GreenDelta
sustainability consulting + software

# LCA and reality

openLCA.conf 2026, Berlin, April 2026

Dr. Andreas Ciroth
GreenDelta GmbH

LCA

# Two points to start the presentation

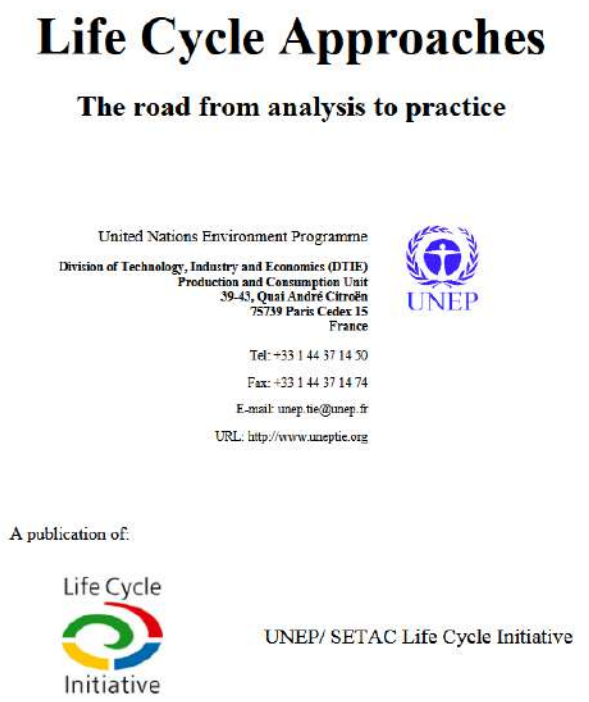
1. it was always the idea that LCA represents the real world, in a holistic, as objective as possible manner, avoiding burden shifting.

2. this reflects a key concept of empirical science, broadly used in engineering, sociology, psychology, natural science

# UNEP 2005: we need science based approaches, such as LCA

state that our efforts "must be linked to the development of cleaner and more resource efficient technologies for a life cycle economy." By life cycle economy the ministers aim at a society that views the production, use and disposal of a product as a comprehensive cycle, covering all processes required: extraction and processing; manufacture; transport and distribution; use, reuse and maintenance; recycling; and final disposal. And in Johannesburg in 2002, the world leaders also recognised that: "We must develop consumption and production policies to improve the products and services provided, while reducing environmental and health impacts, using, where appropriate, science based approaches, such as life cycle analysis" According to the WSSD, life cycle approaches will have to play an essential role on the road towards Sustainable Consumption and Production (SCP).

However, these life cycle approaches must suit the requirements of all relevant stakeholders, particularly also including those from developing countries (see highlight). There is a need to strengthen the implementation of the related policies, and there is a need to reach out to those who are still unfamiliar to the issues. Capacity


Life Cycle Approaches

The road from analysis to practice

United Nations Environment Programme
Division of Technology, Industry and Economics (DTIE)
Production and Consumption Unit
39-43, Quai André Citroën
75739 Paris Cedex 15
France

Tel: +33 1 44 37 14 50
Fax: +33 1 44 37 14 74
E-mail: unep.tie@unep.fr
URL: http://www.uneptie.org

UNEP

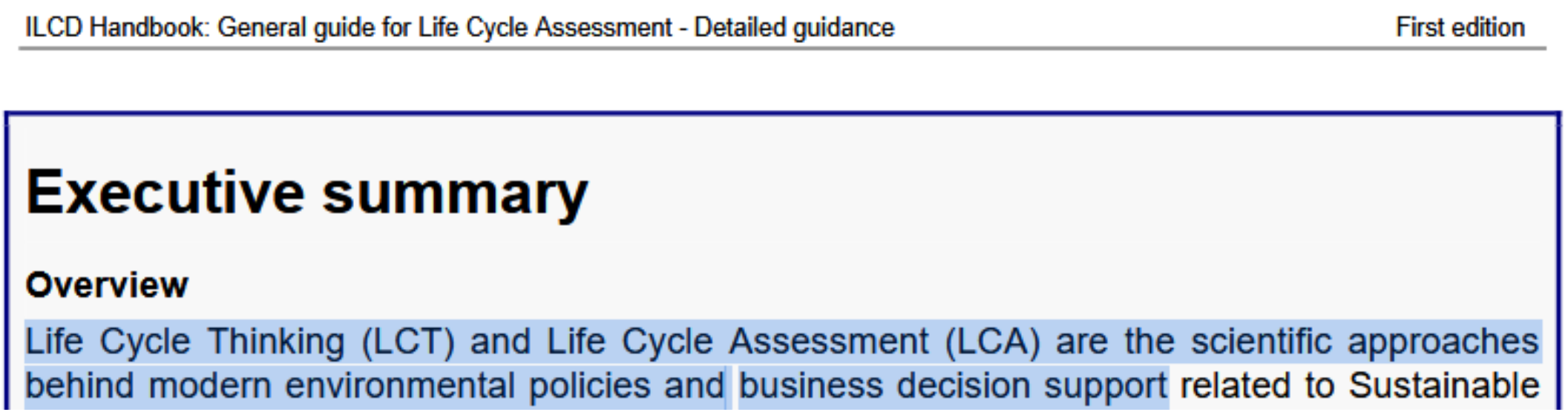
A publication of:

Life Cycle Initiative

UNEP/ SETAC Life Cycle Initiative

UNEP: Life Cycle Approaches: the road from analysis to practice (2005, English, 89 pages)

# ILCD handbook 2010: LCA is the scientific approach



ILCD Handbook: General guide for Life Cycle Assessment - Detailed guidance First edition

## Executive summary

### Overview

Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA) are the scientific approaches behind modern environmental policies and business decision support related to Sustainable

European Commission - Joint Research Centre - Institute for Environment and Sustainability: International Reference Life Cycle Data System (ILCD) Handbook - General guide for Life Cycle Assessment - Detailed guidance. First edition March 2010. EUR 24708 EN. Luxembourg. Publications Office of the European Union; 2010

# (key characteristics of science:

| # | Characteristic | What it means | Evidence |
|---|---|---|---|
| 1 | Empirical & evidence-based | Science builds knowledge from systematic observation, measurement and experiment. | "Scientific method … is an *empirical* method for acquiring knowledge through careful observation…"[67] |
| 2 | Systematic & logical reasoning | The work follows a structured process – observation → hypothesis → deduction/induction → testing – using both inductive and deductive reasoning. | "Among the activities often identified as *characteristic of science* are systematic observation and experimentation, inductive and deductive reasoning, and the formation and testing of hypotheses and theories."[60] |
| 3 | Testability & falsifiability | A scientific claim must be stated so that it can be proved false by data; otherwise it is not scientific. | "A hypothesis … must be *falsifiable*, implying that it is possible to identify a possible outcome … that conflicts with predictions."[67] |
| 4 | Reproducibility / replicability | Independent researchers should be able to repeat an experiment under the same conditions and obtain the same result. This safeguard is essential for the integrity of scientific knowledge. | "The consideration of *reproducibility and replicability* in science is intended to maintain and enhance the integrity of scientific knowledge."[70] |
| 5 | Peer review & communal enterprise | Findings are examined by other experts before publication; science is a collaborative, self-correcting community. | "Each element of the scientific method is subject to *peer review* for possible mistakes."[68] and "*Science is a communal enterprise*."[70] |
| 6 | Tentative / provisional nature | Scientific knowledge is never final; it is presented with degrees of confidence and is open to revision when new evidence appears. | "Science aims for *refined degrees of confidence, rather than complete certainty*."[70] |
| 7 | Objectivity & skepticism | Researchers must strive to limit personal bias and continually question assumptions. | The method includes "rigorous *skepticism* … and experimental validation."[71] |
| 8 | Universality (nature is not capricious) | Science assumes that natural laws operate consistently everywhere, so results obtained in one setting apply elsewhere. | "Nature is not capricious… the basic rules are everywhere the same; knowledge gained … is applicable to other parts."[70] |

)

# However, this testing and empirical evidencing is not straightforward

1. LCA results overall cannot be validated in the real world (!)

   A ship can be put on water, if it sinks, the build was not good; an LCA result cannot be put to a test in a similar way.

Ciroth, A., Becker, H.: Validation – The Missing Link in Life Cycle Assessment.
Towards pragmatic LCAs., Editorial, in: The Int J of LCA 11 (5) p. 295 – 297 (2006).



Editorials

## Validation – The Missing Link in Life Cycle Assessment
### Towards pragmatic LCAs

**Andreas Ciroth[1]* and Henk Becker[2]**

[1] GreenDeltaTC GmbH, Raumerstr. 7, 10437 Berlin, Germany
[2] Utrecht Centre for Applied Sociology, Woestduinlaan 65, 3941 XC Doorn, The Netherlands

* **Corresponding author** (ciroth@greendeltatc.com)

DOI: http://dx.doi.org/10.1065/lca2006.09.271

The Life Cycle Assessment methodology has been astonishingly successful over the past decade. LCA, the concept, has been standardised, the number of conferences and publications have increased and the activities on the European level (e.g. LCA platform and others) proliferate. However, we assert that the power of, and value delivered by, LCA would increase significantly if it were validated. **Validation**, you may recall, is *"the process of ascertaining that the model mimics the real system by comparing the behaviour of the model to that of the real system in which the system can be observed and altering the model to improve its ability to represent the real system"* [1]. In other words, you check whether the model you have built is correct by comparing it to the reality you attempted to model. This editorial will make the case that, in addition to aligning LCA with a more rigorous scientific approach, ensuring cases are validated can provide benchmarks and, when coupled with sensitivity analyses, enhance the practicality of the method. While validation may seem like one additional step in a tool which is already too comprehensive, it could, on the other hand, and as the authors believe, make a convincing case that carrying out LCA contributes, or could, to sustainability.

#### 1 Validation of LCA Models is Not Yet Complete

We need to explain why we think that validation is missing, and why this is a flaw. Let us begin with the first question and sketch out an answer using the example of building a ship. Imagine a group of engineers that are to build a fast and reliable racing yacht. The ship needs to be made from many different components (sail, mast, hull, keel, canvas, and so on). As they want to build a winning boat, the engineers use only high-quality, or light-weight components, which have been thoroughly tested, individually. They also have asked experts for their opinions and follow their, sometimes diverse, advice as well as possible balancing various constraints (**Fig. 1**).

