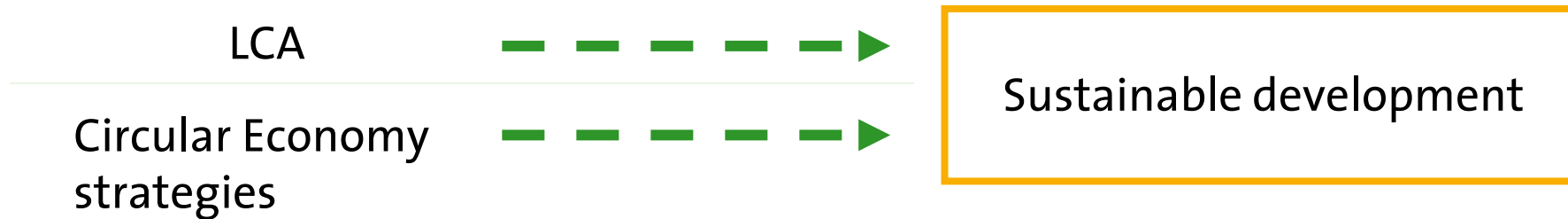


Life Cycle circularity and the circularity package in openLCA

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- LCA has the potential to take into account all the Life Cycle Stages
 - > wide perspective
 - > not really prepared for circularity of materials
- Circular Economy -> measured by circularity indicators
 - > often stays “superficial” / only takes into account later production stages

- 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 = # uses

- 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/3jtevhkbuks-9of4s4/@/preview/1?o>. [Accessed 18 April 2023].

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

Integrate a quantification of Circularity into Life Cycle Assessment:

- Allow LCA models to also calculate and quantify circular economy
- Allow Circular Economy Studies to quantify the improvements with circularity indicators
- Allow the assessment to reach a full Life Cycle



CIRCULAR ECONOMY

Circular Economy

Theoretical Benchmark or Perpetual Motion Machine?

Jonathan M. Cullen

Department of Engineering, Cambridge University, Cambridge, United Kingdom

Ellen MacArthur Foundation, "Material Circularity Indicator (MCI) Method"

<https://emf.thirdlight.com/link/3jtevhlkbukz-9of4s4/@/preview/1?o.> [Accessed 2025-11-21]

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?

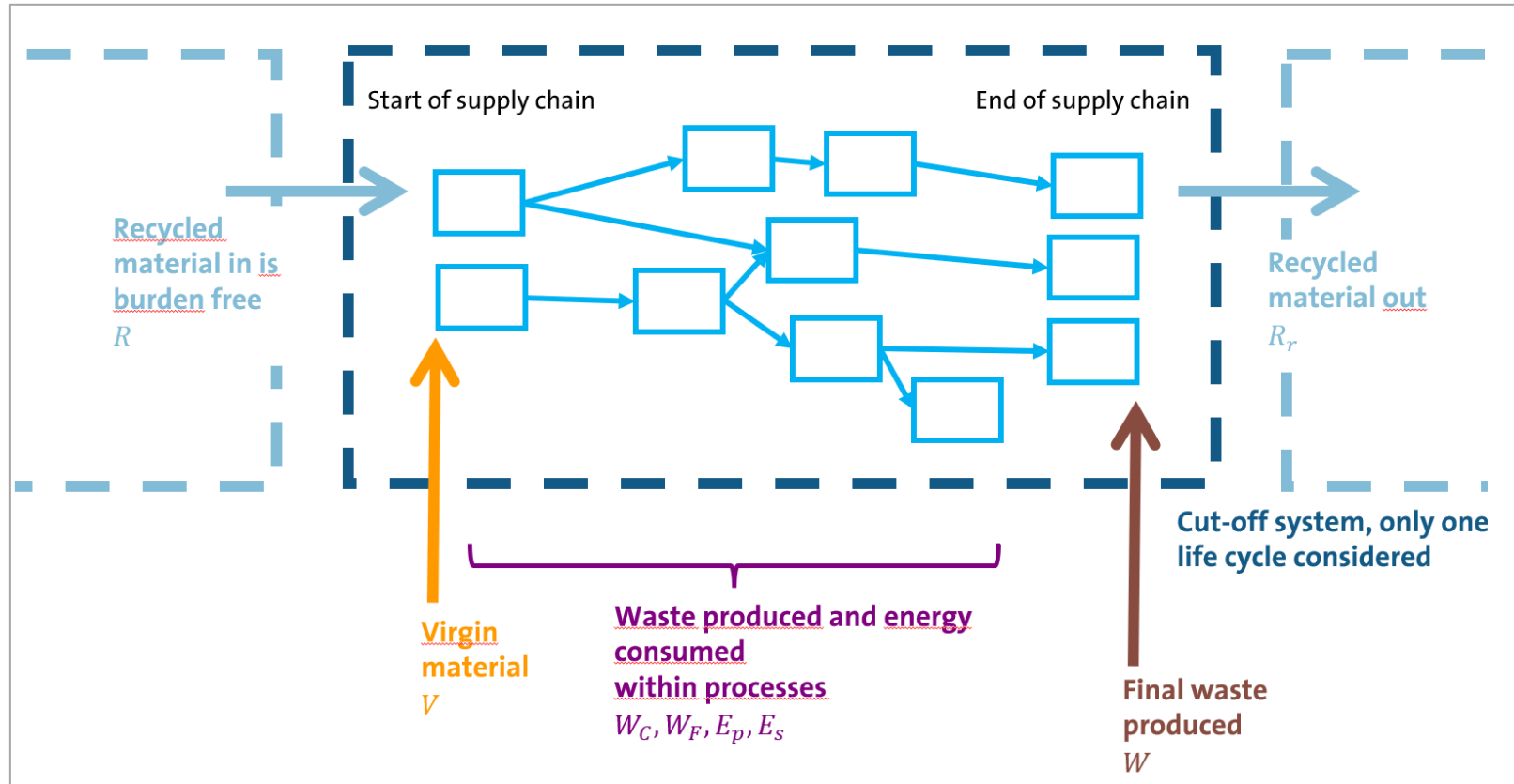
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✓ Avoid double counting

