
Photo by Julia Cilleruelo Palomero | Cuba

Circularity Food Package for openLCA

Documentation & case study example

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Circularity Food package

Funded by

eit RawMaterials
Connecting matters

Funded by
the European Union

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1 Introduction

The Circularity Food Package for openLCA, is the commercialised product of the TRIPLELINK research project, funded by the EIT Raw Materials.

This report first describes the motivation and methodology behind the Circularity Food Package database. The next sections describe how to make a circular model and use the database for that purpose, where a practical example is also offered as a reference at the end. The case study model can be obtained for free here:
https://nexus.openlca.org/casestudy/Other%20free%20case%20studies

2 Motivation

Both LCA as a tool and Circular Economy as a concept work towards sustainable development, only that both approaches are currently done individually: one assessment doesn't include the other. Circular Economy, measured by circularity indicators, 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.

The Circularity Food Package is based on Agribalyse, a database of reference in the agri-food sector in LCA developed by the French Agency for an Ecological Transition (ADEME[1]). The way that Agribalyse is modelled gives space for an enhancement to also track circularity indicators that can offer additional information for the interest of Circular Economy in this specific sector.

3 Methodology

The materials considered for circularity are generally defined as materials taken from nature that are non-renewable. A virgin material is considered a material that is not from reuse, recycling or, for the purposes of this methodology, not from biological materials from Sustained Production.

The Agribalyse database was modified to track the circularity variables, by adding elementary flows that shadow the following circularity elements:

- **Recycled material** flows
- **Virgin material** flows
- **Total waste** for final disposal
- **Waste from recycling** processes

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[1] https://www.ademe.fr/

- **Waste from the production of secondary material** feedstock
- **Energy required for primary material production**
- **Energy required for secondary material production**

Hence, the database can now calculate supply chain results for LCA (Figure 1) and circularity (Figure 2).

Collecting this information is already useful for the visualization of the product's supply chain in terms of circularity. However, these variables can be further processed to calculate the following Circularity Indicators:

Material Circularity Indicator (MCI) – developed by the Ellen MacArthur Foundation and Granta Design[2]. It looks at how the material flows in a product's life cycle, including reuse and recycle material flows for circularity, and also the length and intensity of the product's use.

Circularity Index (CI) – from a scientific publication by Cullen, 2017[3]. Looks at recovered material vs. total material demand, but most interestingly, it also takes into account the energy required for material production, both primary and secondary.

The formulation implemented in openLCA for both indicators can be seen in the Appendix (page 22). Generally, a score of 1 defines a fully circular system, whilst a score of 0 for the CI and 0.1 for the MCI defines a fully linear system, as summarised in the table below.

Table 1 Boundaries of the values that the circularity indicators can take

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

A python script was incorporated to the database, see Figure 3, to allow the calculation of circularity indicators. When running it, it will display a user-friendly window allowing the input of other variables for circularity outside LCA and displaying the circularity indices, Figure 4. These extra variables required are:

- **Life time** of your product compared to average
- **Number of uses** of your product compared to average values

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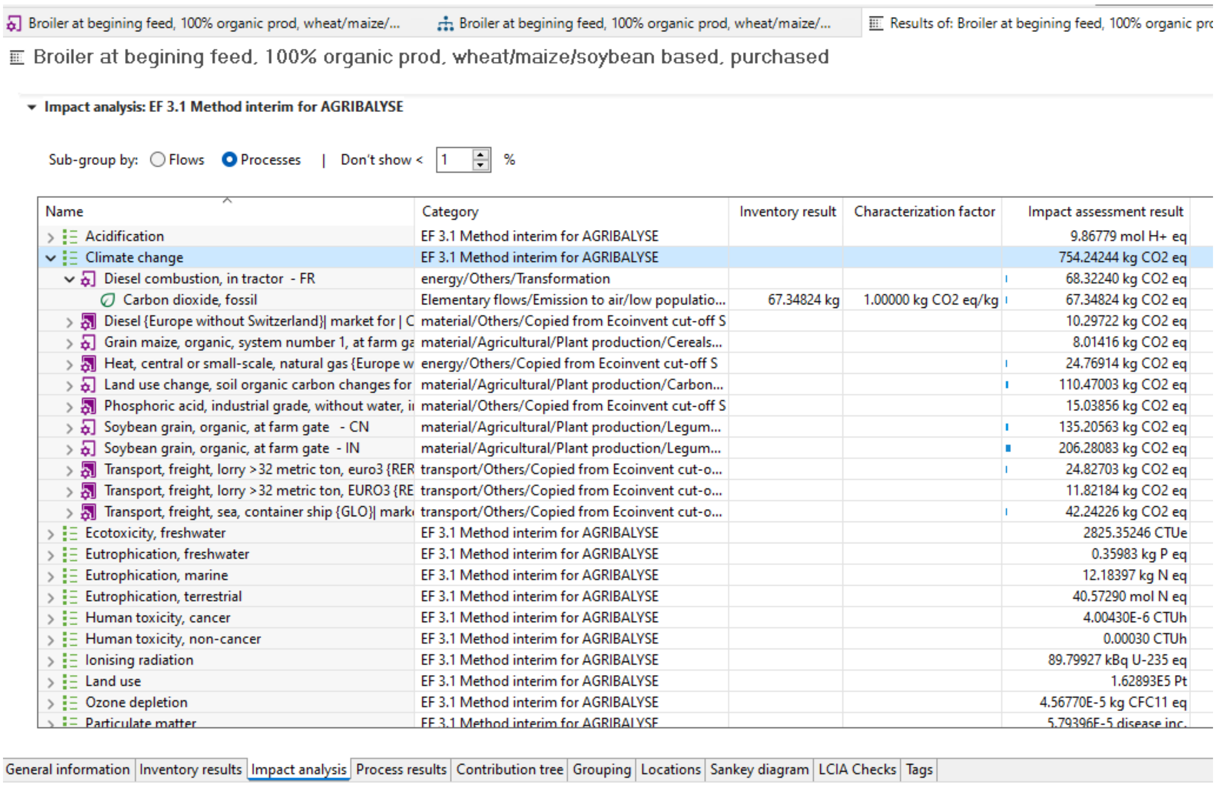
[2] https://ellenmacarthurfoundation.org/material-circularity-indicator

[3] Cullen, Jonathan M. (2017). Circular Economy: Theoretical Benchmark or Perpetual Motion Machine?. Journal of Industrial Ecology, (), –. doi:10.1111/jiec.12599



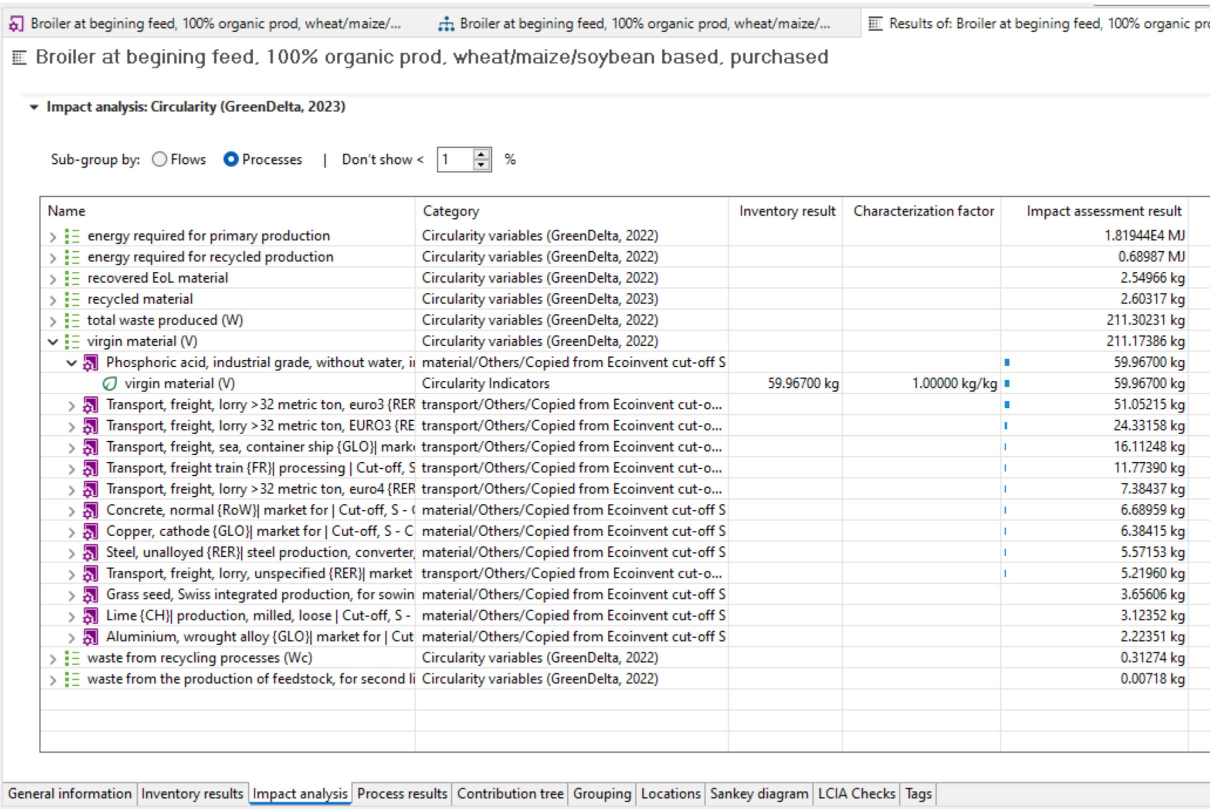
Broiler at begining feed, 100% organic prod, wheat/maize/soybean based, purchased