Quite often, despite the best efforts, and the testing of the prototype, even designs with essentially limitless budgets (e.g. 12-meter boats) require re-engineering prior to achieving their target specifications. The essential conclusion would be, therefore, that the ultimate result must be validated, despite the, often quite extensive, checks in background data, assumptions, material properties and performance. One can no more, quantitatively, model a boat than an environmental assessment. Indeed, the best models, those to which precision exceeds ten decimal places, tend to relate to very specific materials or sub-atomic particles, not complicated composites or devices.

Therefore, this boat-building exercise is very similar to building an Life Cycle Assessment model. In a high quality LCA study, one may

- combine the best process data and impact assessment models available,
- make sure that these 'components' are thoroughly tested, and

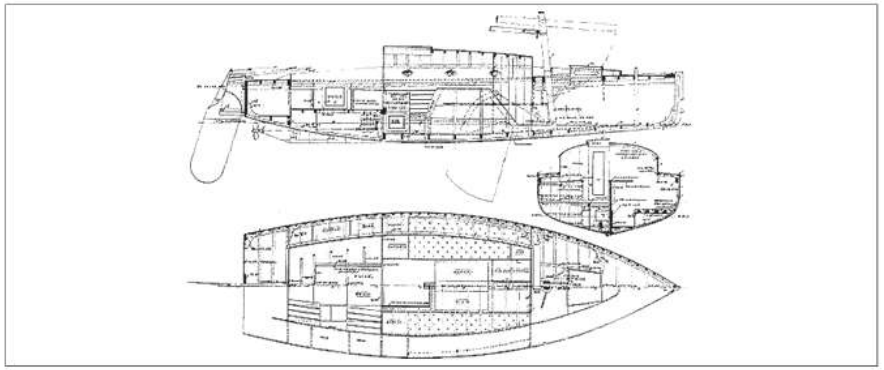
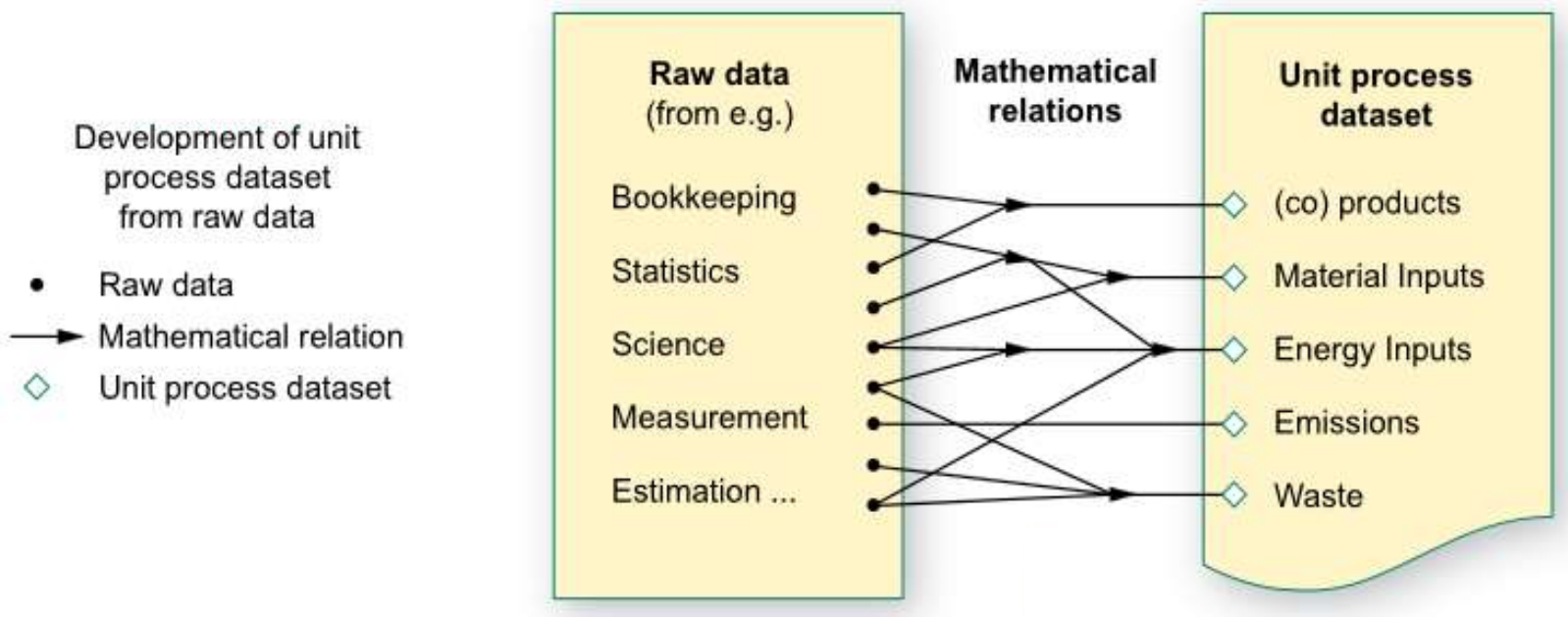


**Fig. 1:** Einstein's 'Tümmler' Yacht from 1929, a sailing ship (Picture by courtesy of Delius Klaesing Verlag, Die Yacht)

# However, this testing and empirical evidencing is not straightforward

## 2. Process details often remain unclear and are often not known



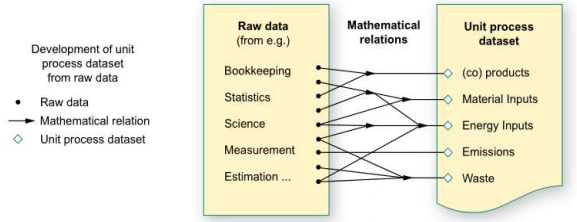

Wang, H., Ciroth, A., Gerber, P., Mbowha, Ch., Mungcharoen, T., Sahnoune, A., Tahara, K., Tikana, L.: Development of Unit Process Datasets, chapter 2 in UNEP Shonan Guidance Principles, 2011, https://www.lifecycleinitiative.org/wp-content/uploads/2012/12/2011%20-%20Global%20Guidance%20Principles.pdf



GreenDelta

# However, this testing and empirical evidencing is not straightforward

2. Process details often remain unclear and are often not known




- Some emissions needed for LCA are not measured on a site
- “Allocation factors” are not exactly known (link from procurement amounts to one specific product)
- Production process details are typically company secret and will not be shared easily
- …

# However, this is not straightforward

3. Life cycle impact assessment results are not real impacts but potential impacts
   - (since beginning)

... and it is of course impossible to “see” the entire impacts of a product over its life cycle, unless the product is a very specific case (all impacts worldwide are caused by one product)

# LCA and reality, status

This “distance” of LCA from reality was recognized in the early development of LCA already, and is broadly accepted today.

# LCA and reality, status

This “distance” of LCA from reality was recognized in the early development of LCA already, and is broadly accepted today.

But the world has changed in the last 30 years:

a) technical development has evidently happened

b) LCA has become much more important, and mainstream

→ This is an opportunity, and brings responsibility

## → So, what does LCA do with these increased possibilities and responsibilities?

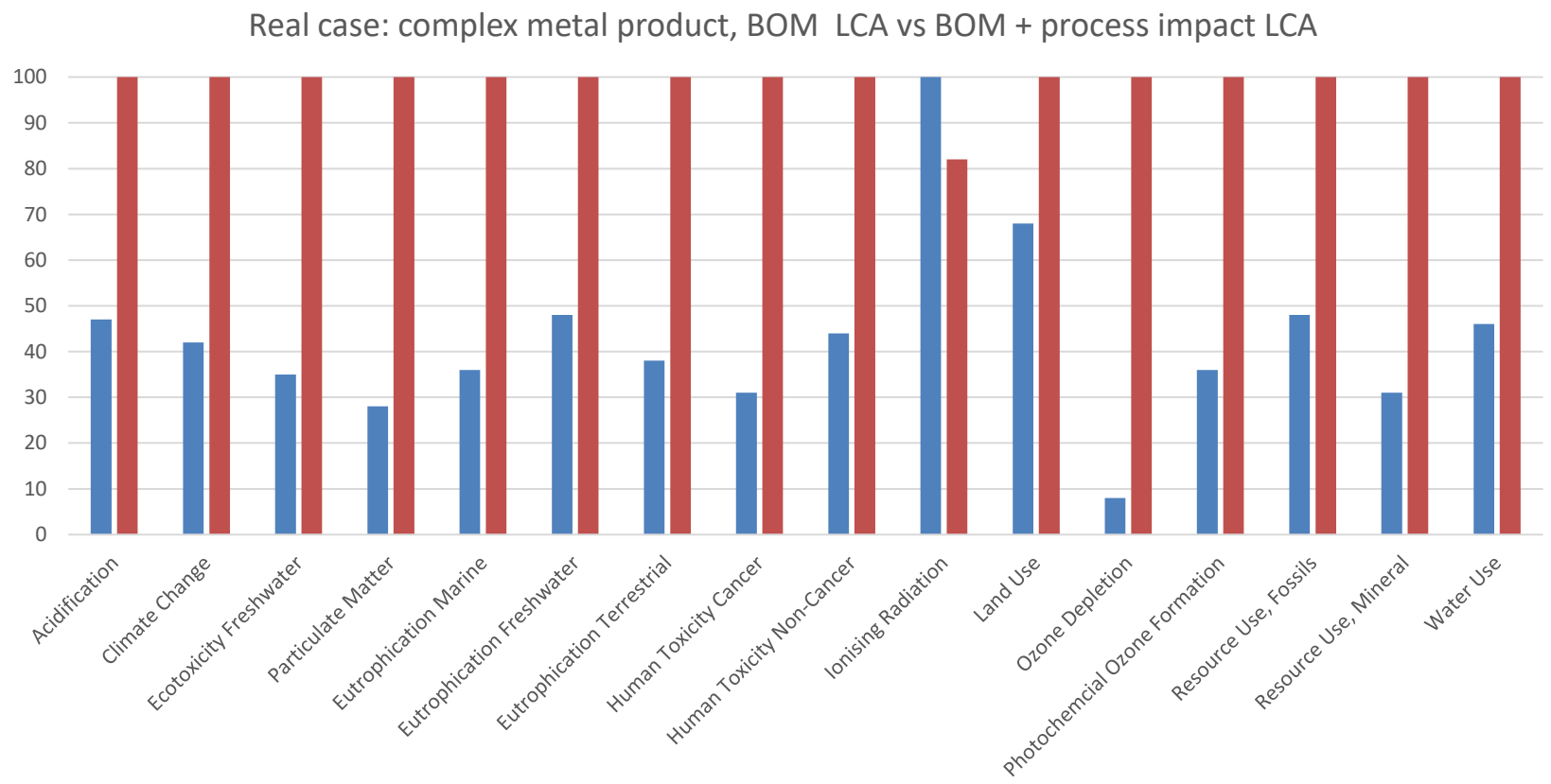
- CBAM, etc.: LCA results become relevant, and are treated as facts

