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

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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



- 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

- **Material Circularity Indicator (MCI)**

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

- **Circularity Index (CI)**

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

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

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

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

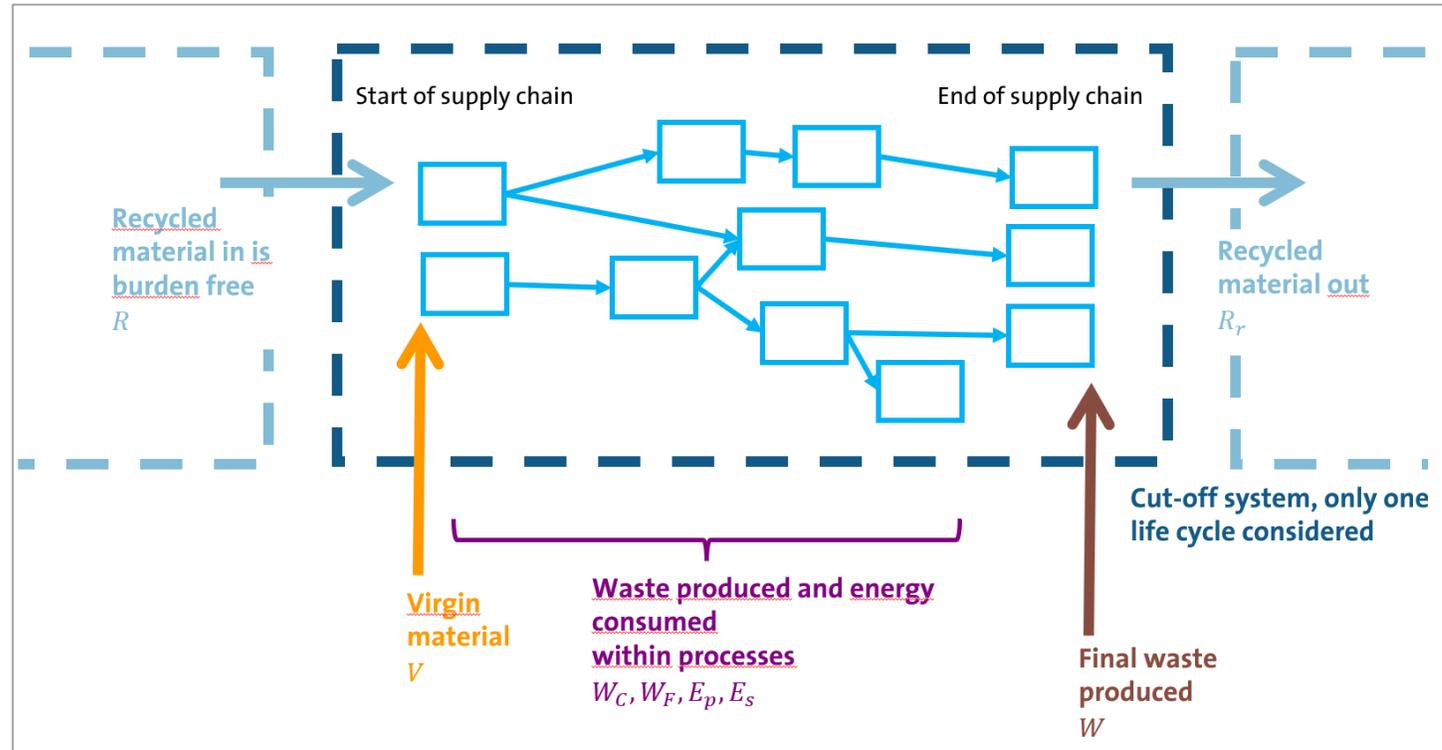
J. Cullen, “Theoretical Benchmark or Perpetual Motion Machine?,” *Journal of Industrial Ecology*, 21, pp. 483-486, 2017.

Applying circularity to LCA

✓ Avoid double counting

Apply new elementary flows to shadow circularity information.

Across all the inventory.



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

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

(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.