Impact analysis: EF 3.1 Method interim for AGRIBALYSE

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

Name	Category	Inventory result	Characterization factor	Impact assessment result
Acidification	EF 3.1 Method interim for AGRIBALYSE			9.86779 mol H+ eq
Climate change	EF 3.1 Method interim for AGRIBALYSE			754.24244 kg CO2 eq
Diesel combustion, in tractor - FR	energy/Others/Transformation			68.32240 kg CO2 eq
Carbon dioxide, fossil	Elementary flows/Emission to air/low populatio...	67.34824 kg	1.00000 kg CO2 eq/kg	67.34824 kg CO2 eq
Diesel {Europe without Switzerland}| market for | C	material/Others/Copied from Ecoinvent cut-off S			10.29722 kg CO2 eq
Grain maize, organic, system number 1, at farm ga	material/Agricultural/Plant production/Cereals...			8.01416 kg CO2 eq
Heat, central or small-scale, natural gas {Europe w	energy/Others/Copied from Ecoinvent cut-off S			24.76914 kg CO2 eq
Land use change, soil organic carbon changes for	material/Agricultural/Plant production/Carbon...			110.47003 kg CO2 eq
Phosphoric acid, industrial grade, without water, in	material/Others/Copied from Ecoinvent cut-off S			15.03856 kg CO2 eq
Soybean grain, organic, at farm gate - CN	material/Agricultural/Plant production/Legum...			135.20563 kg CO2 eq
Soybean grain, organic, at farm gate - IN	material/Agricultural/Plant production/Legum...			206.28083 kg CO2 eq
Transport, freight, lorry >32 metric ton, euro3 {RER	transport/Others/Copied from Ecoinvent cut-o...			24.82703 kg CO2 eq
Transport, freight, lorry >32 metric ton, EURO3 {RE	transport/Others/Copied from Ecoinvent cut-o...			11.82184 kg CO2 eq
Transport, freight, sea, container ship {GLO}| mark	transport/Others/Copied from Ecoinvent cut-o...			42.24226 kg CO2 eq
Ecotoxicity, freshwater	EF 3.1 Method interim for AGRIBALYSE			2825.35246 CTUe
Eutrophication, freshwater	EF 3.1 Method interim for AGRIBALYSE			0.35983 kg P eq
Eutrophication, marine	EF 3.1 Method interim for AGRIBALYSE			12.18397 kg N eq
Eutrophication, terrestrial	EF 3.1 Method interim for AGRIBALYSE			40.57290 mol N eq
Human toxicity, cancer	EF 3.1 Method interim for AGRIBALYSE			4.00430E-6 CTUh
Human toxicity, non-cancer	EF 3.1 Method interim for AGRIBALYSE			0.00030 CTUh
Ionising radiation	EF 3.1 Method interim for AGRIBALYSE			89.79927 kBq U-235 eq
Land use	EF 3.1 Method interim for AGRIBALYSE			1.62893E5 Pt
Ozone depletion	EF 3.1 Method interim for AGRIBALYSE			4.56770E-5 kg CFC11 eq
Particulate matter	EF 3.1 Method interim for AGRIBALYSE			5.79396E-5 disease inc.

Figure 1: LCA results for 1 kg of broiler at beginning feed



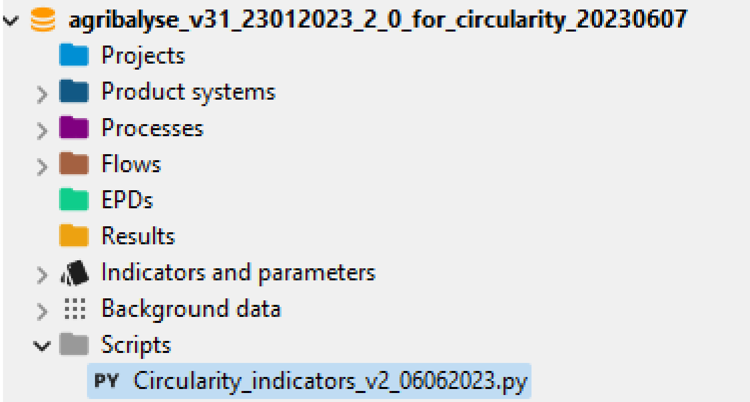
Broiler at begining feed, 100% organic prod, wheat/maize/soybean based, purchased

Impact analysis: Circularity (GreenDelta, 2023)

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

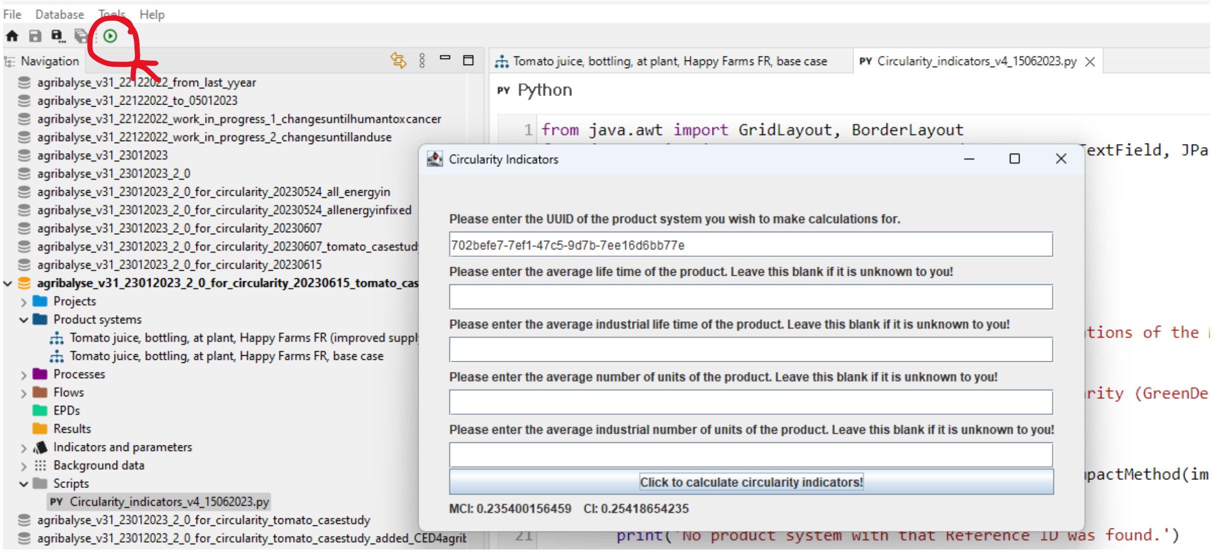
Name	Category	Inventory result	Characterization factor	Impact assessment result
energy required for primary production	Circularity variables (GreenDelta, 2022)			1.81944E4 MJ
energy required for recycled production	Circularity variables (GreenDelta, 2022)			0.68987 MJ
recovered EoL material	Circularity variables (GreenDelta, 2022)			2.54966 kg
recycled material	Circularity variables (GreenDelta, 2023)			2.60317 kg
total waste produced (W)	Circularity variables (GreenDelta, 2022)			211.30231 kg
virgin material (V)	Circularity variables (GreenDelta, 2022)			211.17386 kg
Phosphoric acid, industrial grade, without water, in	material/Others/Copied from Ecoinvent cut-off S			59.96700 kg
virgin material (V)	Circularity Indicators	59.96700 kg	1.00000 kg/kg	59.96700 kg
Transport, freight, lorry >32 metric ton, euro3 {RER	transport/Others/Copied from Ecoinvent cut-o...			51.05215 kg
Transport, freight, lorry >32 metric ton, EURO3 {RE	transport/Others/Copied from Ecoinvent cut-o...			24.33158 kg
Transport, freight, sea, container ship {GLO}| mark	transport/Others/Copied from Ecoinvent cut-o...			16.11248 kg
Transport, freight train {FR}| processing | Cut-off, S	transport/Others/Copied from Ecoinvent cut-o...			11.77390 kg
Transport, freight, lorry >32 metric ton, euro4 {RER	transport/Others/Copied from Ecoinvent cut-o...			7.38437 kg
Concrete, normal {RoW}| market for | Cut-off, S - (	material/Others/Copied from Ecoinvent cut-off S			6.68959 kg
Copper, cathode {GLO}| market for | Cut-off, S - C	material/Others/Copied from Ecoinvent cut-off S			6.38415 kg
Steel, unalloyed {RER}| steel production, converter,	material/Others/Copied from Ecoinvent cut-off S			5.57153 kg
Transport, freight, lorry, unspecified {RER}| market	transport/Others/Copied from Ecoinvent cut-o...			5.21960 kg
Grass seed, Swiss integrated production, for sowin	material/Others/Copied from Ecoinvent cut-off S			3.65606 kg
Lime {CH}| production, milled, loose | Cut-off, S -	material/Others/Copied from Ecoinvent cut-off S			3.12352 kg
Aluminium, wrought alloy {GLO}| market for | Cut	material/Others/Copied from Ecoinvent cut-off S			2.22351 kg
waste from recycling processes (Wc)	Circularity variables (GreenDelta, 2022)			0.31274 kg
waste from the production of feedstock, for second li	Circularity variables (GreenDelta, 2022)			0.00718 kg

Figure 2: Circularity variable results for 1 kg of broiler at beginning feed



agribalyse_v31_23012023_2_0_for_circularity_20230607
Projects
Product systems
Processes
Flows
EPDs
Results
Indicators and parameters
Background data
Scripts
PY Circularity_indicators_v2_06062023.py

Figure 3: Integrated python script for calculating circularity indicators in Agribalyse



```
from java.awt import GridLayout, BorderLayout
```

Please enter the UUID of the product system you wish to make calculations for.