- Linking LCA with reality is difficult (see previous slides), & there are signs that LCA has somewhat developed into a world of its own

# Signs that LCA has somewhat developed into a world of its own

# Bill of material (BOM) calculations, ignoring impacts in the process itself

## (common in some EPDs, LCA databases)

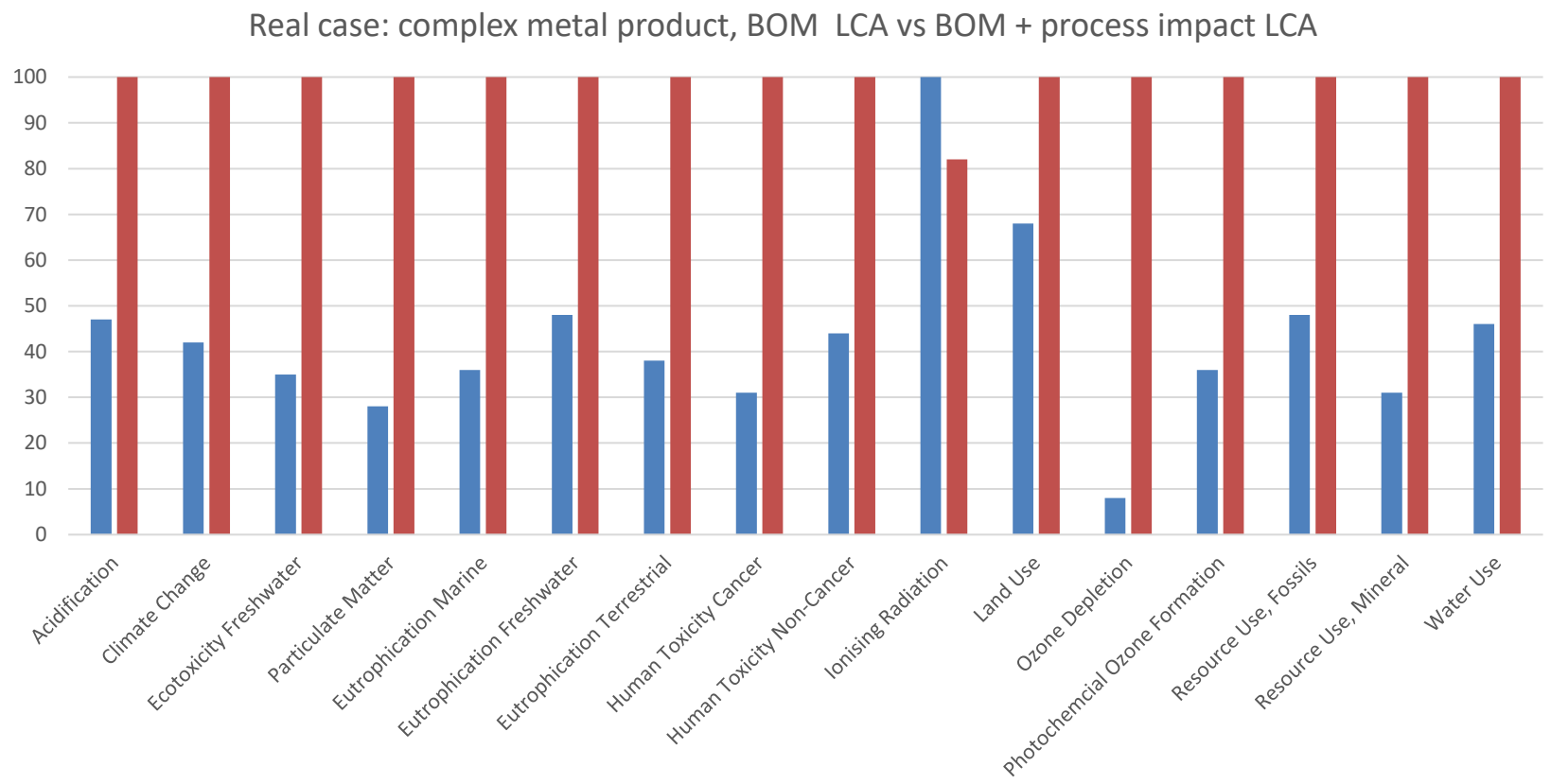





GreenDeLTa

# Bill of material (BOM) calculations, ignoring impacts in the process itself

## (common in some EPDs, LCA databases)




in this specific case, BOM sees only ~ half of the impacts



GreenDelta

# Uncertainty calculations based on data quality scores

## (geometric standard deviation, as provided by the ecoinvent database)

**Inputs/Outputs - operation, printer, laser, colour, per kg printed paper | printed paper | Cutoff, U - CA-QC**

Inputs

| Flow | Category | Amount | Unit | Costs/Revenues | Uncertainty | Avoided waste | Provider | Data quality en |
|---|---|---|---|---|---|---|---|---|
| electricity, low voltage | D:Electricity, gas, steam and air c... | 0.25000 | kWh | | lognormal: gmean=0.250000 gsigma=1.00000 | | market for ... | (2; 3; 5; 5; 1) |
| paper, woodcontaining, light... | C:Manufacturing/17:Manufactur... | 1.00000 | kg | | none | | market for ... | |
| printer, laser, colour | C:Manufacturing/26:Manufactur... | 0.00021 | Item(s) | | lognormal: gmean=0.000208333 gsigma=1.10517 | | market for ... | (3; 3; 5; 5; 1) |
| toner module, laser printer, co... | C:Manufacturing/28:Manufactur... | 0.04000 | Item(s) | | lognormal: gmean=0.0400000 gsigma=1.10517 | | market for ... | (2; 3; 5; 1; 1) |

| Indicator score | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Reliability | 1.00 | 1.05 | 1.10 | 1.20 | 1.50 |
| Completeness | 1.00 | 1.02 | 1.05 | 1.10 | 1.20 |
| Temporal correlation | 1.00 | 1.03 | 1.10 | 1.20 | 1.50 |
| Geographical correlation | 1.00 | 1.01 | 1.02 | | 1.10 |
| Further technological correlation | 1.00 | | 1.20 | 1.50 | 2.00 |

Uncertainty factors used in the ecoinvent database (version 2 & 3)

# Uncertainty calculations based on data quality scores

## (geometric standard deviation, as provided by the ecoinvent database)

| Indicator score | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Reliability | 1 | 1.54* | 1.61 | 1.69 | (n.a.)** |
| Completeness | 1 | 1.03 | 1.04 | 1.08 | (n.a.)** |
| Temporal correlation | 1 | 1.03 | 1.10 | 1.19 | 1.29 |
| Geographical correlation | 1 | 1.04 | 1.08 | 1.11 | (n.a.)** |
| Further technological correlation | 1 | 1.18 | 1.65 | 2.08 | 2.80 |

**interim ** > 5

Ciroth, A., Muller, S., Weidema, B. et al. (2016): Empirically based uncertainty factors for the pedigree matrix in ecoinvent . Int J Life Cycle Assess 21 , 1338–1348. https://doi.org/10.1007/s11367-013-0670-5

| Indicator score | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Reliability | 1.00 | 1.05 | 1.10 | 1.20 | 1.50 |
| Completeness | 1.00 | 1.02 | 1.05 | 1.10 | 1.20 |
| Temporal correlation | 1.00 | 1.03 | 1.10 | 1.20 | 1.50 |
| Geographical correlation | 1.00 | 1.01 | 1.02 | | 1.10 |
| Further technological correlation | 1.00 | | 1.20 | 1.50 | 2.00 |

Uncertainty factors used in the ecoinvent database (version 2 & 3)

# Uncertainty calculations based on data quality scores

## (geometric standard deviation, as provided by the ecoinvent database)

| Indicator score | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Reliability | 1 | 1.54* | 1.61 | 1.69 | (n.a.)** |
| Completeness | 1 | 1.03 | 1.04 | 1.08 | (n.a.)** |
| Temporal correlation | 1 | 1.03 | 1.10 | 1.19 | 1.29 |
| Geographical correlation | 1 | 1.04 | 1.08 | 1.11 | (n.a.)** |
| Further technological correlation | 1 | 1.18 | 1.65 | 2.08 | 2.80 |

**interim ** > 5

Ciroth, A., Muller, S., Weidema, B. et al. (2016): Empirically based uncertainty factors for the pedigree matrix in ecoinvent . Int J Life Cycle Assess 21 , 1338–1348. https://doi.org/10.1007/s11367-013-0670-5

| Indicator score | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Reliability | 1.00 | 1.05 | 1.10 | 1.20 | 1.50 |
| Completeness | 1.00 | 1.02 | 1.05 | 1.10 | 1.20 |
| Temporal correlation | 1.00 | 1.03 | 1.10 | 1.20 | 1.50 |
| Geographical correlation | 1.00 | 1.01 | 1.02 | | 1.10 |
| Further technological correlation | 1.00 | | 1.20 | 1.50 | 2.00 |

Uncertainty factors used in the ecoinvent database (version 2 & 3)

# Uncertainty calculations based on data quality scores

## (geometric standard deviation, as provided by the ecoinvent database)

| Indicator score | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Reliability | 1 | 1.54* | 1.61 | 1.69 | (n.a.)** |
| Completeness | 1 | 1.03 | 1.04 | 1.08 | (n.a.)** |
| Temporal correlation | 1 | 1.03 | 1.10 | 1.19 | 1.29 |
| Geographical correlation | 1 | 1.04 | 1.08 | 1.11 | (n.a.)** |
| Further technological correlation | 1 | 1.18 | 1.65 | 2.08 | 2.80 |

**interim ** > 5

Ciroth, A., Muller, S., Weidema, B. et al. (2016): Empirically based uncertainty factors for the pedigree matrix in ecoinvent . Int J Life Cycle Assess 21 , 1338–1348. https://doi.org/10.1007/s11367-013-0670-5

| Indicator score | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Reliability | 1.00 | 1.05 | 1.10 | 1.20 | 1.50 |
| Completeness | 1.00 | 1.02 | 1.05 | 1.10 | 1.20 |
| Temporal correlation | 1.00 | 1.03 | 1.10 | 1.20 | 1.50 |
| Geographical correlation | 1.00 | 1.01 | 1.02 | | 1.10 |
| Further technological correlation | 1.00 | | 1.20 | 1.50 | 2.00 |

