

# LCM 2023

## THE 11TH INTERNATIONAL CONFERENCE ON LIFE CYCLE MANAGEMENT

## **Integrating Circularity into Life Cycle Assessment: Circularity with a life-cycle perspective**

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## Introduction

Both Life Cycle Assessment (LCA) as a tool and Circular Economy (CE) as a concept work towards sustainable development, only that both approaches are currently done individually: one assessment doesn't include the other.

Circularity indicators, which aim to quantify **Circular Economy, can benefit hugely from a life** cycle perspective, where circularity is considered not only in the last production stages but from the very beginning of raw material extraction. However, there is no current wellrounded and transparent solution for the integration of both, even though there have been initiatives from common LCA software.

## **Recent History**

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)

In this research, a methodology of integrating LCA and CE is proposed and practically applied in an LCA database.

## Methodology

After an initial assessment, two indicators were chosen for their completeness and ability to be integrated into LCA.

Material Circularity Indicator (MCI) [4]

**Circularity Index (CI)** [5]

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

e... Uncertai... Avoided

lognorm.

Costs/Re... Uncertai... Avoi

lognorm...

lognorm...

lognorm...

lognorm...

lognorm..

lognorm...

lognorm...

none

none

The ecoinvent 3.8 cut-off database was modified with the following:

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

diesel, burned in building machine 431:Demolition and ...

v 🖿 Flows	5 gravel production, crushed   gravel, crus	shed   Cutoff, U - RoW $ imes$				
A:Agriculture, forestry and fishing	a Inputs/Outputs: gravel proc	duction, crushed	gravel, c	rushed	Cutoff, U	J - RoW
> B:Mining and quarrying					-	
> 🖿 C:Manufacturing	✓ Inputs					
Circularity Indicators	Flow	Category	Amount	Unit	Costs/Re	Uncertai
energy required for primary production (E_p)	🕸 tap water	360:Water collection	0.00517		00000/1101	lognorm
energy required for secondary production (E_s)	a recultivation, limestone mine	390:Remediation act	1.27000E	-		lognorm
radioactive waste (Wr)	building, hall, steel construction	410:Construction of	2.85000E			lognorm
recovered EoL materials (R_r)	gravel/sand quarry infrastructure	429:Construction of	4.75000E	💷 Item(s)		lognorm
	_					

Outputs

Flow

Ø Water

Ø Water

Particulates, < 2.5 um</p>

Particulates, > 10 um

Ø virgin material (V)

waste mineral oil

municipal solid waste

Particulates, > 2.5 um, and < 10um</p>

© energy required for primary production

- 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].

## Visualisation of the database (Results)

A dataset for the production (& EoL) of an EV battery was run with the methodology. Functional Unit: 1 EV battery (454kg)

battery production, Li-ion, rechargeable, prismatic | battery, Li-ion, rechargeable, prismatic | Cutoff, U

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



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

Name	Impact assessment result	
E energy required for primary production	1.70954E4 MJ	
> E 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	
✓ I virgin material (V)	1.96764E4 kg	
✓ Ø virgin material (V)	<ul> <li>1.96764E4 kg</li> </ul>	
copper mine operation and beneficiation	4412.52488 kg	
copper mine operation and beneficiation	4250.65742 kg	
copper mine operation and beneficiation	1340.47948 kg	
copper mine operation and beneficiation	1149.38789 kg	
copper mine operation and beneficiation	907.22213 kg	
copper mine operation and beneficiation	894.71018 kg	
copper mine operation and beneficiation	603.70484 kg	
<section-header> bauxite mine operation   bauxite   Cuto</section-header>	540.07063 kg	
hard coal mine operation and hard coa	523.59528 kg	
copper mine operation and beneficiation	517.48486 kg	
Gold mine operation and gold product	371.54513 kg	
copper mine operation and beneficiation	323.15995 kg	
🗸 hard coal mine operation, open cast, dr	228.16789 kg	
😓 gravel and sand quarry operation   grav	205.21472 kg	
> 🗄 waste from recycling processes (Wc)	36.51925 kg	
> $\blacksquare$ 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