702befe7-7ef1-47c5-9d7b-7ee16d6bb77e

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!

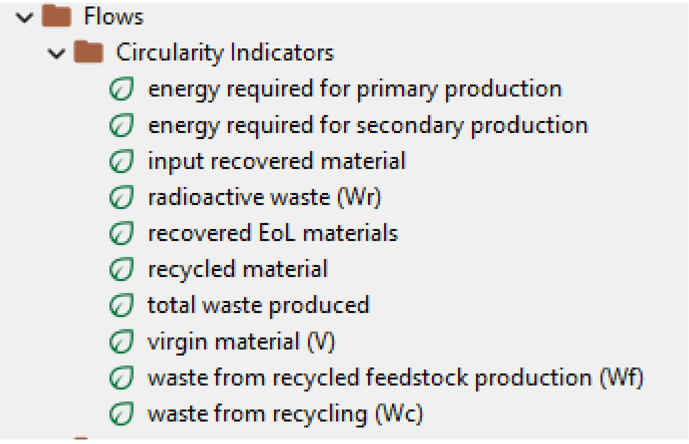
Please enter the average industrial number of units of the product. Leave this blank if it is unknown to you!

MCI: 0.235400156459 CI: 0.25418654235

Figure 4: This window allows to enter variables that are usually not consistently found in LCA, like life time of a product or utility

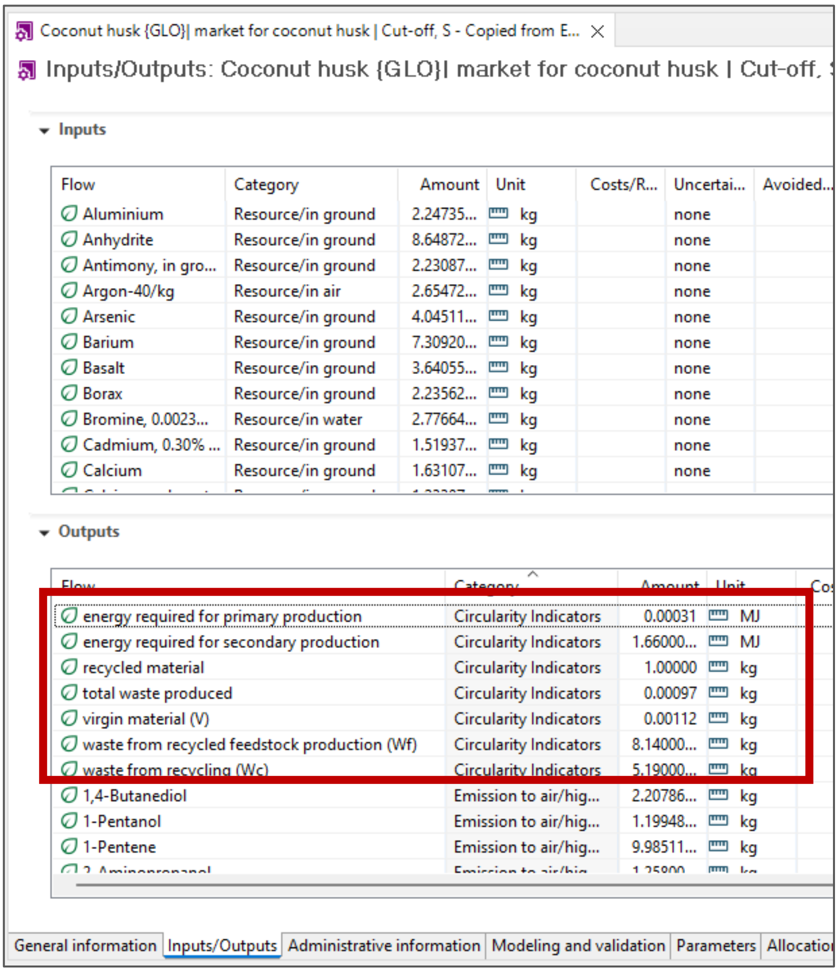
4 How to implement circularity in your model?

The database is prepared to trace circularity down the supply chain. Each relevant process has shadowing elementary flows that carry information about circularity at that particular step. See Figure 5 for what variables are traced by the database and an example implementation in Figure 6.



- Flows
  - Circularity Indicators
    - energy required for primary production
    - energy required for secondary production
    - input recovered material
    - radioactive waste (Wr)
    - recovered EoL materials
    - recycled material
    - total waste produced
    - virgin material (V)
    - waste from recycled feedstock production (Wf)
    - waste from recycling (Wc)

Figure 5: These elementary flows represent circularity variables and are found in relevant processes in the Agribalyse database



Coconut husk {GLO}| market for coconut husk | Cut-off, S - Copied from E...

Inputs/Outputs: Coconut husk {GLO}| market for coconut husk | Cut-off,

Inputs

Flow	Category	Amount	Unit	Costs/R...	Uncertai...	Avoided...
Aluminium	Resource/in ground	2.24735...	kg		none	
Anhydrite	Resource/in ground	8.64872...	kg		none	
Antimony, in gro...	Resource/in ground	2.23087...	kg		none	
Argon-40/kg	Resource/in air	2.65472...	kg		none	
Arsenic	Resource/in ground	4.04511...	kg		none	
Barium	Resource/in ground	7.30920...	kg		none	
Basalt	Resource/in ground	3.64055...	kg		none	
Borax	Resource/in ground	2.23562...	kg		none	
Bromine, 0.0023...	Resource/in water	2.77664...	kg		none	
Cadmium, 0.30% ...	Resource/in ground	1.51937...	kg		none	
Calcium	Resource/in ground	1.63107...	kg		none	

Outputs

Flow	Category	Amount	Unit
energy required for primary production	Circularity Indicators	0.00031	MJ
energy required for secondary production	Circularity Indicators	1.66000...	MJ
recycled material	Circularity Indicators	1.00000	kg
total waste produced	Circularity Indicators	0.00097	kg
virgin material (V)	Circularity Indicators	0.00112	kg
waste from recycled feedstock production (Wf)	Circularity Indicators	8.14000...	kg
waste from recycling (Wc)	Circularity Indicators	5.19000...	kg
1,4-Butanediol	Emission to air/hig...	2.20786...	kg
1-Pentanol	Emission to air/hig...	1.19948...	kg
1-Pentene	Emission to air/hig...	9.98511...	kg

Figure 6: Circularity variables placed in a system process in the Agribalyse database. This information was obtained from the ecoinvent database, and passed on to the Agribalyse database.

For your information, Table 2 briefly explains the criteria used when placing elementary flows for circularity in the database.

Table 2: Summary of elementary flows for circularity and how they are placed in the database

Elementary flow	Where is it used?
Energy required for primary production	Energy used in a process which makes a primary material or product
Energy required for secondary production	Energy used in a process which produces secondary material, such as a recycling process
Recovered end of life materials	Amount of material recovered that can be used again in the market, per process
Recycled material	This flow shadows materials that are burden free, if they are positive inputs then they are recycled materials used, if they are negative inputs then they are secondary materials produced by the process.
Total waste produced	This is shadowed at the end of the supply chain, usually at the level of incineration or landfill.
Virgin material	Virgin material extracted from earth
Waste from recycled feedstock production	Shadows waste from processes that produce secondary material
Waste from recycling	Shadows waste from recycling processes

When making a model that has circular elements, the modeller must make sure that the shadowing elementary flows are placed in the model. The database already contains such flows, but the modeller might need to add extra in the following cases:

4.1 Case 1 – Creation of a process that makes a primary material, or product

Add the elementary flow "energy required for primary production" with the amount of energy used, as shown in Figure 7.

4.2 Case 2 – Creation of a secondary material dummy process (burden free)

Add the elementary flow "recycled material" as in Figure 8.

4.3 Case 3 – Creation of a process that makes a secondary material or product

Add the elementary flow "energy required for secondary production" to shadow the amount of energy used in the process, as in Figure 9.

