

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

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- 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

# Does a solution of LCA & CE combined exist?

Well-known LCA software have launched initiatives/products:

- **SimaPro** proposes a calculation of the MCI within the software with the use of parameters for the variables required for the MCI calculation [1], but stays in the superficial model and doesn't look into the supply chain (background database)
- **GaBi** proposed in 2018 a circularity tool with an approach similar to that proposed in this presentation. It is no longer available in the market [2].
- **OneClick LCA** promotes the calculation of a “building circularity score”, which applies circularity for the buildings sector [3].

[1] SimaPro, “7 steps to combining circular economy and LCA in SimaPro,” [Online]. Available: <https://support.simapro.com/articles/Article/7-steps-to-combining-circular-economy-and-LCA-in-SimaPro/>. [Accessed 20 April 2023].

[2] A. S. (. D. E. Peter Shonfield (thinkstep). [Online]. Available: <https://cdn2.hubspot.net/hubfs/2591272/Circularity/GaBi-Circularity-Tool.pdf.pdf>. [Accessed 28 06 2023].

[3] OneClick LCA, “Building Circularity: Circular Assessment,” [Online]. Available: <https://oneclicklca.zendesk.com/hc/en-us/articles/360014998199-Building-Circularity-Circular-Assessment>. [Accessed 28 06 2023].

# Circularity Indicators

- **Material Circularity Indicator**

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

*V = virgin material*  
*W = waste*  
*L = life duration*  
*U = utility*

- **Circularity Index**

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

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

Ellen MacArthur Foundation, “Material Circularity Indicator (MCI) Methodology,” 2019. [Online]. Available: <https://emf.thirdlight.com/link/3jtevh1kbukz-gof4s4/@/preview/1?o>. [Accessed 18 April 2023].

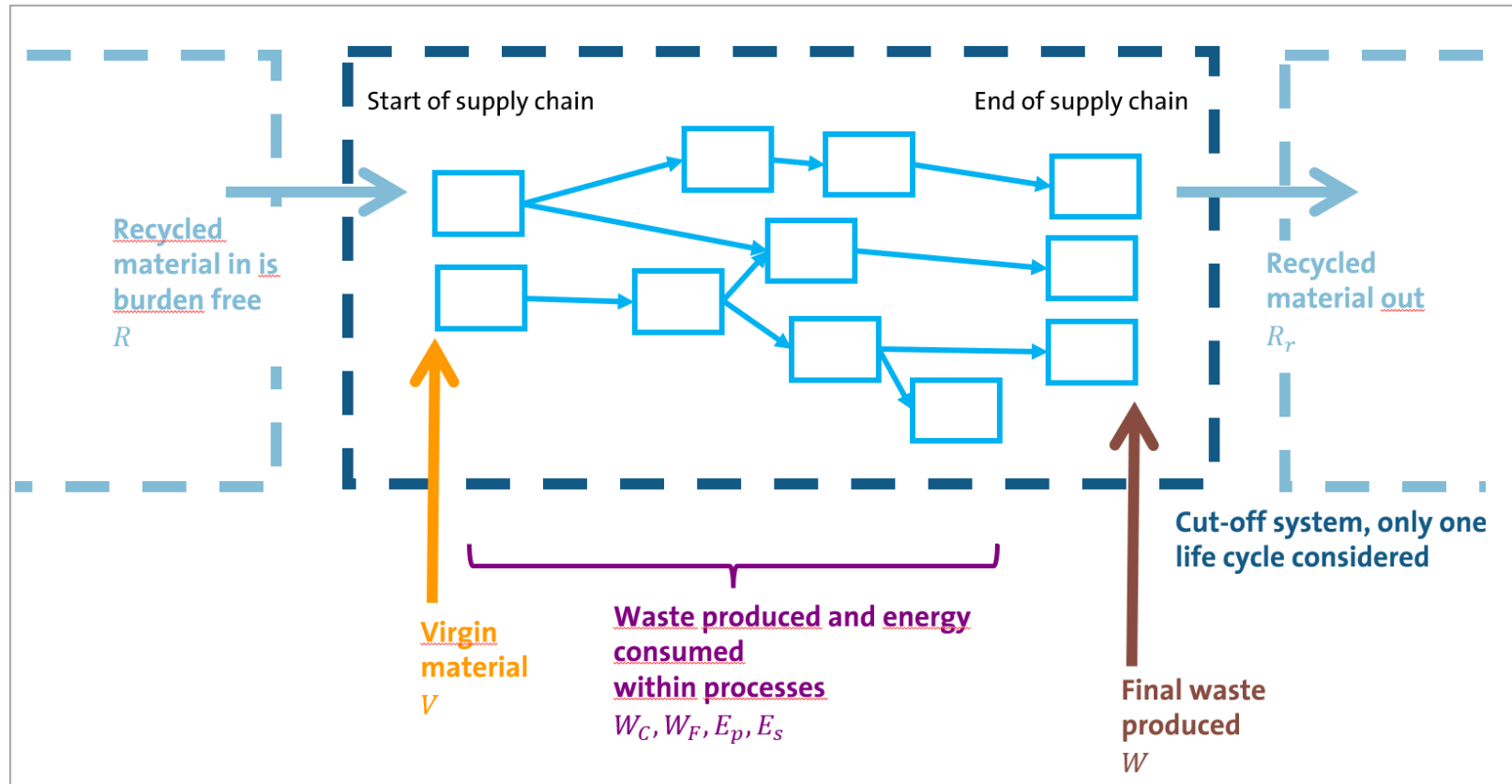
J. Cullen, “Theoretical Benchmark or Perpetual Motion Machine?,” *Journal of Industrial Ecology*, 21, pp. 483-486, 2017.