#### **Proposed improvement:**

total waste produced (W)
🗸 virgin material (V)
Ø waste from recycled feedstock production (Wf)
waste from recycling (Wc)

Gravel, in ground	Resource/in ground	1.04000 🚥 kg	lognorm
O Water, unspecified natural origin	Resource/in water	0.00111 🚥 m3	lognorm
Occupation, lake, artificial	Resource/land	6.27000E 📼 m2*a	lognorm
$\mathcal O$ Occupation, mineral extraction site	Resource/land	0.00029 🚥 m2*a	lognorm
Ø Transformation, from unspecified	Resource/land	3.51000E 📼 m2	lognorm
O Transformation, to lake, artificial	Resource/land	6.27000E 📼 m2	lognorm
✓ Transformation, to mineral extract	Resource/land	2.88000E 🚥 m2	lognorm

Category

Emission to water/u.

Emission to air/unsp.

Emission to air/low.

Emission to air/low.

Emission to air/low.

Circularity Indicators

Circularity Indicators

382:Waste treatment...

0.01430 📼 MJ

Amount Unit

0.00082 📼 m3

0.00031 📼 m3

4.00000E... 📼 ka

5.60000E... 📼 ka

2.00000E... 📼 kg

0.05183 📼 MJ

1.04000 📟 kg

2.50000E... 📼 kg

## Hotspot: Copper mining from the huge amounts of virgin material extracted: 83kg of "Gangue, in ground" / 1kg of copper. **Use 50% recycled copper for battery** production.

	Base case	Improved case		
Name	Impact assessi	ment 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		

**Triggering a hotspot reduced the need of virgin material by 63%**, and improved all of the other circularity variables.

The circularity indicators show that the system is close to fully linear, proving that LCA datasets represent a linear world reality. The proposed improvement also shows improvements in both circularity indicators. The same model can also be run with LCA.

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

Indicators and parameters

recycled material (R)

- Impact assessment methods
- ecoinvent\_38\_methods
- > openLCA LCIA methods 2\_1\_3 😍 Circularity (GreenDelta, 2023)

#### Impact categories

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

3. Python script for final calculation and to **allow** to add extra variables through a pop-up **window** which also displays results.

382:Waste treatment... 1.59697E... 📼 kg



10

Data quality systems

> III Background data Scripts

elt

PY Circularity\_indicators\_v4\_15062023.py ecoinvent\_38\_cuto 3011\_with\_methods\_for\_circularity\_with\_script\_202 ecoinvent\_38\_cutoff\_011\_with\_methods\_for\_circularity\_with\_script\_230 ecoinvent\_38\_cutc 1) The script is stored in the ecoinvent 38 cuto ecoinvent\_38\_cutc database, double click to open ecoinvent\_38\_cutoff\_3011\_with\_methods\_tor\_MCI\_15112022\_2\_V\_flows\_ ecoinvent\_38\_cutoff\_3011\_with\_methods\_for\_MCI\_15112022\_3\_Wr\_add ant 29 cutoff 2011 with mathads for MCL 15112022 / WO add

775eed89-fe63-4474-8ea7-4e99cf0fbeef

Please enter the average life time of the product. Leave this blank if it is unknown to you!

Please enter the average industrial life time of the product. Leave this blank if it is unknown to you!

Please enter the average number of units of the product. Leave this blank if it is unknown to you!

Please enter the average industrial number of units of the product. Leave this blank if it is unknown to you!

Click to calculate circularity indicators! MCI: 0.361439844775 CI: 0.0827995533835

#### References

[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/enus/articles/360014998199-Building-Circularity-Circular-Assessment. [Accessed 28 06 2023].

[4] Ellen MacArthur Foundation, "Circularity-Indicators\_MCI-Product-Level-Dynamic-Modelling-Tool\_May2015.xlsx," 2015. [Online]. Available: https://emf.thirdlight.com/link/6af3fwmj26q8-p62fj0/@/preview/1?o

[5] J. Cullen, "Theoretical Benchmark or Perpetual Motion Machine?," Journal of Industrial Ecology, 21, pp. 483-486, 2017.

#### RawMaterials Connecting matters openLca TRIPLELINK GreenDelta Funded by the European Union

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