Uncertainty factors used in the ecoinvent database (version 2 & 3)

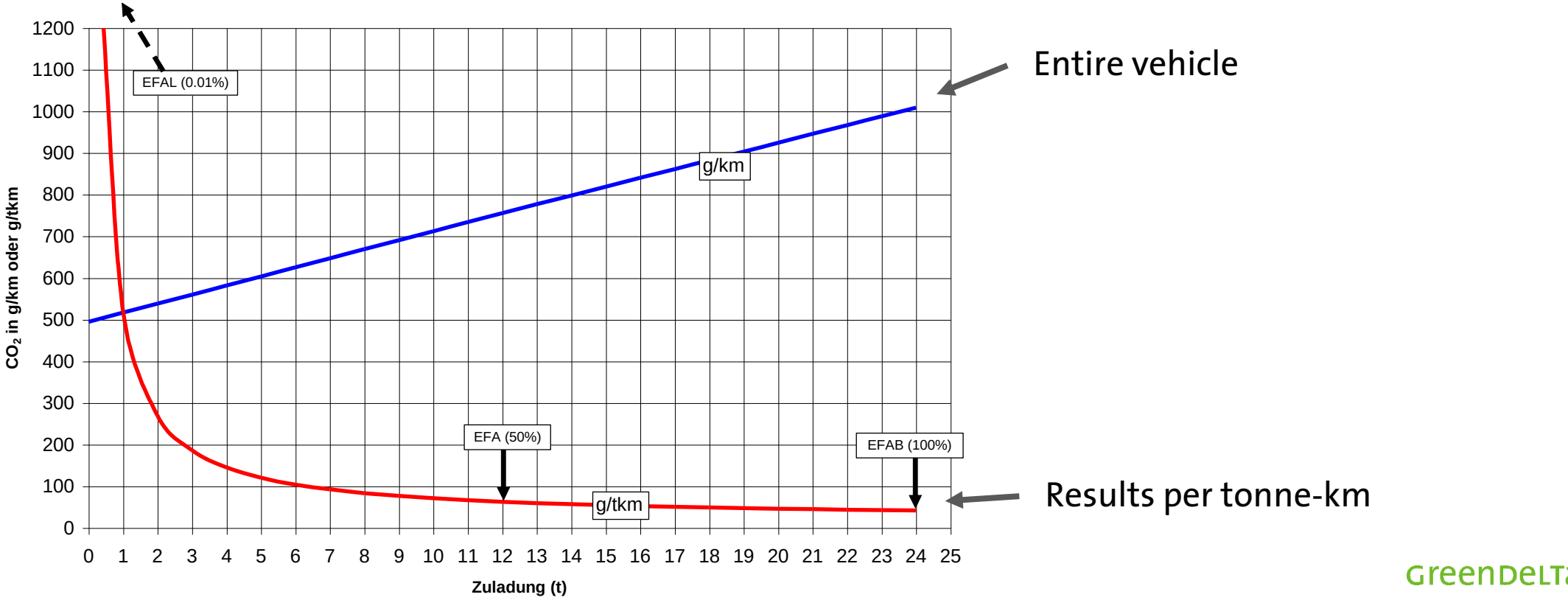
Difference is e.g.

$e^{1.1}$ vs $e^{5}$

# Transport modeling

## Transport effort depends on payload, to a very large extent

(TREMOD Transport Emission Model, version 5.0.4)

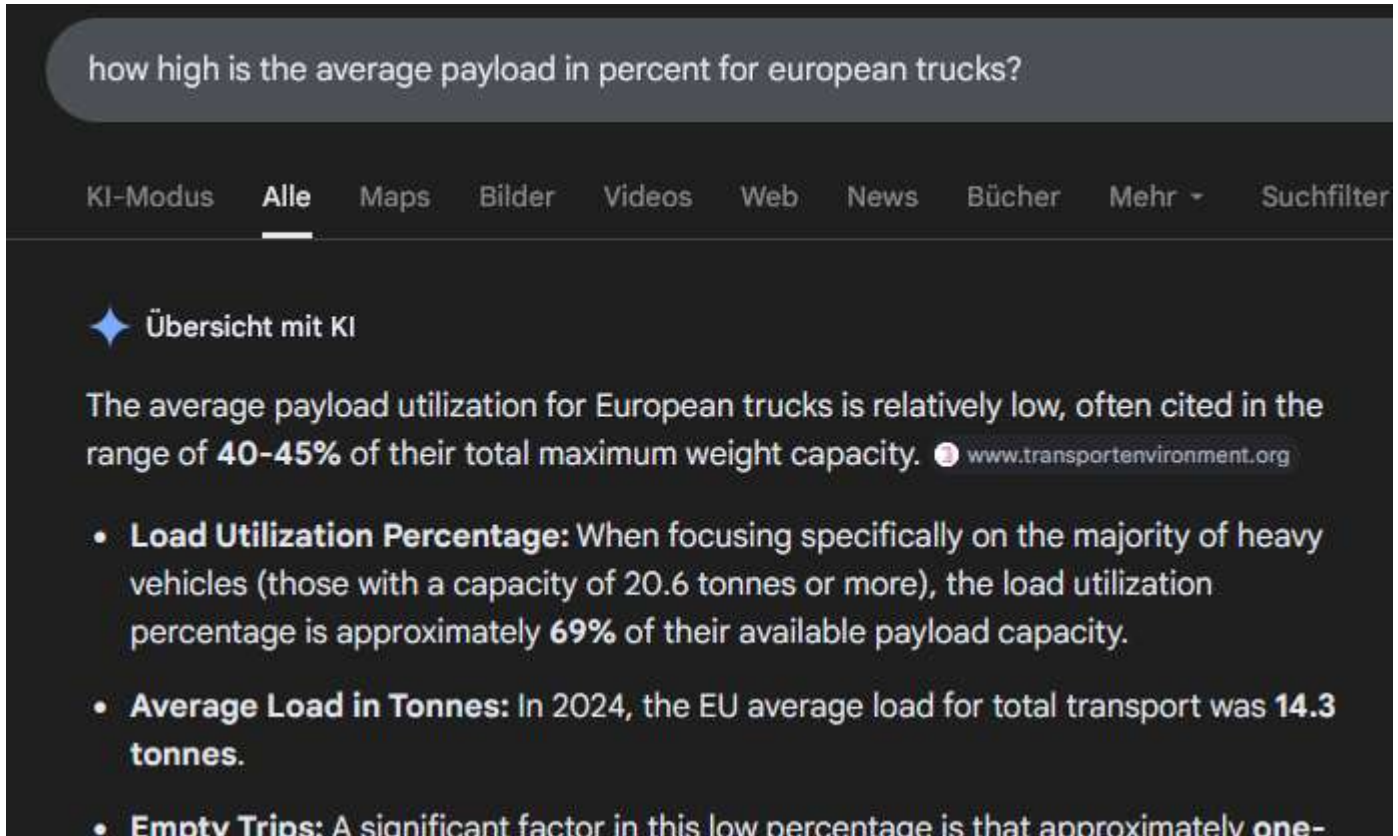





GreenDelta

# Transport modeling

## Transport effort depends on payload, to a very large extent – how high is it, in reality?



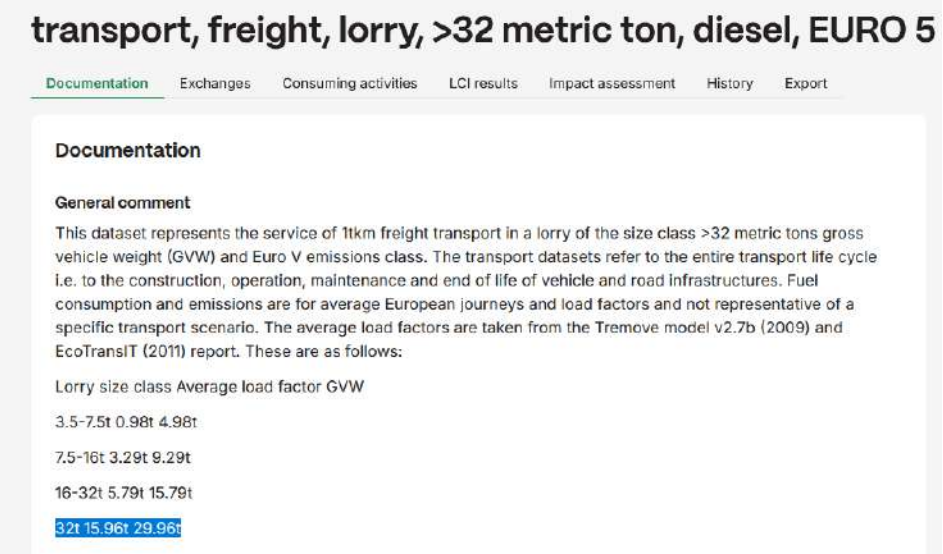



GreenDelta

# Transport modeling

Transport effort depends on payload, to a very large extent – how high is it, in reality?

ecoinvent: heavy road transport payload, fix, cannot be changed.