# How is an LCA database adapted for CE?

(applied to ecoinvent 3.8 cut-off)

✓ Avoid double counting

Apply new elementary flows to shadow circularity information



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

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

# 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/>

## Applied per database

### 1. Placed elementary flows to shadow the circularity variables across the database

- Flows
  - A: Agriculture, forestry and fishing
  - B: Mining and quarrying
  - C: Manufacturing
  - Circularity Indicators**
    - energy required for primary production (E<sub>p</sub>)
    - energy required for secondary production (E<sub>s</sub>)
    - radioactive waste (Wr)
    - recovered EoL materials (R<sub>r</sub>)
    - recycled material (R)
    - total waste produced (W)
    - virgin material (V)
    - waste from recycled feedstock production (Wf)
    - waste from recycling (Wc)

gravel production, crushed | gravel, crushed | Cutoff, U - RoW

Inputs/Outputs: gravel production, crushed | gravel, crushed | Cutoff, U - RoW

Flow	Category	Amount	Unit	Costs/Re...	Uncertai...	Avoided
tap water	360:Water collection...	0.00517	kg		lognorm...	
recultivation, limestone mine	390:Remediation act...	1.27000E...	m2		lognorm...	
building, hall, steel construction	410:Construction of ...	2.85000E...	m2		lognorm...	
gravel/sand quarry infrastructure	429:Construction of ...	4.75000E...	Item(s)		lognorm...	
diesel, burned in building machine	431:Demolition and ...	0.01430	MJ		lognorm...	
Gravel, in ground	Resource/in ground	1.04000	kg		lognorm...	
Water, unspecified natural origin	Resource/in water	0.00111	m3		lognorm...	
Occupation, lake, artificial	Resource/land	6.27000E...	m2*a		lognorm...	
Occupation, mineral extraction site	Resource/land	0.00029	m2*a		lognorm...	
Transformation, from unspecified	Resource/land	3.51000E...	m2		lognorm...	
Transformation, to lake, artificial	Resource/land	6.27000E...	m2		lognorm...	
Transformation, to mineral extract...	Resource/land	2.88000E...	m2		lognorm...	

Flow	Category	Amount	Unit	Costs/Re...	Uncertai...	Avoi
Water	Emission to water/u...	0.00082	m3		lognorm...	
Water	Emission to air/unspe...	0.00031	m3		lognorm...	
Particulates, < 2.5 um	Emission to air/low ...	4.00000E...	kg		lognorm...	
Particulates, > 10 um	Emission to air/low ...	5.60000E...	kg		lognorm...	
Particulates, > 2.5 um, and < 10um	Emission to air/low ...	2.00000E...	kg		lognorm...	
energy required for primary production	Circularity Indicators	0.05183	MJ		none	
virgin material (V)	Circularity Indicators	1.04000	kg		none	
waste mineral oil	382:Waste treatment...	2.50000E...	kg		lognorm...	
municipal solid waste	382:Waste treatment...	1.59697E...	kg		lognorm...	

### 2. Collected those flows in the Circularity LCIA Method

- Indicators and parameters
  - Impact assessment methods
    - ecoinvent\_38\_methods
    - openLCA LCIA methods 2\_1\_3
      - Circularity (GreenDelta, 2023)**

Impact categories

Name	Reference unit
energy required for primary production	MJ
energy required for recycled production	MJ
recovered EoL material	kg
recycled material	kg
total waste produced (W)	kg
virgin material (V)	kg
waste from recycling processes (Wc)	kg
waste from the production of feedstock, for second life (Wf)	kg



## Extra software functionality

3. Allow to add extra variables through a pop-up window which displays results

The screenshot illustrates the workflow for running a circularity script in openLCA. It shows three main components:

- Database:** A tree view on the left shows the project structure. A callout box labeled "1) The script is stored in the database, double click to open" points to the file `Circularity_indicators_v4_15062023.py` under the `Scripts` folder.
- Code Editor:** A window titled `Python` displays the script code. A callout box labeled "2) Run the script" points to the `Run` button in the top toolbar.
- Pop-up Window:** A window titled `Circularity Indicators` prompts for user input. It contains several text boxes for:
  - UUID of the product system (filled with `775eed89-fe63-4474-8ea7-4e99cf0fbee7`)
  - Average life time of the product (filled with `10`)
  - Average industrial life time of the product (filled with `8`)
  - Average number of units of the product (empty)
  - Average industrial number of units of the product (empty)
 A button at the bottom reads "Click to calculate circularity indicators!". Below the button, the results are displayed: `MCI: 0.361439844775` and `CI: 0.0827995533835`. A callout box labeled "3) pop-up window to finalise calculation and obtain results" points to the button.



