TRANS
PHARM

Steering towards sustainable pharmaceutical manufacturing - *Applying a life cycle thinking approach*

Public symposium - Espoo, Finland

11/09/2026

Funded by the European Union

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Dr. Lieselot Boone; Postdoctoral researcher; Ghent University

POLLUTION | CRISIS - POLLUTION CRISES

An Invisible Crisis: The Hidden Environmental Impact of Pharmaceutical Waste

BY TANUSRI SARADHI | GLOBAL COMMONS | MAR 17TH 2026 | 6 MINS

DONATE EARTH.ORG IS POWERED BY OVER 150 CONTRIBUTING WRITERS

Product Carbon Footprint (PCF) will be a market access requirement (2028)

WHO calls for transformative action towards a greener future in pharmaceutical manufacturing and distribution

23 December 2024 | Departmental update |Reading time: 2 min (467 words)

Modern medicine has transformed global health, but its
overlooked. Around the world, traces of pharmaceutical
waterbodies including rivers, lakes, and groundwater, re
pollution.

Greener Pharmaceuticals: WHO's call for innovative regulatory practices and eco-friendly innovations

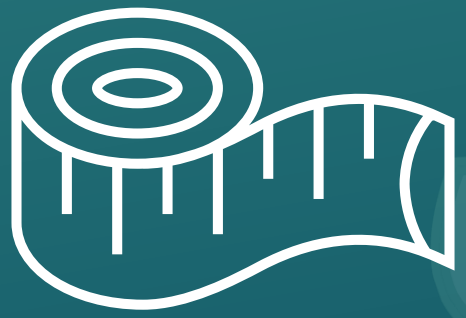
HOME/PHARMA NEWS | Posted 15/01/2025 0 Post your comment

The World Health Organization (WHO) has launched the 'Greener Pharmaceuticals' Regulatory Highway' initiative to promote sustainability in the pharmaceutical sector. The initiative calls for innovative regulatory practices, sustainable manufacturing, and eco-friendly innovations to reduce the environmental impact of healthcare products.

Drugmakers take Brussels to court, warn new EU rules could drive some treatment costs up 25-fold

