground"
Recycled material	R	x		x	Processes that contain "Recycled Content cut-off" in their name.
Recovered recycled materials	R_r	x		x	Input flows with negative amounts. These are recovered materials in ecoinvent.
Input recycled materials	R_i	x		(x)	Calculated variable: $R_i = R + R_r$
Mass	M	x		(x)	Calculated variable: $M = V + R_i$
Total waste for final disposal	W	x		x	Mainly processes under the category "3821: Treatment and disposal of non-hazardous waste" and "3822: Treatment and disposal of hazardous waste"
Waste from recycling processes	W_C	x		x	Mainly processes under the category "3811: Collection of non-hazardous waste"
Waste from the production of secondary material feedstock for second life material	W_F	x		x	Processes that produce recycled material, at the category "C: Manufacturing"
Energy required for primary material production	E_p		x	x	Energy required in processes that involve the production of primary materials or products
Energy required for secondary material production	E_s		x	x	Energy required in processes that involve the production of secondary materials
Life time of product	L	x		(x)	Input by user
Utility of product (number of uses)	U	x		(x)	Input by user

https://ecoinvent.org/

The openLCA ecosystem