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

## Circularity Results

battery production, Li-ion, rechargeable, prismatic | battery, L

Impact analysis: Circularity (GreenDelta, 2023)

Sub-group by:  Flows  Processes | Don't show < 1 %

Name	Impact assessment result
> energy required for primary production	1.70954E4 MJ
> energy required for recycled production	277.46935 MJ
> recovered EoL material	356.27583 kg
> recycled material	-160.71076 kg
> total waste produced (W)	4.16045E4 kg
✓ virgin material (V)	1.96764E4 kg
✓ virgin material (V)	1.96764E4 kg
copper mine operation and beneficiati	4412.52488 kg
copper mine operation and beneficiati	4250.65742 kg
copper mine operation and beneficiati	1340.47948 kg
copper mine operation and beneficiati	1149.38789 kg
copper mine operation and beneficiati	907.22213 kg
copper mine operation and beneficiati	894.71018 kg
copper mine operation and beneficiati	603.70484 kg
bauxite mine operation   bauxite   Cuto	540.07063 kg
hard coal mine operation and hard coa	523.59528 kg
copper mine operation and beneficiati	517.48486 kg
gold mine operation and gold product	371.54513 kg
copper mine operation and beneficiati	323.15995 kg
hard coal mine operation, open cast, di	228.16789 kg
gravel and sand quarry operation   grav	205.21472 kg
> waste from recycling processes (Wc)	36.51925 kg
> waste from the production of feedstock, for s	0.30841 kg

- 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

Circularity Indicators

Please enter the UUID of the product system you wish to measure:

945f71a8-dda5-4800-8256-4f3b9e4d1042

Please enter the average life time of the product. Leave this blank:

Please enter the average industrial life time of the product:

Please enter the average number of units of the product. Leave this blank:

Please enter the average industrial number of units of the product:

Click to calculate circularity

MCI: 0.116522476529 CI: 0.0176375338709

## Improvements in circularity

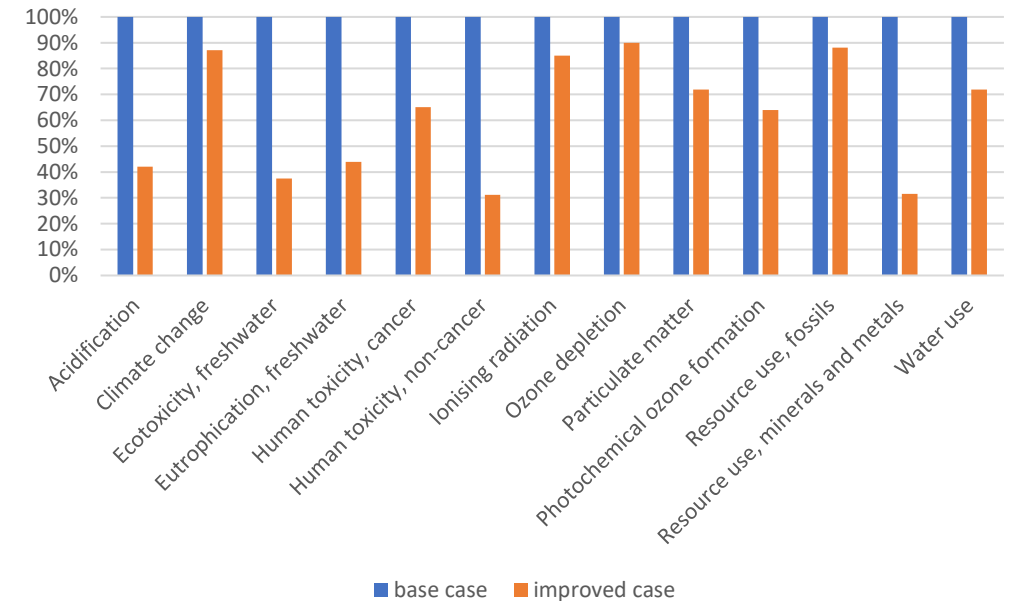
VIRGIN MATERIAL -> We saw that copper was a hotspot from the big amounts of “Gangue, in ground” extracted in copper mining.

**Improved case: use 50% copper from recycled sources**

### Circularity Indicators

Name	Base case Impact assessment result	Improved case	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)	<b>0.11652</b>	<b>0.13807</b>		
CI (from LCA)	<b>0.01764</b>	<b>0.04355</b>		

### LCA normalised results (EF3.0)



Next steps: investigate EoL circular strategies

## WE HAVE SHOWN:

- The integration of Circularity Indicators into an LCA database and software.

## RESULTS DEMONSTRATE:

- There are big numbers of virgin material used, and waste produced, in the supply chain of the investigated system, which should not be ignored.
- Targeting improvements for the Circular Economy will benefit from a life cycle perspective.

# Thank you!

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