(applied to ecoinvent cut-off)

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

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 m

945f71a8-dda5-4800-8256-4f3b9e4d1042

Please enter the average life time of the product. Leave thi

Please enter the average industrial life time of the product.

Please enter the average number of units of the product. L

Please enter the average industrial number of units of the p

Click to calculate circular

MCI: 0.116522476529 CI: 0.0176375338709

Result II

Improvements in circularity

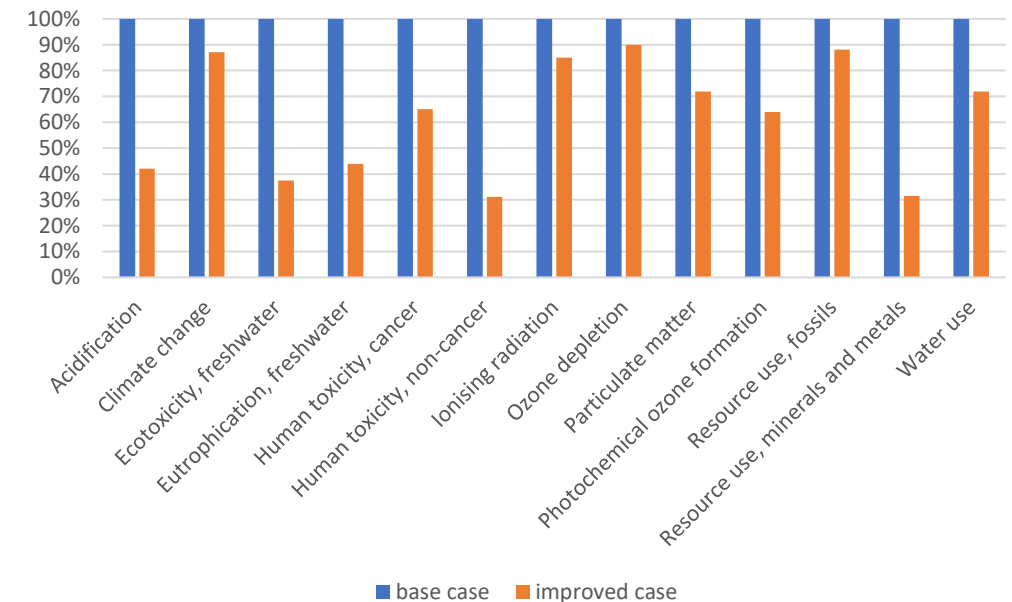
VIRGIN MATERIAL -> We saw that copper was a hotspot from the big amounts of “Gangue, in ground” extracted in copper mining.

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)	0.11652	0.13807		
CI (from LCA)	0.01764	0.04355		

LCA normalised results (EF3.o)



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.
- Cilleruelo Palomero, J., Citroth, A., Freboeuf, L., Sonnemann, G., (2024): **Integrating circularity into Life Cycle Assessment: Circularity with a life-cycle perspective**, Journal of Cleaner Environmental Systems. <https://doi.org/10.1016/j.cesys.2024.100175>.
- Next Circularity Package update by end of the year, ontop of ecoinvent 3.12 cut-off

Thank you!

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