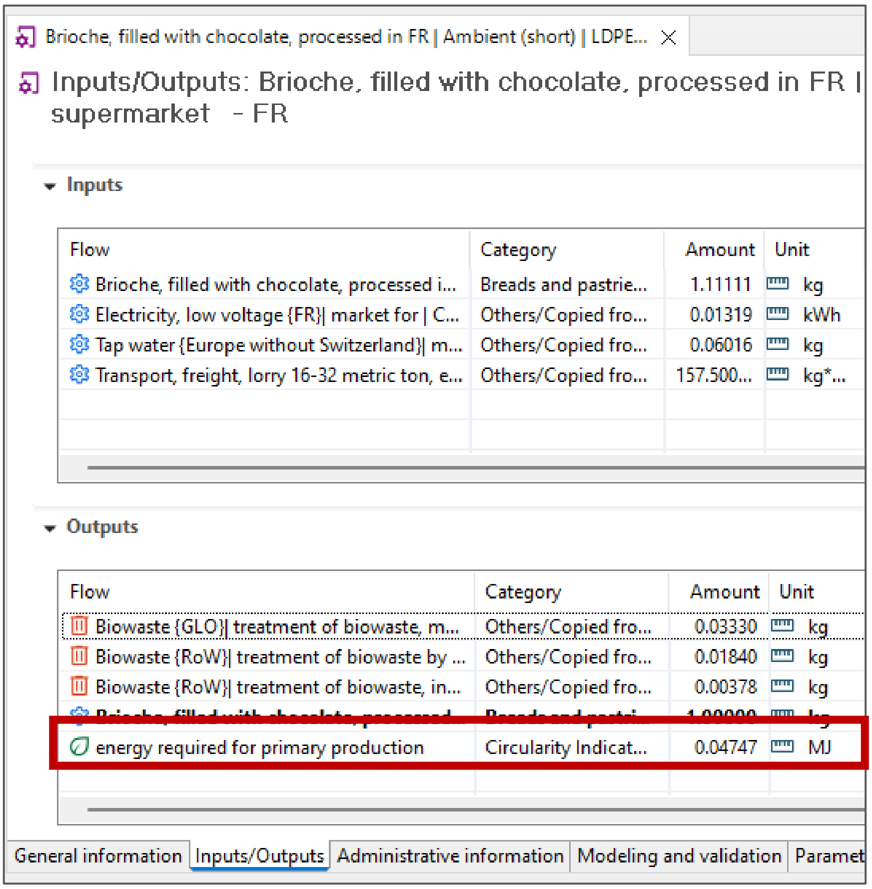
Additionally, if the process is

a) A **recycling process**, the amount of waste produced at the process should be shadowed by the elementary flow "waste from recycling (Wc)"

b) A **production of secondary feedstock process**, the waste produced at the process should be shadowed by the elementary flow “waste from recycled feedstock production (Wf)”, see Figure 9.

4.4 Case 4 – creation of a process that produces secondary material as an outcome

Secondary material produced by a process is shown as negative inputs, following the modelling of the ecoinvent[4] database. This material recovery should be tracked with the elementary flow “recovered EoL materials”, as shown in the example in Figure 10.



Brioche, filled with chocolate, processed in FR | Ambient (short) | LDPE...

Inputs/Outputs: Brioche, filled with chocolate, processed in FR | supermarket - FR

Inputs

Flow	Category	Amount	Unit
Brioche, filled with chocolate, processed i...	Breads and pastrie...	1.11111	kg
Electricity, low voltage {FR}| market for | C...	Others/Copied fro...	0.01319	kWh
Tap water {Europe without Switzerland}| m...	Others/Copied fro...	0.06016	kg
Transport, freight, lorry 16-32 metric ton, e...	Others/Copied fro...	157.500...	kg*...

Outputs

Flow	Category	Amount	Unit
Biowaste {GLO}| treatment of biowaste, m...	Others/Copied fro...	0.03330	kg
Biowaste {RoW}| treatment of biowaste by ...	Others/Copied fro...	0.01840	kg
Biowaste {RoW}| treatment of biowaste, in...	Others/Copied fro...	0.00378	kg
Brioche, filled with chocolate, processed...	Breads and pastri...	1.00000	kg
energy required for primary production	Circularity Indicat...	0.04747	MJ

Figure 7: Process that uses energy and produces a primary material or product

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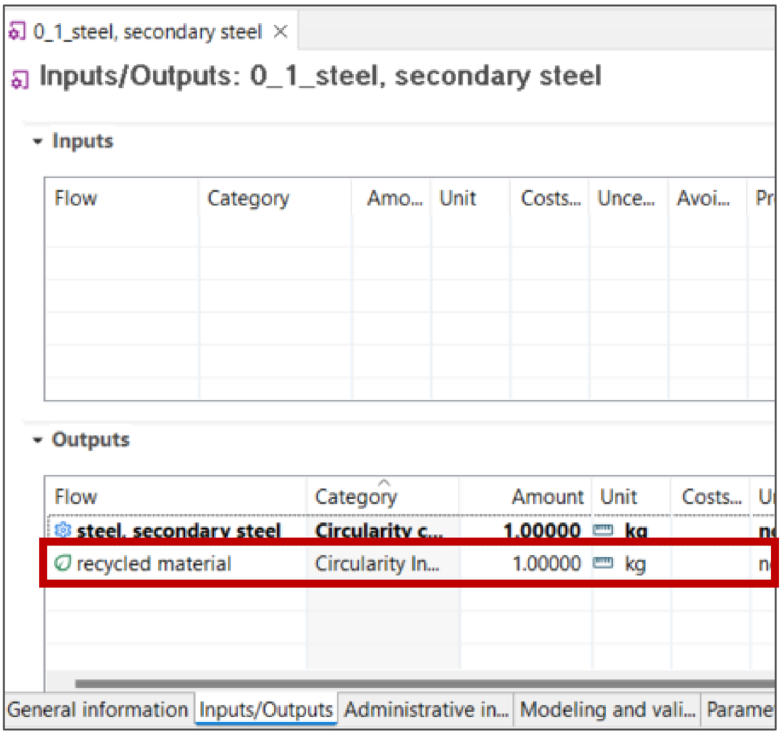
[4] https://ecoinvent.org/



Inputs/Outputs: 0_1_steel, secondary steel

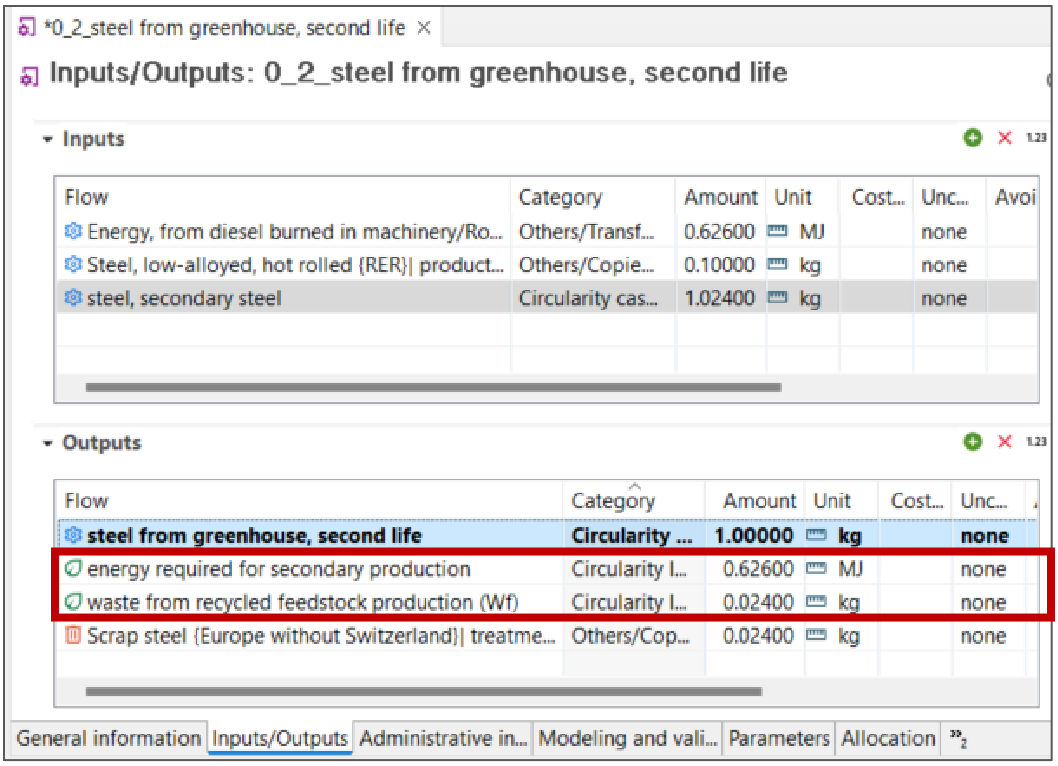
Inputs

Flow	Category	Amo...	Unit	Costs...	Unce...	Avoi...	Pr

Outputs

Flow	Category	Amount	Unit	Costs...	Ur
steel, secondary steel	**Circularity c...**	**1.00000**	**kg**		**nc**
recycled material	Circularity In...	1.00000	kg		n