- Flows
 - A:Agriculture, forestry and fishing
 - B:Mining and quarrying
 - C:Manufacturing
 - Circularity Indicators
 - energy required for primary production (E_p)
 - energy required for secondary production (E_s)
 - radioactive waste (Wr)
 - recovered EoL materials (R_r)
 - 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... | |

(example from ecoinvent dataset)

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

- Impact assessment methods
 - ecoinvent 3.10 LCIA Methods
 - Circularity (GreenDelta, 2024)

Impact categories

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

Note: the background datasets already trace circularity!

How to execute circularity in openLCA ?

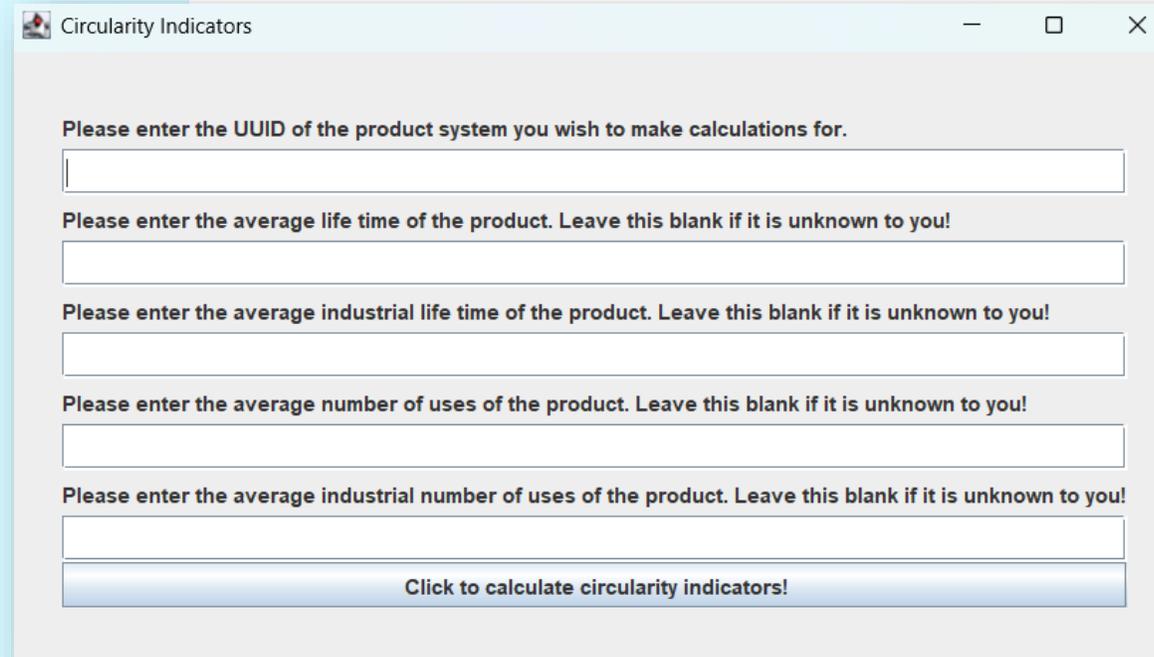
3. Add extra variables through a pop-up window which displays results

>> 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*



Circularity Indicators

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

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 uses of the product. Leave this blank if it is unknown to you!

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

Click to calculate circularity indicators!

Example

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 |
| v 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