GreenDelta

# Omission of infrastructure

## It is quite common in LCA and LCA databases (e.g., from Sphera), to exclude “infrastructure” (=machinery etc.)

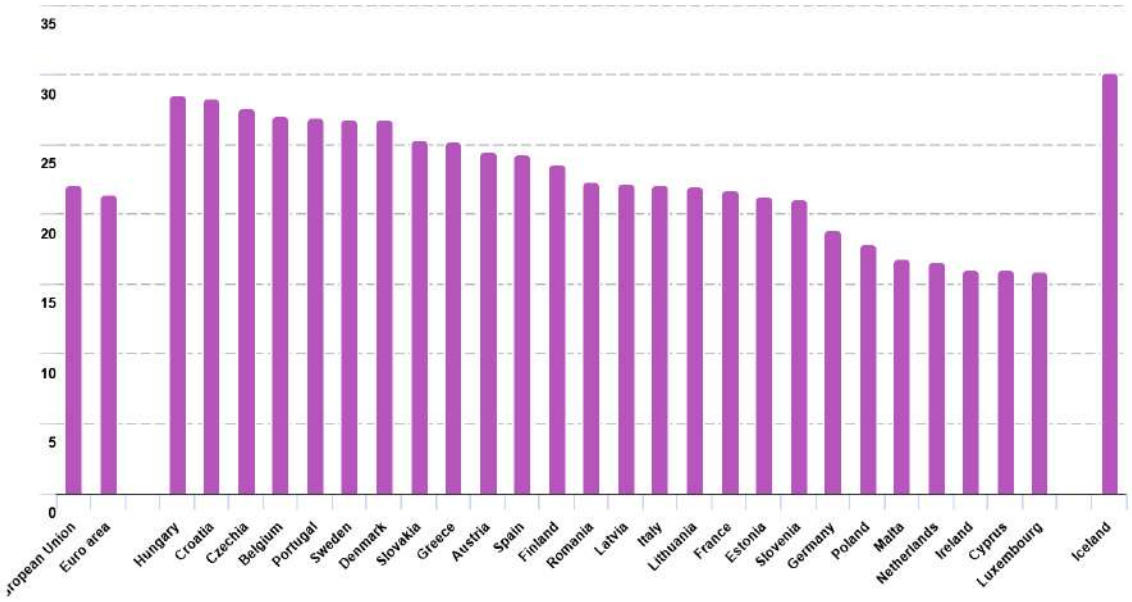
But investment rate of companies

in Europe in 2024 (-> investment in infrastructure): 20-28%

There will be connected environmental impact

**Gross investment rate of non-financial corporations, 2024**

(% ratio of gross fixed capital formation to gross value added)



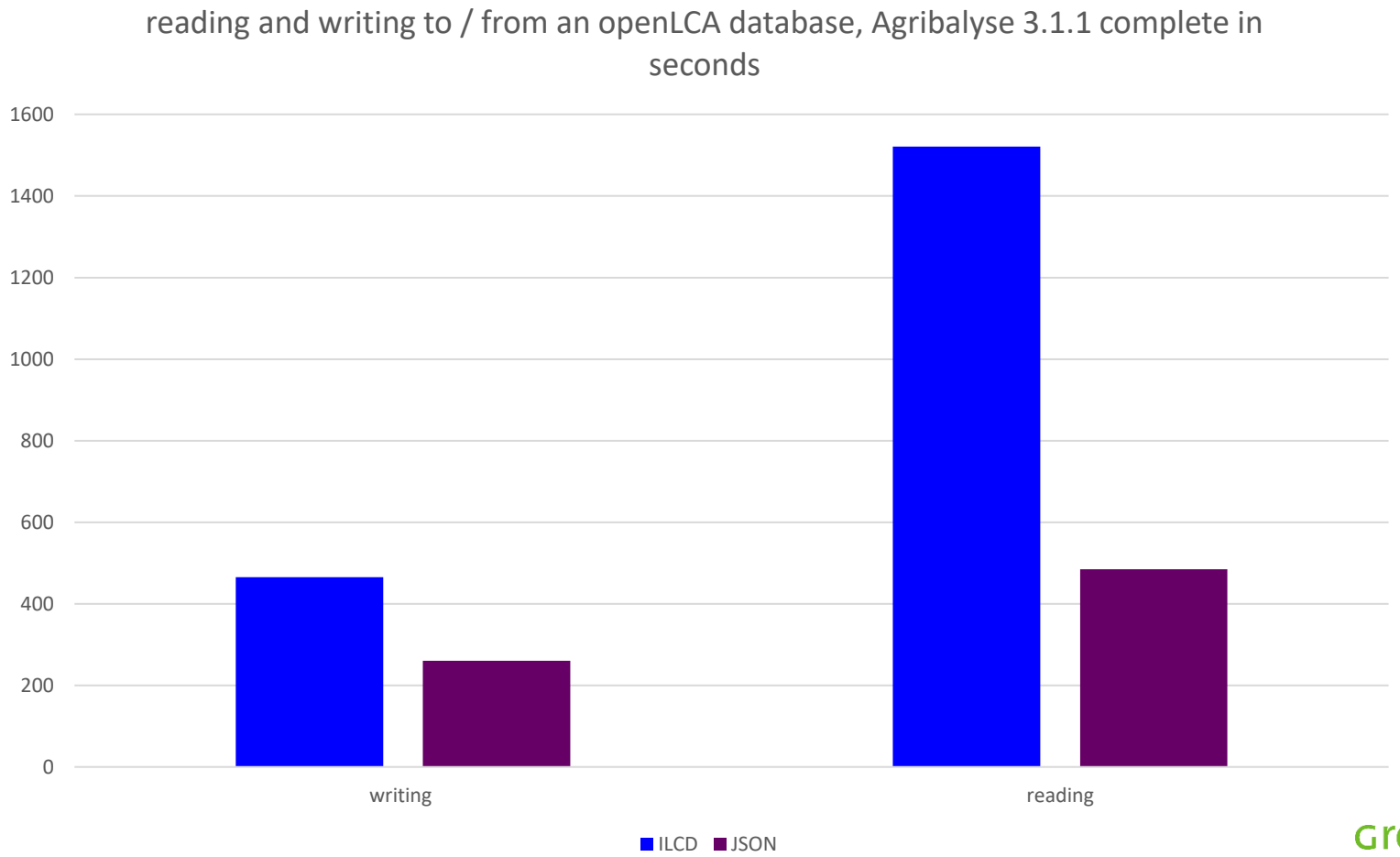

Source: Eurostat - nasa_10_nf_tr



eurostat

# Continuous use of old, slow technology because it was once decided

## ILCD vs JSON data format






GreenDelta

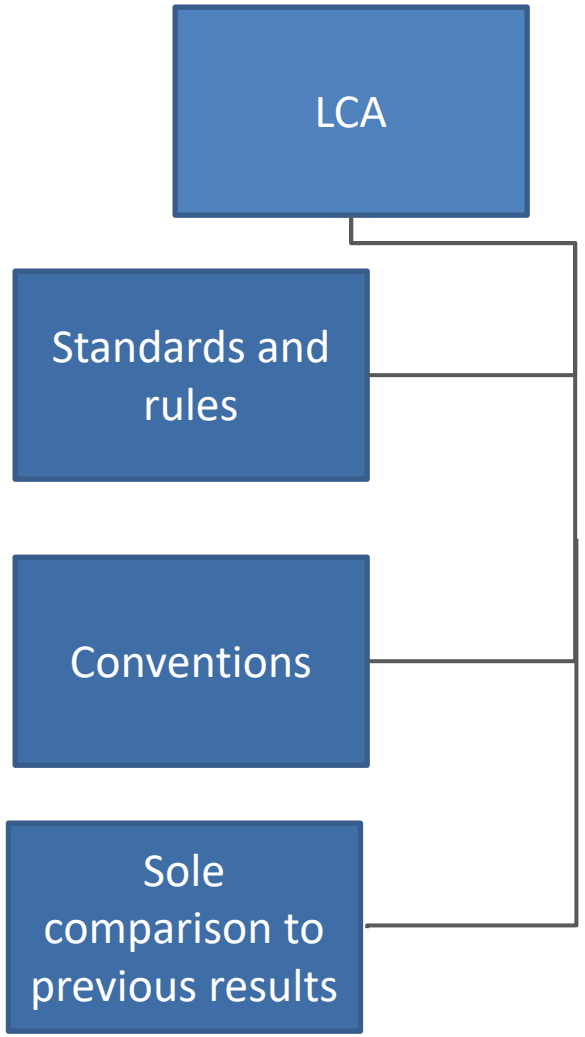
# So -

Point is not that LCA is not perfect (no method is perfect), but that existing disconnects to reality are not challenged.

Rather: we do this because this is how you do it.

This can lead to a self-referential, disconnected own world, which is not good.

# We need to avoid this




# Make LCA better reflect the real world – why exactly?

# So, why is it good if LCA models and results better reflect the real world?

1) a good representation of the real world is implicitly claimed already now for LCA results, e.g. when they are used in procurement, international trade, etc.;
   a better connection to reality makes LCA live up to this claim
2) decisions supported by LCA are better if the LCA is based on reality (more fair, more objective)

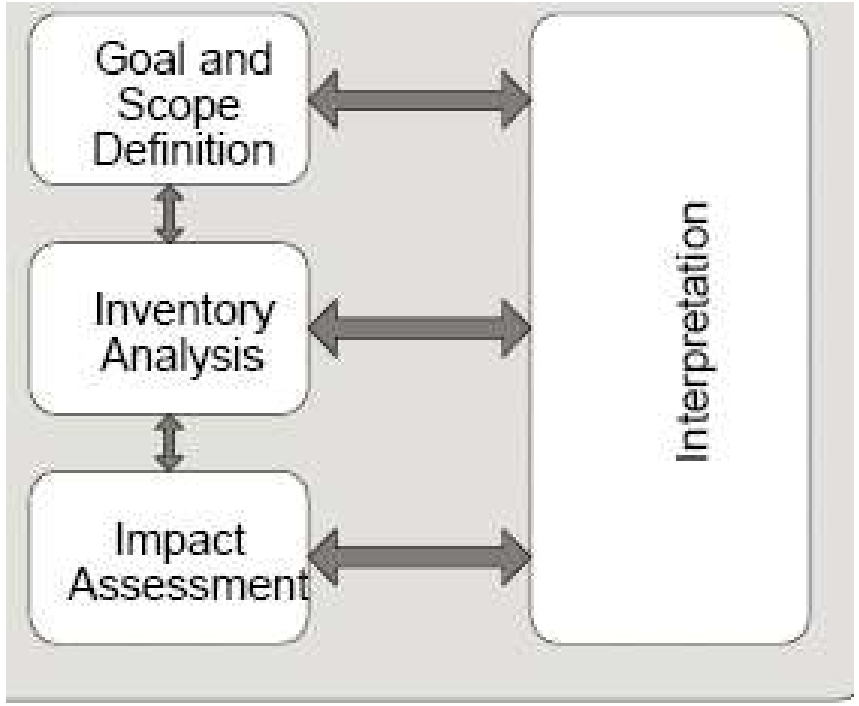
# So, why is it good if LCA models and results better reflect the real world?

3) When used in procurement and international trade, there is an implicit “race to the bottom” (everybody is trying to be lower than the competitors).
   An accepted system where 25% (infrastructure) and then from the 75% again 50% (BOM) is excluded will be very attractive -> this is responsibility for those who set rules.