Figure 8*:* Shadowing secondary material



Inputs/Outputs: 0_2_steel from greenhouse, second life

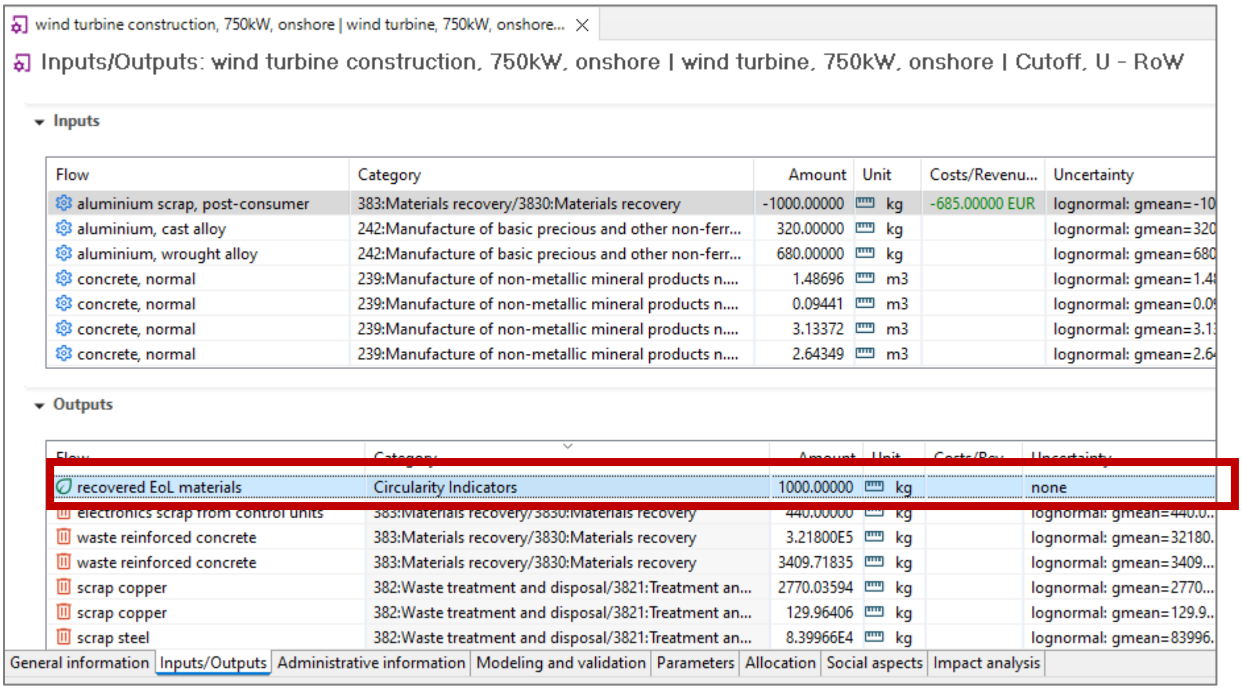
Inputs

Flow	Category	Amount	Unit	Cost...	Unc...	Avoi
Energy, from diesel burned in machinery/Ro...	Others/Transf...	0.62600	MJ		none	
Steel, low-alloyed, hot rolled {RER}| product...	Others/Copie...	0.10000	kg		none	
steel, secondary steel	Circularity cas...	1.02400	kg		none	

Outputs

Flow	Category	Amount	Unit	Cost...	Unc...
steel from greenhouse, second life	**Circularity ...**	**1.00000**	**kg**		**none**
energy required for secondary production	Circularity I...	0.62600	MJ		none
waste from recycled feedstock production (Wf)	Circularity I...	0.02400	kg		none
Scrap steel {Europe without Switzerland}| treatme...	Others/Cop...	0.02400	kg		none

Figure 9*:* Process for a product that uses secondary material



Inputs/Outputs: wind turbine construction, 750kW, onshore | wind turbine, 750kW, onshore | Cutoff, U - RoW

Inputs

Flow	Category	Amount	Unit	Costs/Revenu...	Uncertainty
aluminium scrap, post-consumer	383:Materials recovery/3830:Materials recovery	-1000.00000	kg	-685.00000 EUR	lognormal: gmean=-10
aluminium, cast alloy	242:Manufacture of basic precious and other non-ferr...	320.00000	kg		lognormal: gmean=320
aluminium, wrought alloy	242:Manufacture of basic precious and other non-ferr...	680.00000	kg		lognormal: gmean=680
concrete, normal	239:Manufacture of non-metallic mineral products n....	1.48696	m3		lognormal: gmean=1.4
concrete, normal	239:Manufacture of non-metallic mineral products n....	0.09441	m3		lognormal: gmean=0.0
concrete, normal	239:Manufacture of non-metallic mineral products n....	3.13372	m3		lognormal: gmean=3.1
concrete, normal	239:Manufacture of non-metallic mineral products n....	2.64349	m3		lognormal: gmean=2.6

Outputs

Flow	Category	Amount	Unit	Costs/Rev...	Uncertainty
recovered EoL materials	Circularity Indicators	1000.00000	kg		none
electronics scrap from control units	383:Materials recovery/3830:Materials recovery	440.00000	kg		lognormal: gmean=440.0..
waste reinforced concrete	383:Materials recovery/3830:Materials recovery	3.21800E5	kg		lognormal: gmean=32180.
waste reinforced concrete	383:Materials recovery/3830:Materials recovery	3409.71835	kg		lognormal: gmean=3409...
scrap copper	382:Waste treatment and disposal/3821:Treatment an...	2770.03594	kg		lognormal: gmean=2770...
scrap copper	382:Waste treatment and disposal/3821:Treatment an...	129.96406	kg		lognormal: gmean=129.9..
scrap steel	382:Waste treatment and disposal/3821:Treatment an...	8.39966E4	kg		lognormal: gmean=83996.

Figure 10: Process showing recovered material

5 Case study example: organic, local, tomato juice production

5.1 Case study presentation and base case results

Happy Farms FR produces tomato juice from fresh, French tomatoes from their own farms. Their secret formula and the tastiness of the tomatoes has increased the demand for their products to such an extent that they now look to build new tomato plantations and juicing facility. They want to take this opportunity to become more circular.

The cradle-to-gate diagram of how their processing looks at the moment is shown in

Figure 11. The Agribalyse process "Tomato, average basket, conventional, soil based, non-heated greenhouse, at greenhouse - FR" is used at the start of the supply chain.

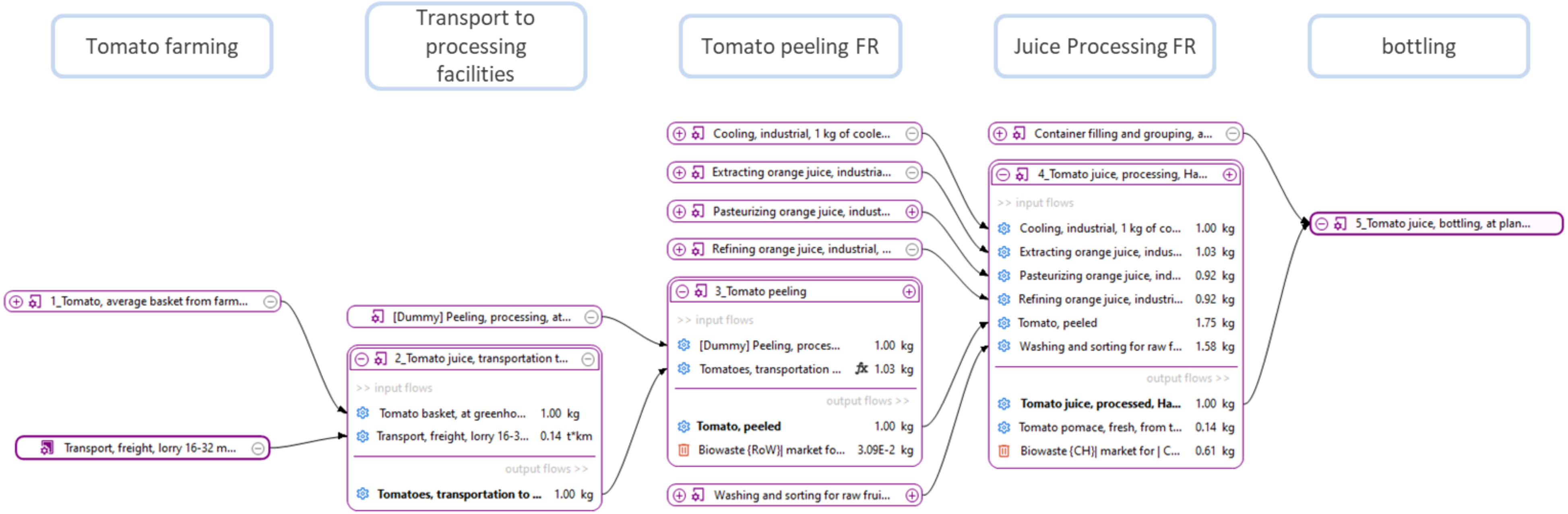
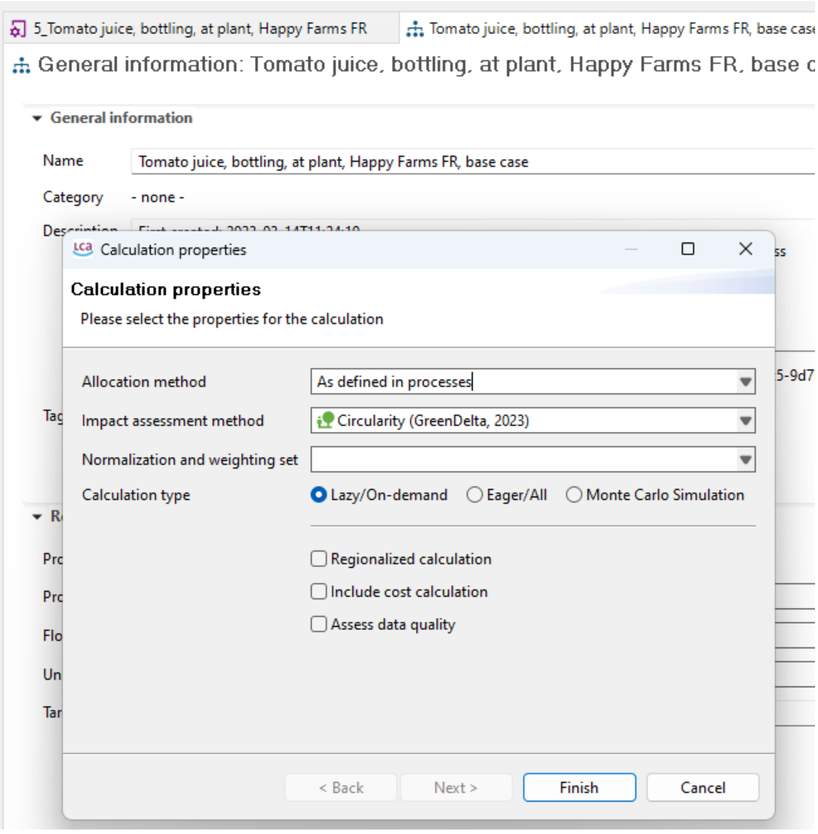