Example

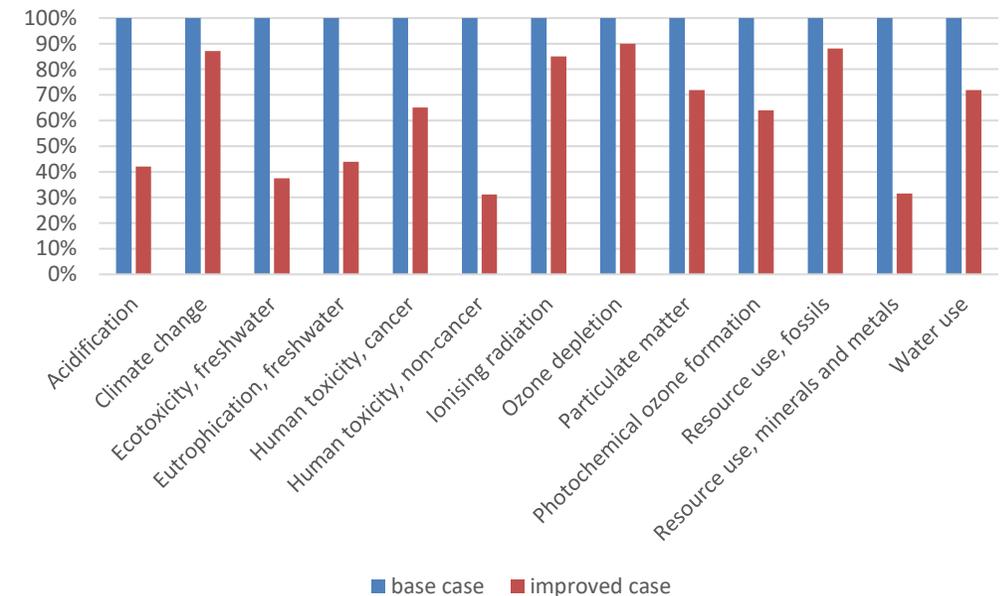
VIRGIN MATERIAL -> We saw that copper was a hotspot from the big amounts of “Gangue, in ground” extracted in copper mining.

Improved case: use 50% copper from recycled sources

Circularity Indicators

| 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 (EF3.1)



Development of the Circularity Package

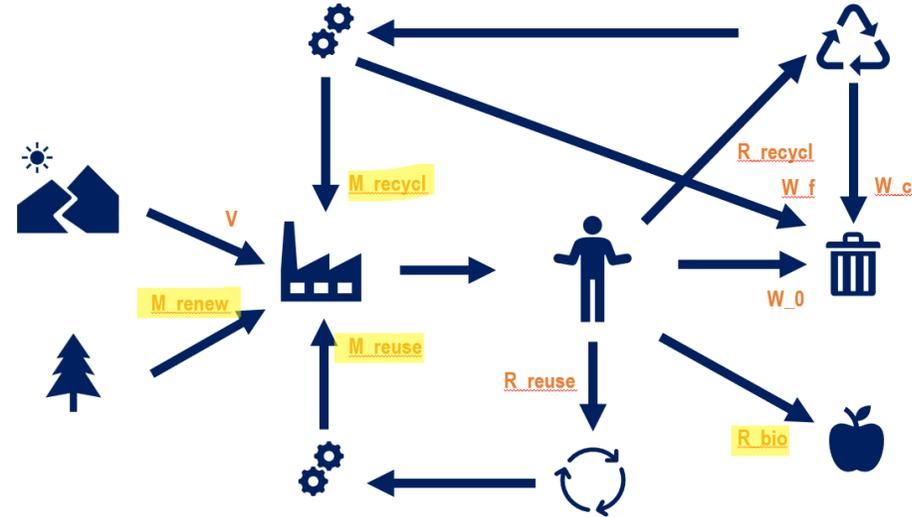
Project by GreenDelta GmbH

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

J. Cilleruelo Palomero, L. Freboeuf, A. Citroth, 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



ecoinvent 3.12 Cutoff (Unit) 2025-11-21_for

- Projects
- Product systems
- Processes
- Flows
- EPDs
- Results
- Indicators and parameters
 - Impact assessment methods
 - ecoinvent 3.12 Methods
 - Circularity (GreenDelta, 2026)
 - waste to landfill
 - Impact categories
 - Social indicators
 - Global parameters
 - Data quality systems
 - Background data

tags: Add a tag

Source: - none - X

Code:

▼ Impact categories

| Name |
|--|
| energy required for primary production (Ep) |
| energy required for recycled production (Es) |
| Material in, from reuse (M_reuse) |
| Material in, recycled (M_Recycl) |
| Material in, renewable (M_Renewable) |
| Material in, total |
| Material in, virgin (V) |
| recovered biological material (R_bio) |
| recovered material for recycling (R_recycl) |
| recovered material for reuse (R_reuse) |
| recovered material, total |
| waste from recycling processes (Wc) |
| waste from the production of feedstock, for second life (Wf) |
| waste to incineration |
| waste to landfill |

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.



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...Any questions?

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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 | <u>Circularity Package</u> | <u>Location in ecoinvent database</u> |
|--|-------|-----|----|----------------------------|---|
| 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