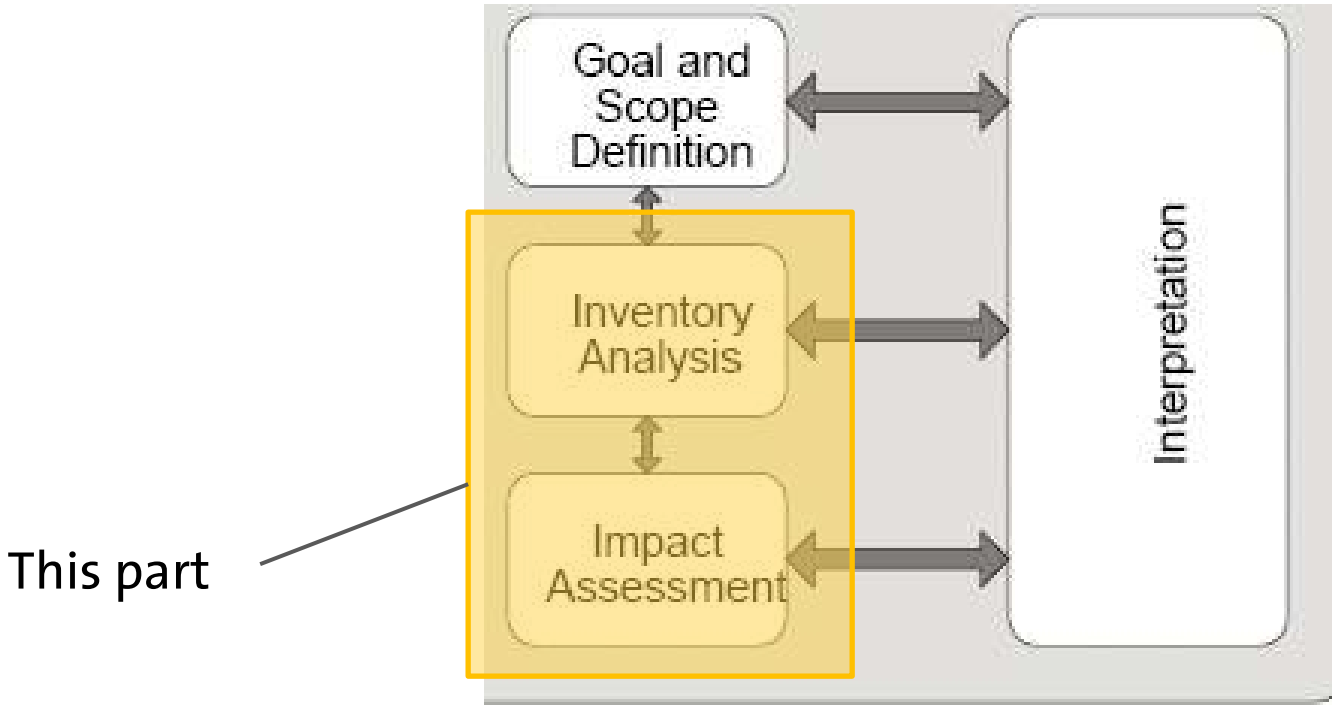
4) AI training is better with LCA models supported by real world data (!)

# How can LCA be more connected to reality?

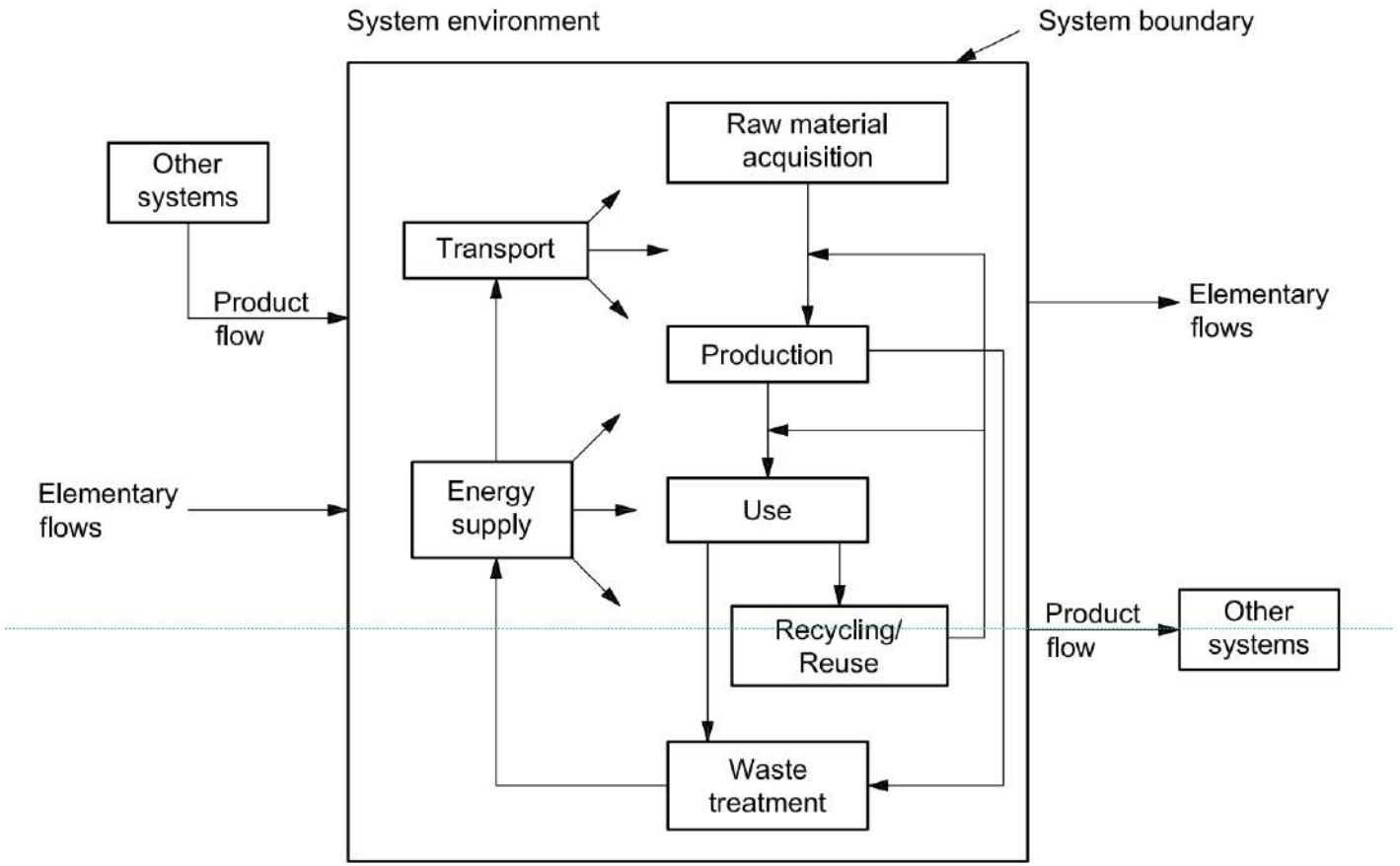
# How can LCA be better connected to the real world?