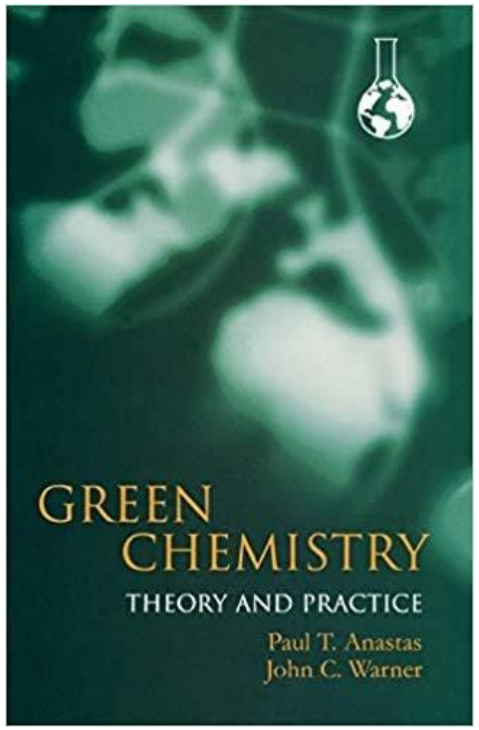
29. 04. 2026 POPULATION HEALTH

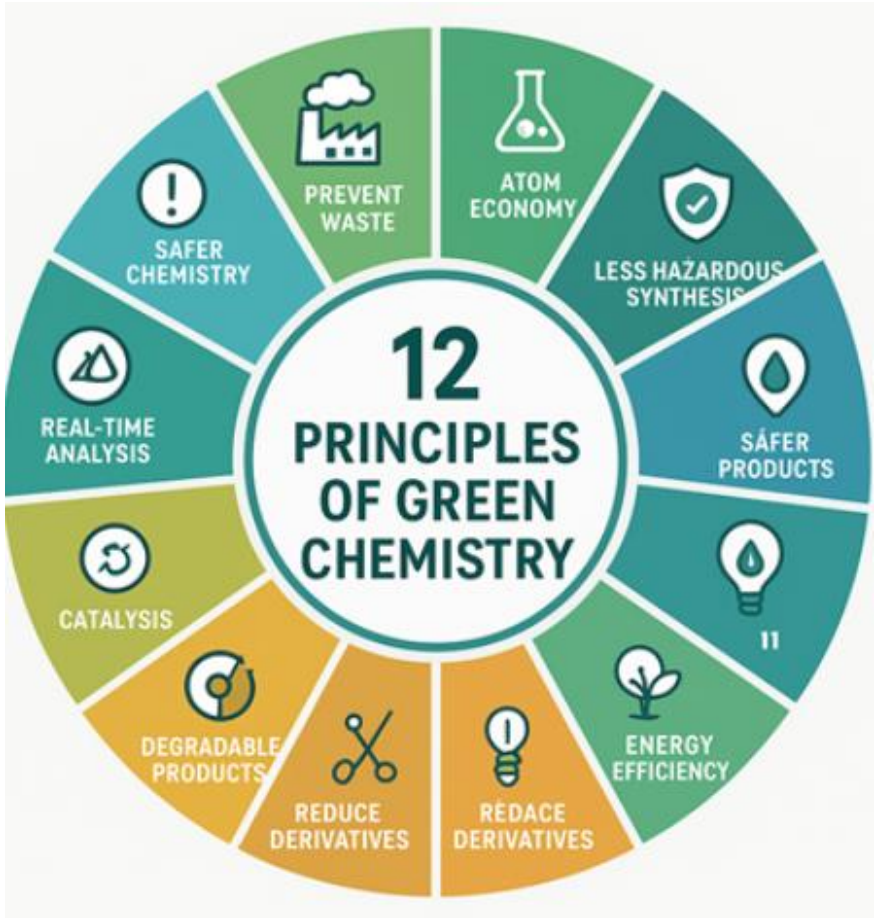
Measuring sustainability



Green chemistry principles

Paul T. Anastas and John Warner
“12 Principles of Green Chemistry” (1998)





Bhardwaj et al. (2025)
10.5281/zenodo.17275894

From principles to measuring

Green chemistry metrics

Atom Economy (AE)	•Molecular weight of the product divided by the sum of the molecular weights of the reactants involved in the reaction
Carbon Efficiency (CE)	•Carbon percentage from the reagent that remains in the final product
Eco scale	•Based on a 100-point system that considers time, safety, price, set-up, temperature, workup and purification of the reaction.
Effective Mass Yield (EMY)	•Considers mass of the product compared to the toxic and hazardous reagents used
Environmental factor (E-factor)	•The mass ratio of waste to the desired product
Process Mass Intensity (PMI)	•Ratio of total mass used in the process to the mass of the product
Reaction Mass Efficiency (RME)	•An inverse of E-factor that allows to identify the steps of the process that impact the score

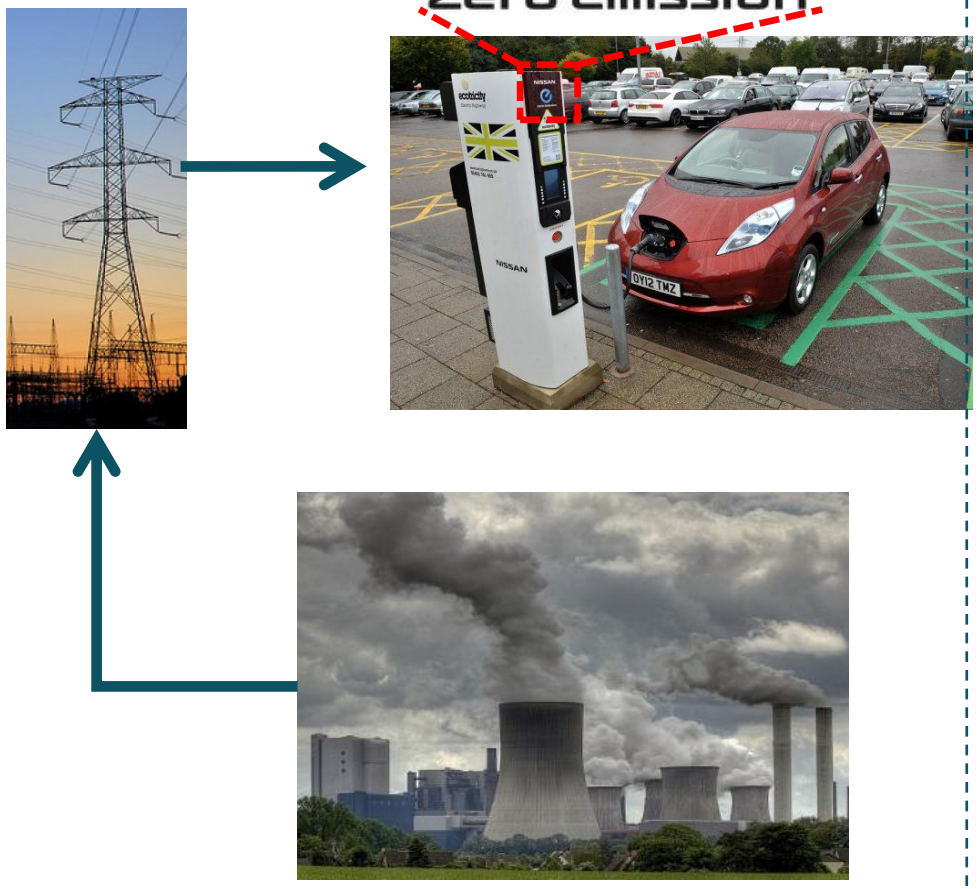
iGAL 2.0
green chemistry principles + life cycle thinking