Figure 11: Cradle-to-gate flow diagram of the production of one bottle of tomato juice, base case

The product system was run with the LCIA Method developed for Circularity, as shown in Figure 12, to get an idea of the hotspots of the model.



5_Tomato juice, bottling, at plant, Happy Farms FR

Tomato juice, bottling, at plant, Happy Farms FR, base cas

General information: Tomato juice, bottling, at plant, Happy Farms FR, base c

General information

Name: Tomato juice, bottling, at plant, Happy Farms FR, base case

Category: - none -

Calculation properties

Please select the properties for the calculation

Allocation method: As defined in processes

Impact assessment method: Circularity (GreenDelta, 2023)

Normalization and weighting set:

Calculation type: ● Lazy/On-demand ○ Eager/All ○ Monte Carlo Simulation

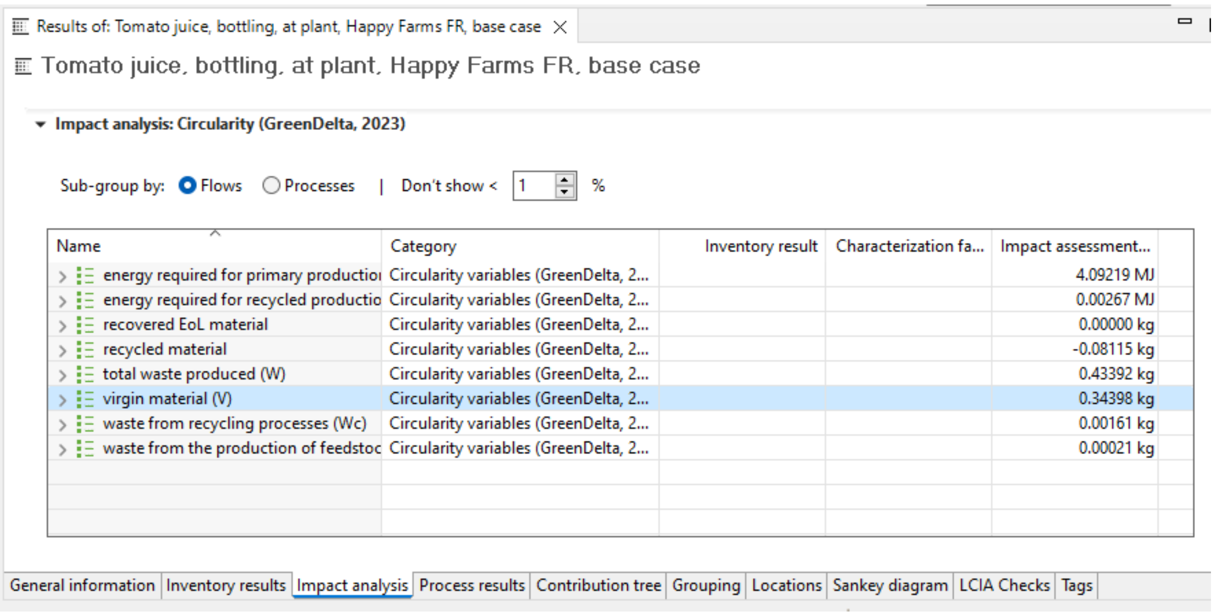
☐ Regionalized calculation

☐ Include cost calculation

☐ Assess data quality

Figure 12: The Circularity LCIA Method is used to show circularity variable results across the supply chain

The impact categories of virgin material used, energy for primary production, and total waste produced were analysed using e.g. the impact analysis tab and the contribution tree (Figure 13, Figure 14). Higher process contributions to these impact categories meant worse scores in the circularity indicators.



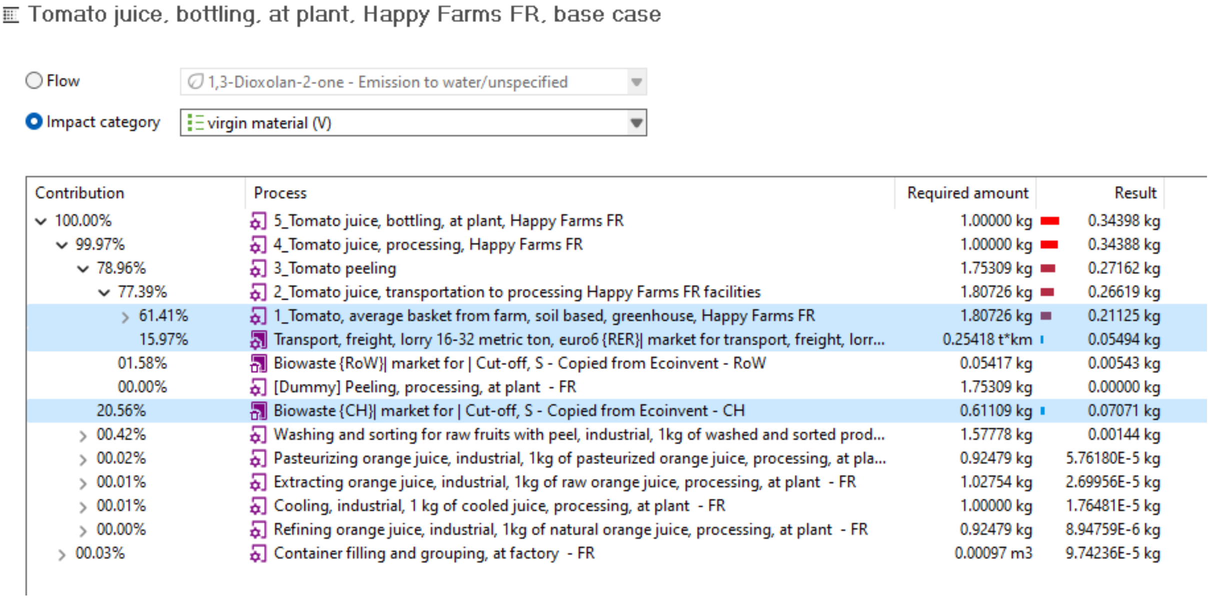
Tomato juice, bottling, at plant, Happy Farms FR, base case

Impact analysis: Circularity (GreenDelta, 2023)

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

Name	Category	Inventory result	Characterization fa...	Impact assessment...
energy required for primary productio	Circularity variables (GreenDelta, 2...			4.09219 MJ
energy required for recycled productio	Circularity variables (GreenDelta, 2...			0.00267 MJ
recovered EoL material	Circularity variables (GreenDelta, 2...			0.00000 kg
recycled material	Circularity variables (GreenDelta, 2...			-0.08115 kg
total waste produced (W)	Circularity variables (GreenDelta, 2...			0.43392 kg
virgin material (V)	Circularity variables (GreenDelta, 2...			0.34398 kg
waste from recycling processes (Wc)	Circularity variables (GreenDelta, 2...			0.00161 kg
waste from the production of feedstoc	Circularity variables (GreenDelta, 2...			0.00021 kg

Figure 13: Results per circularity variable are seen at the impact analysis tab


Tomato juice, bottling, at plant, Happy Farms FR, base case

○ Flow: 1,3-Dioxolan-2-one - Emission to water/unspecified

● Impact category: virgin material (V)