# How can LCA be better connected to the real world?



# How can LCA be better connected to the real world?



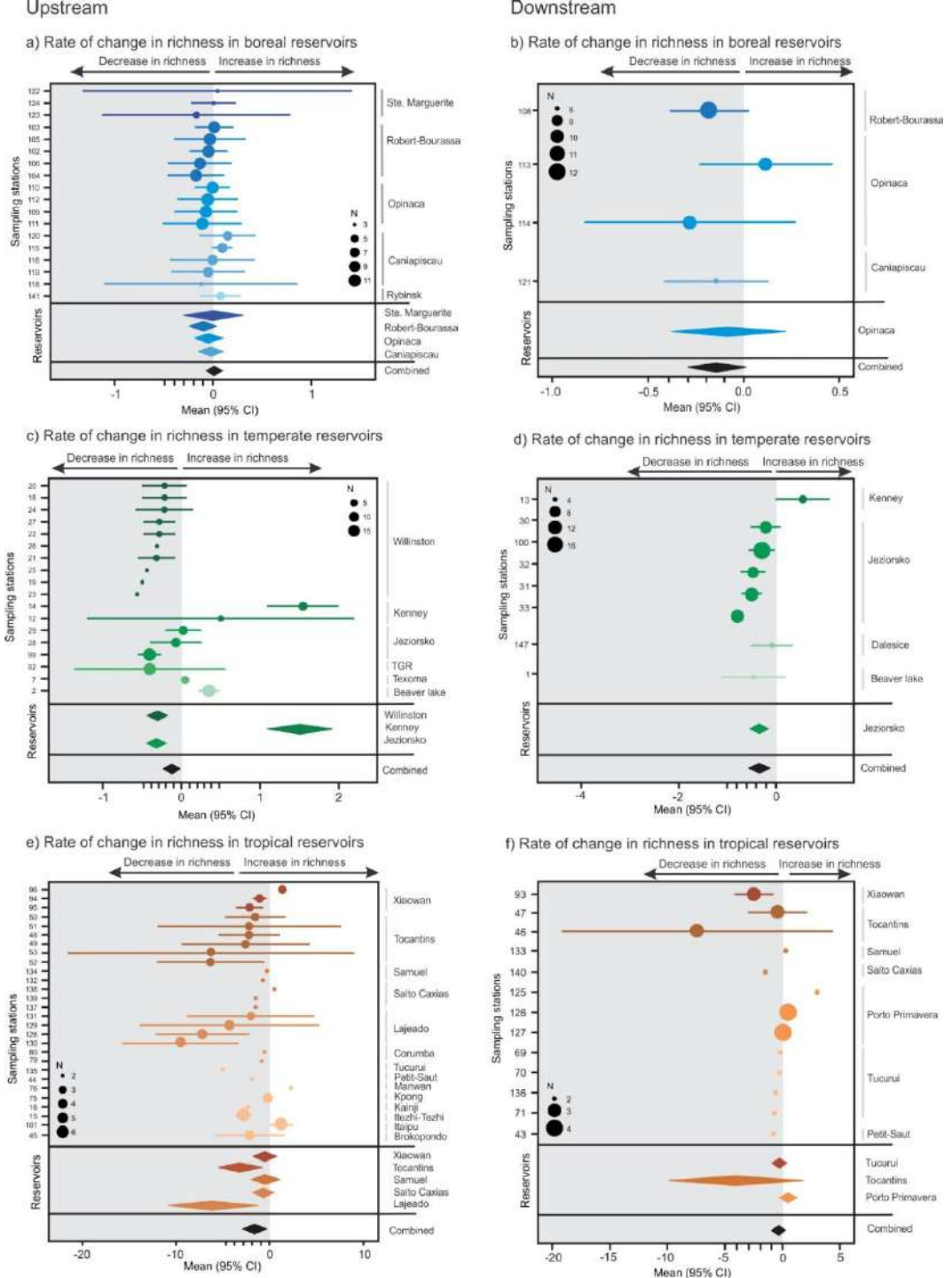

ISO 14040, fig. 2



GreenDelta

# How can LCA be better connected to the real world?

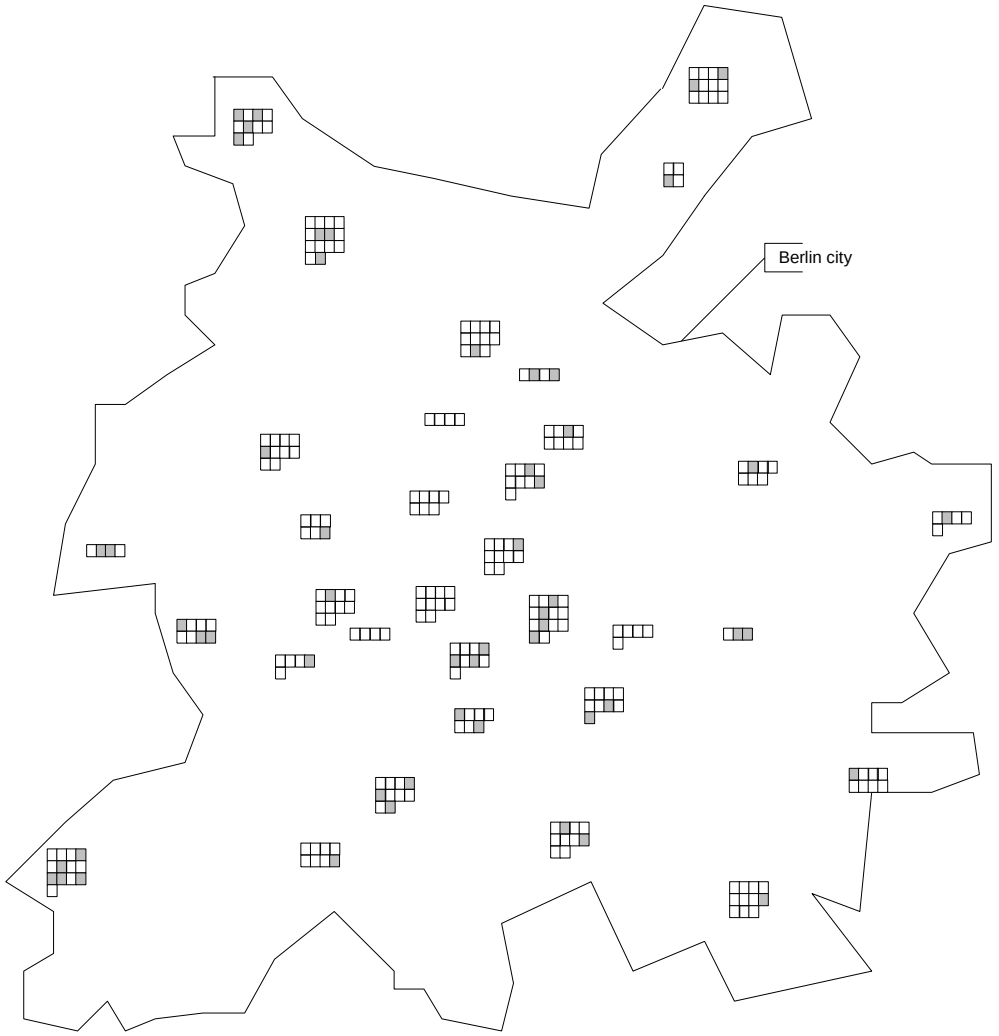
LCIA: several good examples, easier for climate change than for toxicity




Katrine Turgeon, Gabrielle Trottier, Christian Turpin, Cécile Bulle, Manuele Margni, Empirical characterization factors to be used in LCA and assessing the effects of hydropower on fish richness,
Ecological Indicators, Volume 121, 2021, 107047, ISSN 1470-160X,
https://doi.org/10.1016/j.ecolind.2020.107047.

# How can LCA be better connected to the real world?

LCI: Some developments (but not too well picked up):
1, empirical investigation of yoghurt cup weights in Berlin; statistical sampling



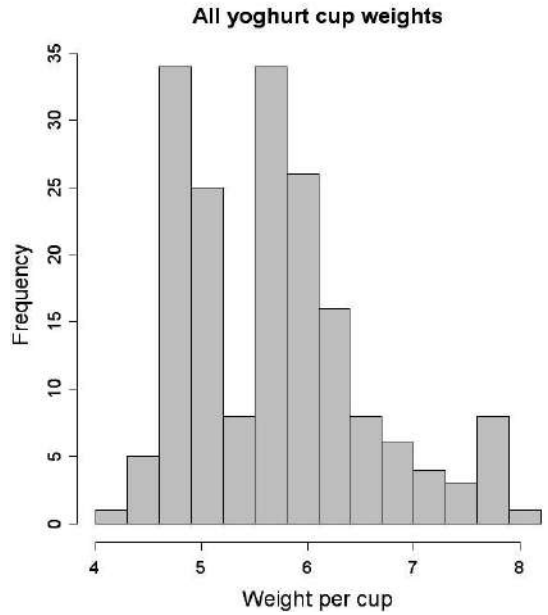

Ciroth, A., Srocka, M. (2008): How to Obtain a Precise and Representative Estimate for Parameters in LCA: A case study for the functional unit, in: The Int J of LCA 13 LCA (3) p. 265 – 277 (2008).

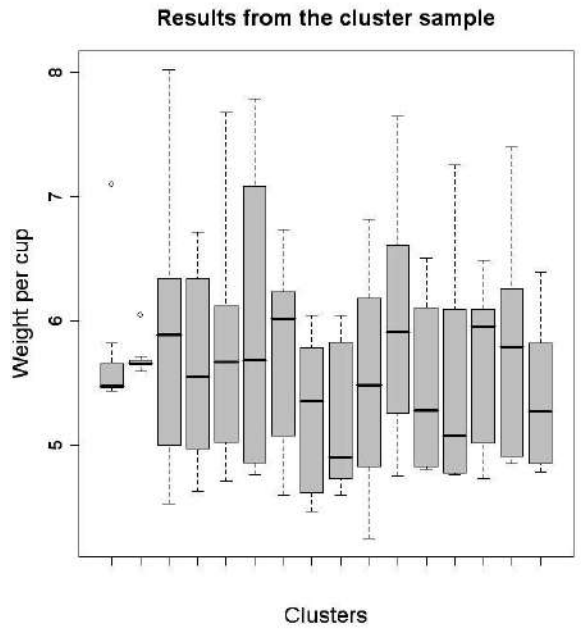
# How can LCA be better connected to the real world?

## Empirical investigation of yoghurt cup weights in Berlin:

-> fully representative sampling (!);

-> yoghurt cup weight can be obtained easily




Ciroth, A., Srocka, M. (2008): How to Obtain a Precise and Representative Estimate for Parameters in LCA: A case study for the functional unit, in: The Int J of LCA 13 LCA (3) p. 265 – 277 (2008).

# How can LCA be better connected to the real world?

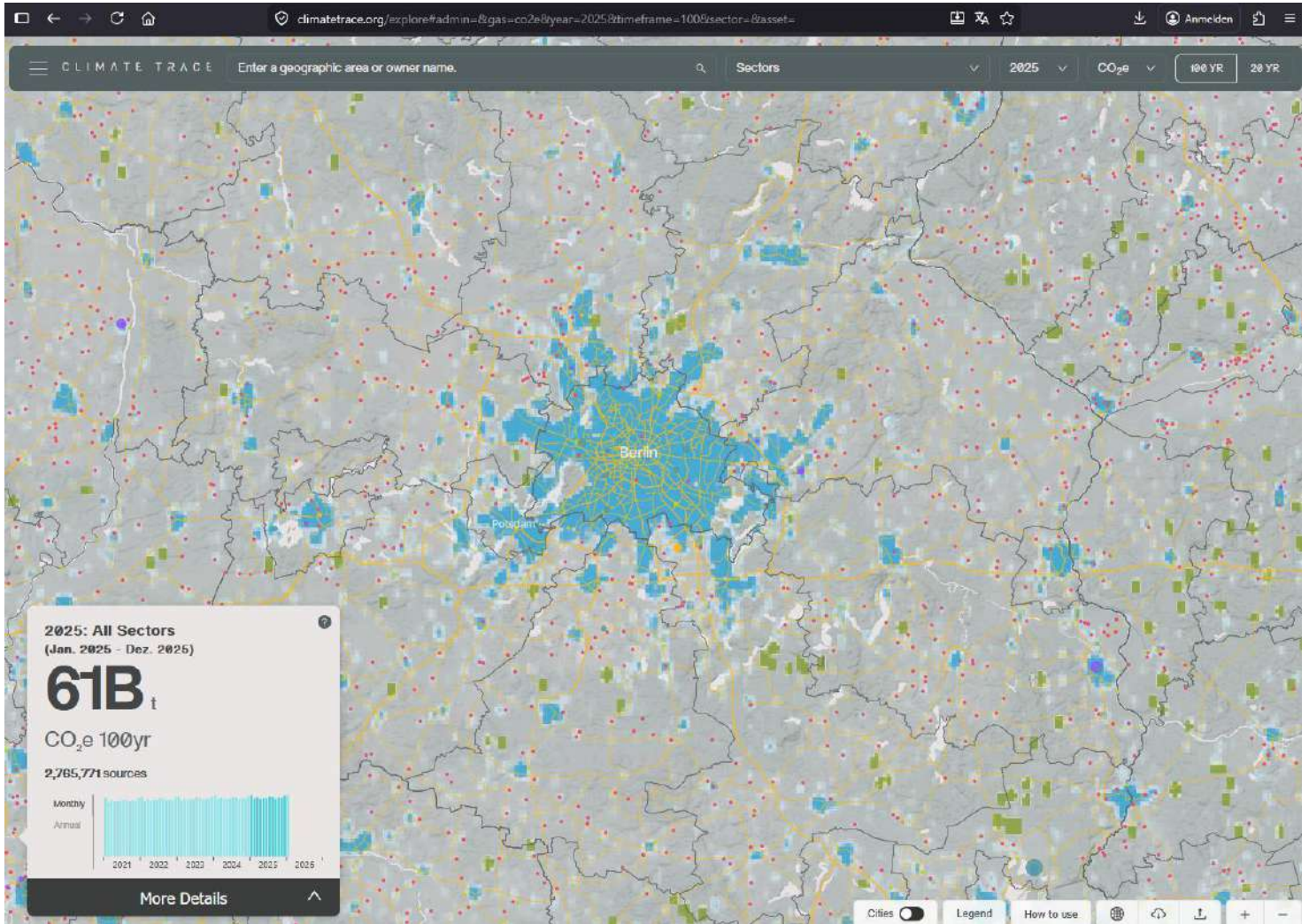
## New data sources

E.g., climate trace

# How can LCA be better connected to the real world?

## New data sources

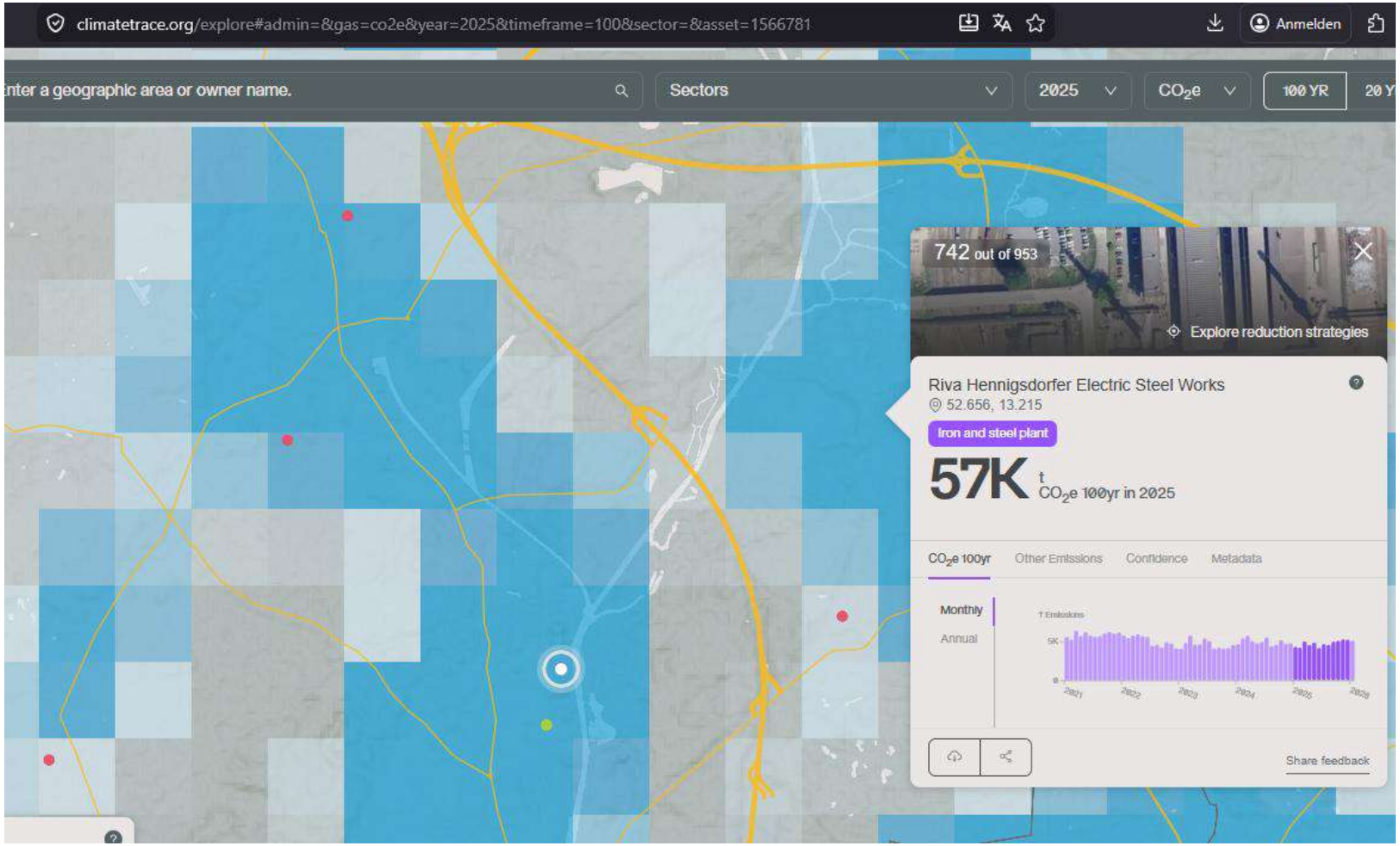
E.g., climate trace



# How can LCA be better connected to the real world?

## New data sources

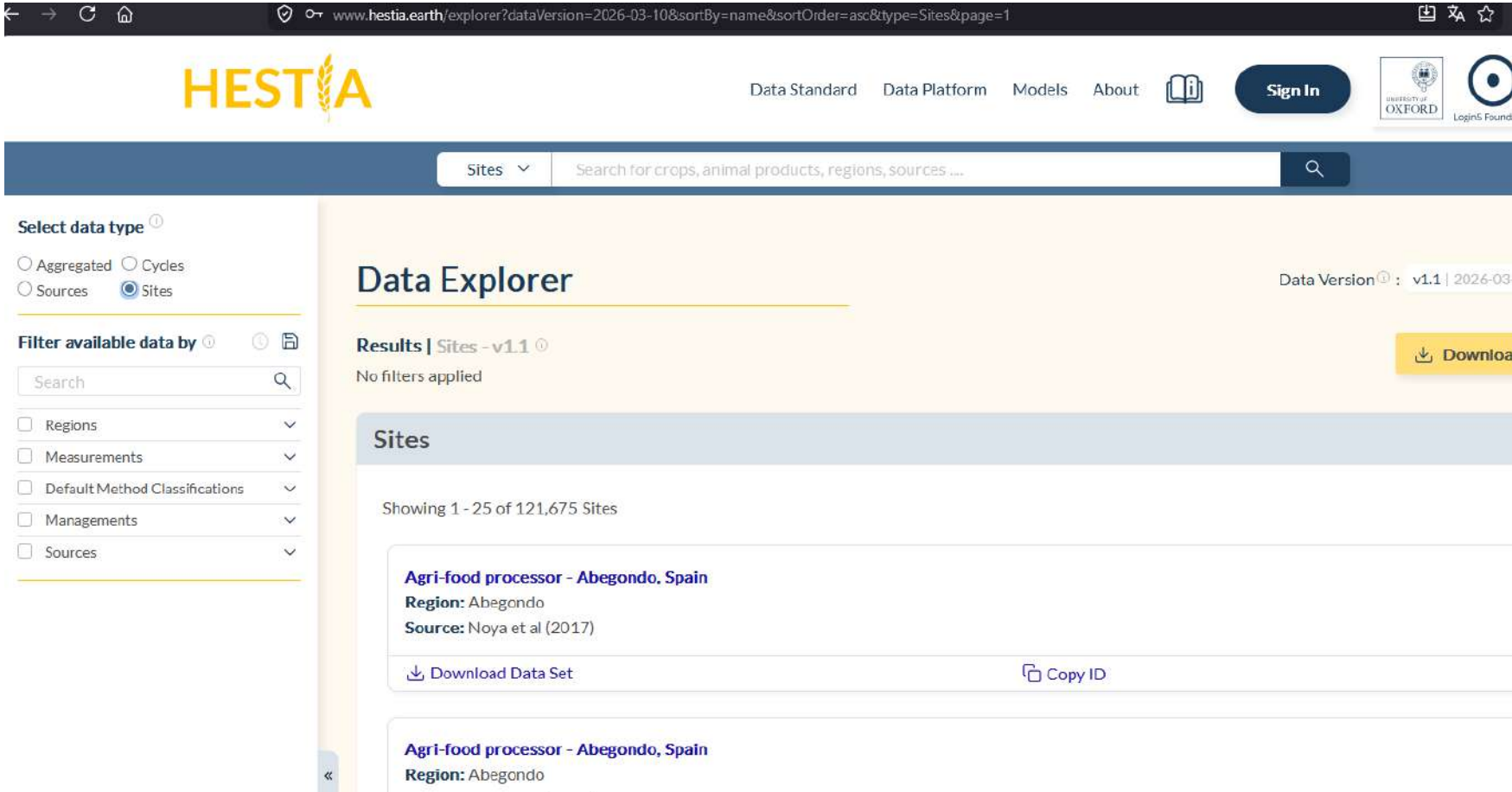
E.g., climate trace



# How can LCA be better connected to the real world?

## New data sources

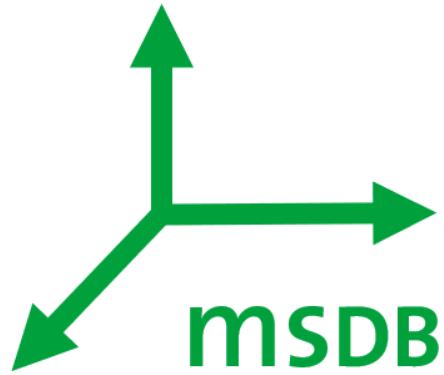
E.g., HESTIA



# How can LCA be better connected to the real world?

## Build a different database for LCA

(see
Data quality management in the MSDB database - what are good LCA datasets,
session T6.3 - Validating LCA Datasets
)



# How can LCA be better connected to the real world?

Recognise patterns and structures better, and extend LCA with system dynamics to better get a system view

System dynamics

LCA

# How can LCA be better connected to the real world?

## Keep LCA elements verifiable

## (key characteristics

| # | Characteristic | |
|---|---|---|
| 1 | Empirical & evidence-based | Science b observati |
| 2 | Systematic & logical reasoning | The work observati deductior inductive |
| 3 | Testability & falsifiability | A scientif can be pr not scient |

# How can LCA be better connected to the real world?

## Keep LCA elements verifiable

- System processes are not really verifiable; we need to believe the review
- LCIA results are even less verifiable, directly (but for EPDs, an elaborate verification process has been developed)
- Unit processes are easier verifiable, but an external verification is not often done in my view

# So, conclusions

# LCA and reality

## With increased possibilities, and increased importance of LCA results, it is time to challenge LCA and ourselves as LCA community

1) We need to be awake and prepared to question established things in LCA: method, technologies we use
2) It is time to become creative, to think again, to exchange, and to discuss
3) And let's be constructive ("konstruktives Misstrauensvotum") – propose something better, and demonstrate that it works.

→ Welcome to the 3rd openLCA conference!

GreenDelta
sustainability consulting + software

# LCA and reality

thank you!

Dr. Andreas Ciroth
GreenDelta GmbH