Contribution	Process	Required amount	Result
100.00%	5_Tomato juice, bottling, at plant, Happy Farms FR	1.00000 kg	0.34398 kg
99.97%	4_Tomato juice, processing, Happy Farms FR	1.00000 kg	0.34388 kg
78.96%	3_Tomato peeling	1.75309 kg	0.27162 kg
77.39%	2_Tomato juice, transportation to processing Happy Farms FR facilities	1.80726 kg	0.26619 kg
61.41%	1_Tomato, average basket from farm, soil based, greenhouse, Happy Farms FR	1.80726 kg	0.21125 kg
15.97%	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorr...	0.25418 t*km	0.05494 kg
01.58%	Biowaste {RoW}| market for | Cut-off, S - Copied from Ecoinvent - RoW	0.05417 kg	0.00543 kg
00.00%	[Dummy] Peeling, processing, at plant - FR	1.75309 kg	0.00000 kg
20.56%	Biowaste {CH}| market for | Cut-off, S - Copied from Ecoinvent - CH	0.61109 kg	0.07071 kg
00.42%	Washing and sorting for raw fruits with peel, industrial, 1kg of washed and sorted prod...	1.57778 kg	0.00144 kg
00.02%	Pasteurizing orange juice, industrial, 1kg of pasteurized orange juice, processing, at pla...	0.92479 kg	5.76180E-5 kg
00.01%	Extracting orange juice, industrial, 1kg of raw orange juice, processing, at plant - FR	1.02754 kg	2.69956E-5 kg
00.01%	Cooling, industrial, 1 kg of cooled juice, processing, at plant - FR	1.00000 kg	1.76481E-5 kg
00.00%	Refining orange juice, industrial, 1kg of natural orange juice, processing, at plant - FR	0.92479 kg	8.94759E-6 kg
00.03%	Container filling and grouping, at factory - FR	0.00097 m3	9.74236E-5 kg

Figure 14: The contribution tree tab can help you understand where hotspots lie within a supply chain

Table 3: Hotspots of the base case model

Identified hotspots	Circular economy applied	Life Cycle Stage location
Steel from greenhouse infrastructure	Using secondary material for greenhouse	1_Tomato farming
Transport from tomato plantation to processing	Plantation and processing in the same site – reduces transport	2_Transportation
Biowaste, probably transport here	Make compost?	3_Tomato peeling
Peat used in tomato seeding		1_Tomato farming
Fertilizer use	Using waste from other industries (cattle) as fertiliser	1_Tomato farming
	Adopting biological pest control and eliminating pesticide use	
	Crop rotation (healthier land & higher production)	

5.2 Circularity plan

Further investigation and a sensitivity analysis was made to see how to best design the tomato plantation and processing facility to increase circularity. The following circularity plan was considered:

a) **Re-thinking the greenhouse structure:** a plastic tunnel showed lower contributions than a bigger greenhouse due to the steel infrastructure. Therefore:
  - Use 90% secondary steel frameworks from previous greenhouses
  - Use 20% less concrete
  - make sure the steel frame is fully taken to recycling at end of life

b) Locate the **plantation site next to the processing site**
  - 15 km of transport from plantation to processing

c) **More organic fertilizer, from local farm** only 15 km away
  - 80% coming from compost
  - 20% from rendered animals, to ensure phosphorus supply

5.3 Application of the circularity plan in openLCA:

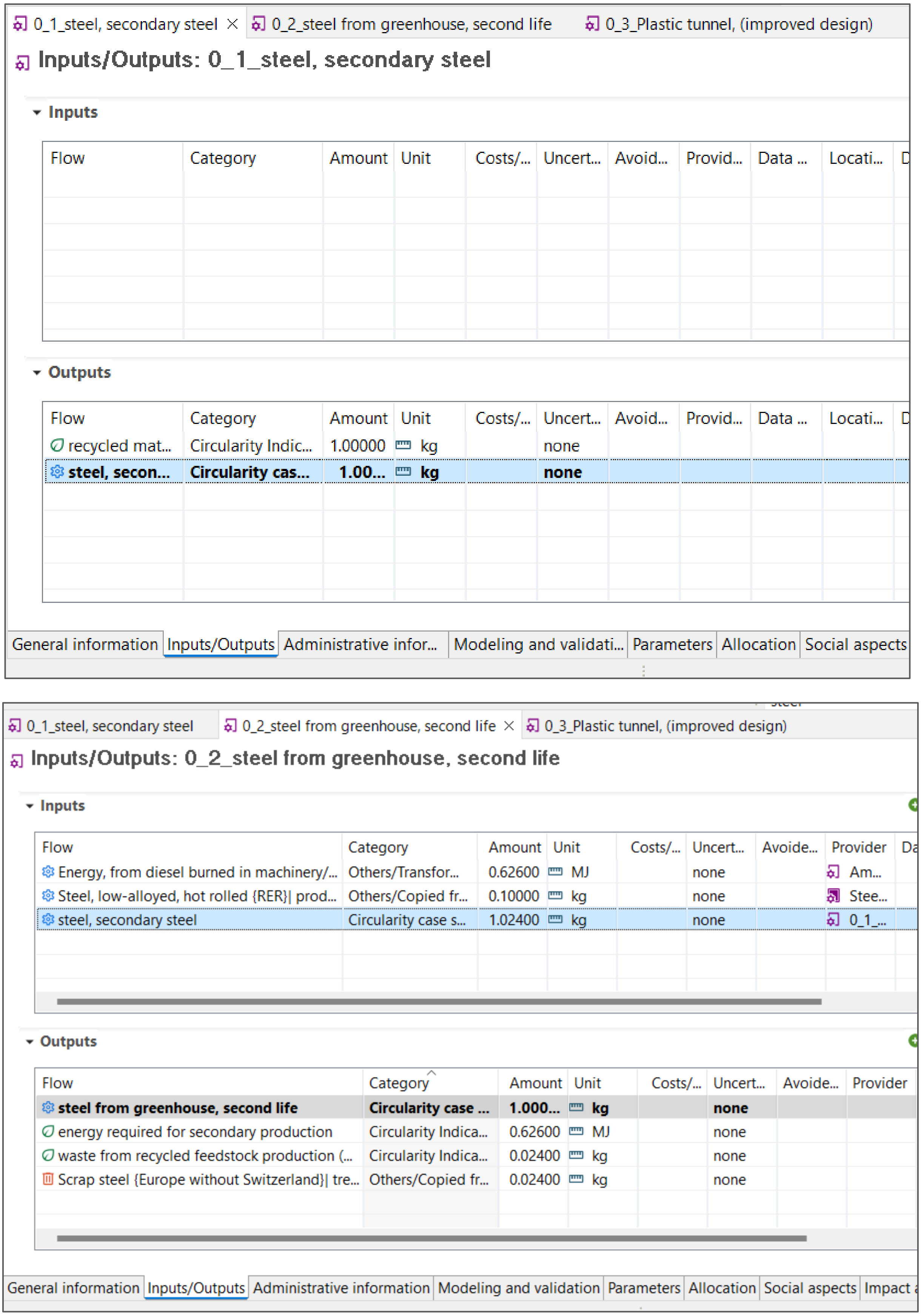
Happy Farms, case study
  Happy Farms, base case
  Happy Farms, improved case
    0_1_steel, secondary steel
    0_2_steel from greenhouse, second life
    0_3_Plastic tunnel, (improved design)
    1_Tomato, average basket, (improved farming)
    2_Tomato juice, transportation to processing Happy Farms FR facilities (improved supply chain)
    3_Tomato peeling (improved supply chain)
    4_Tomato juice, processing, Happy Farms FR (improved supply chain)
    5_Tomato juice, bottling, at plant, Happy Farms FR (improved supply chain)

First, the production of secondary steel was modelled as shown in Figure 15. This was used in the process for the production of the plastic tunnel, where 20% less concrete was also used compared to the standard plastic tunnel production.

Then, 1320.414 kg of mineral fertilizer was substituted with 1500 kg organic fertilizer (80% compost and 20% rendered animal) curing the tomato farming process.

Finally, a new process was created for the transport of tomato from the plantation to the processing plant, with only 15 km distance between them, see Figure 16.

These processes were connected to a similar supply chain for peeling, processing and bottling as in the base case model.



Inputs/Outputs: 0_1_steel, secondary steel

Inputs

Flow	Category	Amount	Unit	Costs/...	Uncert...	Avoid...	Provid...	Data ...	Locati...

Outputs

Flow	Category	Amount	Unit	Costs/...	Uncert...	Avoid...	Provid...	Data ...	Locati...
recycled mat...	Circularity Indic...	1.00000	kg		none				
steel, secon...	**Circularity cas...**	**1.00...**	**kg**		**none**				

Inputs/Outputs: 0_2_steel from greenhouse, second life

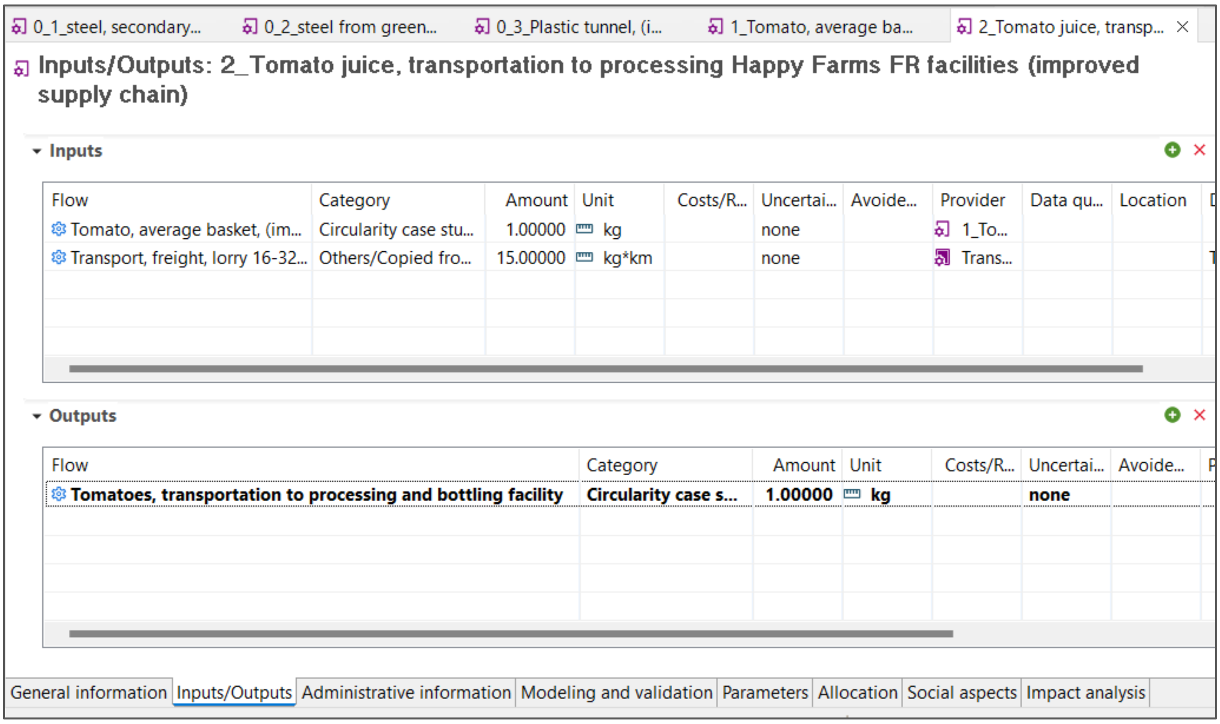
Inputs

Flow	Category	Amount	Unit	Costs/...	Uncert...	Avoide...	Provider
Energy, from diesel burned in machinery/...	Others/Transfor...	0.62600	MJ		none		Am...
Steel, low-alloyed, hot rolled {RER}| prod...	Others/Copied fr...	0.10000	kg		none		Stee...
steel, secondary steel	Circularity case s...	1.02400	kg		none		0_1_...

Outputs

Flow	Category	Amount	Unit	Costs/...	Uncert...	Avoide...	Provider
steel from greenhouse, second life	**Circularity case ...**	**1.000...**	**kg**		**none**		
energy required for secondary production	Circularity Indica...	0.62600	MJ		none		
waste from recycled feedstock production (...	Circularity Indica...	0.02400	kg		none		
Scrap steel {Europe without Switzerland}| tre...	Others/Copied fr...	0.02400	kg		none		

Figure 15: Processes for the production of the structure from secondary steel to be used in the greenhouse.



Inputs/Outputs: 2_Tomato juice, transportation to processing Happy Farms FR facilities (improved supply chain)

Inputs

Flow	Category	Amount	Unit	Costs/R...	Uncertai...	Avoide...	Provider	Data qu...	Location
Tomato, average basket, (im...	Circularity case stu...	1.00000	kg		none		1_To...		
Transport, freight, lorry 16-32...	Others/Copied fro...	15.00000	kg*km		none		Trans...		

Outputs

Flow	Category	Amount	Unit	Costs/R...	Uncertai...	Avoide...
Tomatoes, transportation to processing and bottling facility	**Circularity case s...**	**1.00000**	**kg**		**none**	

Figure 16: Transport process for tomatoes from farming to processing

5.4 Results & Conclusions

The product systems were run with the Circularity (GreenDelta, 2023) LCIA Method and the allocation method “as defined in process”.

Table 4: Results for circularity variables and indicators for the base case and the improved case, for 1kg of tomato juice

Impact categories	Unit	base case	improved case
energy required for primary production	MJ	4.09219	3.9939
energy required for recycled production	MJ	0.00267	0.00677
recovered EoL material	kg	0.08966	0.08544
recycled material	kg	-0.08115	-0.07144
total waste produced (W)	kg	0.43392	0.18563
virgin material (V)	kg	0.34398	0.20613
waste from recycling processes (Wc)	kg	0.00161	0.00108
waste from feedstock production, second life (Wf)	kg	0.00021	0.00034
MCI		**0.23540**	**0.32739**
CI		**0.25418**	**0.38747**

From the table above, it can be seen that the circularity scores for both indicators do improve considerably with the proposed circularity plan, taking into consideration that a score of 1 is a fully circular model. In fact, the new design uses:

- 40% less virgin materials
- 57% less total waste produced
- 3% less energy

For 50 tonnes of tomato juice produced per year, the savings would scale to:

- 6.7 tonnes of virgin material saved per year
- 12.5 tonnes of waste not being produced per year
- 4,900 MJ (or 1,360 kWh) of energy saved per year

The sustainability team thought that the improvements were very promising and passed the plan to the finance team to also take into account the difference in costs for both models. After this, both assessments will be considered and a decision will be made.

6 How to obtain the database?

You can acquire the database licence in our marketplace for data: openLCA Nexus https://nexus.openlca.org/databases

Licence holders will also have access to maintenance updates.

Do you have any questions? You can contact us following this link: https://www.openlca.org/contact/

Need support? Book direct support with us through Nexus: https://nexus.openlca.org/service/openLCA%20Support%20(help%20desk)

7 Appendix: formulas for circularity indicators

- V – amount of virgin materials (flow reference id: 8f2148cb-2cf7-4138-a496-6f2de5a1d04b)
- M – mass of finished product
- L – average life time of product
- L_{av} – average life time of industrial average of product
- U – average number of units of use
- U_{av} – average number of units of use of an industrial average
- W_{C} – unrecoverable waste generating in recycling (flow reference id: b1def92b-1ea4-4277-8d5f-dd99f9f577a6)
- W_{F} – unrecoverable waste when producing recycling feedstock (flow reference id: bd6325ab-21ee-4a22-a45a-7ccd9e8de307)
- W_0 – direct waste produced
- W – total waste produced
- $\mathrm{MCI}_{\mathrm{P}}$ – Material Circularity Indicator of a product

Material Circularity Indicator

Formulas based on the documentation from the Ellen MacArthur Foundation:

https://ellenmacarthurfoundation.org/material-circularity-indicator

$$\mathrm{V} = \Sigma(\mathrm{x})\ \mathrm{V}(\mathrm{x}) \tag{1}$$

$$\mathrm{W} = \mathrm{W}_0 + \frac{\mathrm{W}_{\mathrm{F}} + \mathrm{W}_{\mathrm{C}}}{2} \tag{2}$$

Usually the total waste, W, recorded by the LCIA Method for circularity made will be larger than V because it also takes into account generic waste. For this reason, direct waste is calculated with formula 3:

$$\mathrm{W}_0 = \mathrm{V} - \left(\frac{\mathrm{W}_{\mathrm{F}} + \mathrm{W}_{\mathrm{c}}}{2}\right) - \text{recovered material} \tag{3}$$

If we insert this formula for W_0 into the formula for W:

$$\mathrm{W} = \mathrm{W}_0 + \frac{\mathrm{W}_\mathrm{F} + \mathrm{W}_\mathrm{C}}{2} \quad 4$$

The formula for W simplifies to:

$$\mathrm{W} = \mathrm{V} - \text{recovered material} \quad 5$$

If this is then inserted into the formula for LFI:

$$\mathrm{LFI} = \frac{\mathrm{V} + \mathrm{W}}{2\mathrm{M} + \frac{\mathrm{W}_\mathrm{F} - \mathrm{W}_\mathrm{C}}{2}} \quad 6$$

We can get rid of having to calculate W at all by simply calculating LFI like this:

$$\mathrm{LFI} = \frac{2\mathrm{V} - \text{recovered material}}{2\mathrm{M} + \frac{\mathrm{W}_\mathrm{F} - \mathrm{W}_\mathrm{C}}{2}} \quad 7$$

$$X = \frac{L}{L_{av}} \cdot \frac{U}{Uav} \quad 8$$

$$F(X) = \frac{0.9}{X} \quad 9$$

$$MCI_P = 1 - LFI \cdot F(X) \quad 10$$

$$MCI_P = max\,(0, MCI_P) \quad 11$$

Circularity Index

Formulas obtained from

Cullen, Jonathan M. (2017). Circular Economy: Theoretical Benchmark or Perpetual Motion Machine?. Journal of Industrial Ecology, (), –. doi:10.1111/jiec.12599

$$\alpha = \frac{\text{recovered EoL material}}{\text{total material demand}} \quad 12$$

$$\beta = 1 - \frac{\text{energy required to recover material}}{\text{energy required for primary production}} \quad 13$$

$$\mathrm{CI} = \alpha\beta \qquad (14)$$

$$\mathrm{CI}_{\mathrm{max}} = 1 \qquad (15)$$