Sequeira et al. (2022)
10.3390/suschem1020010

Roschanger et al. (2022)
https://doi.org/10.1021/acssuschemeng.1c01940

Moving towards life cycle thinking

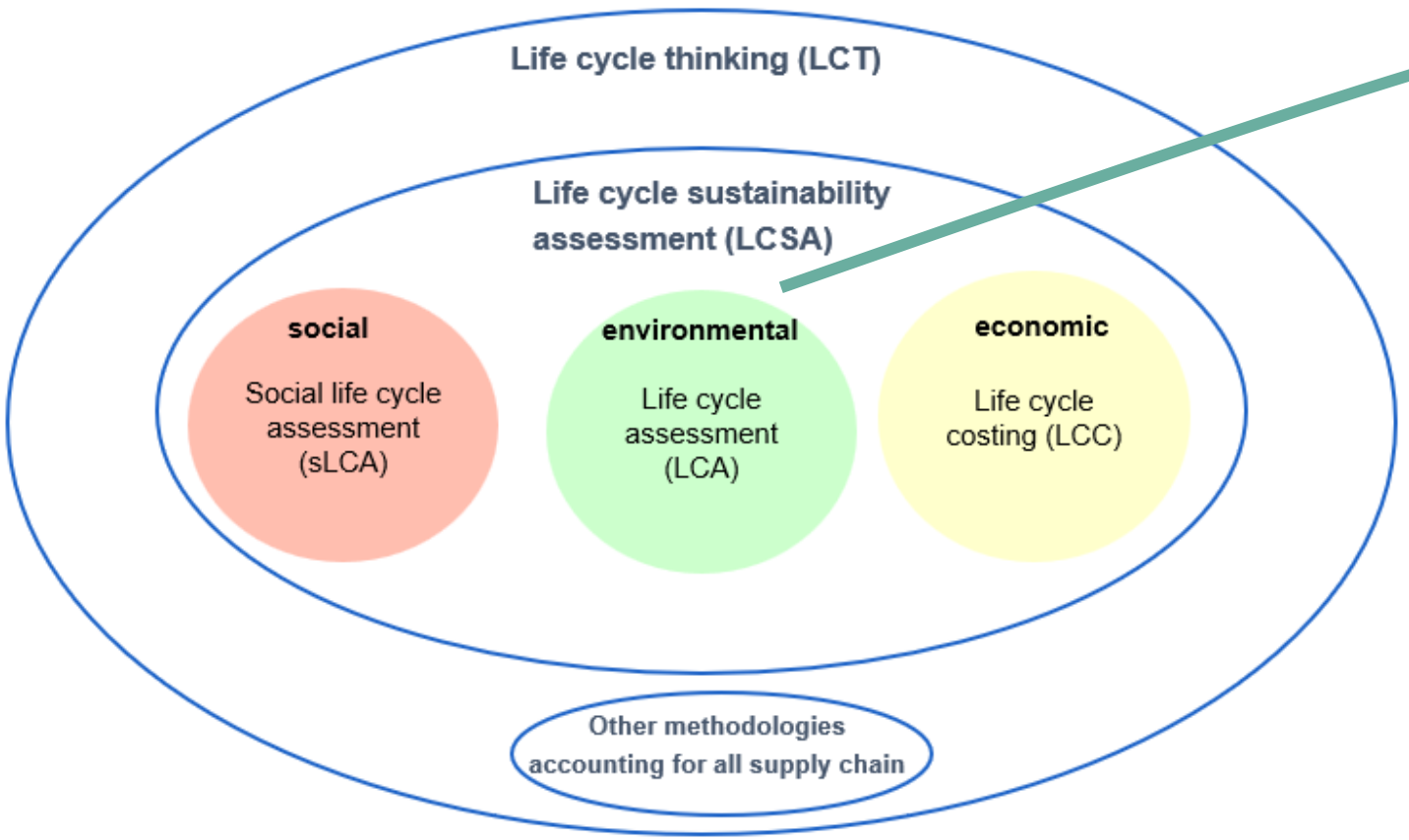
Life cycle thinking concept



vs.

- “Zero emission” only at certain life-cycle stage
- There are emissions happening elsewhere

Sustainability assessment toolbox



After Dewulf et al. (2016)

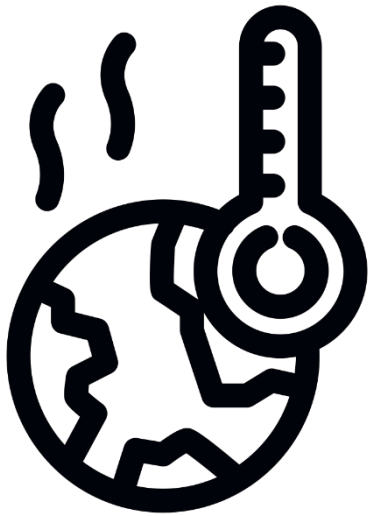
LCA is the most advanced tool and prominent to quantify environmental sustainability

- Standards
- Handbooks with guidance

Environmental sustainability assessment by LCA

LCA addresses the (potential) environmental impacts of a product or service throughout its lifecycle

For example:



Environmental sustainability assessment by LCA

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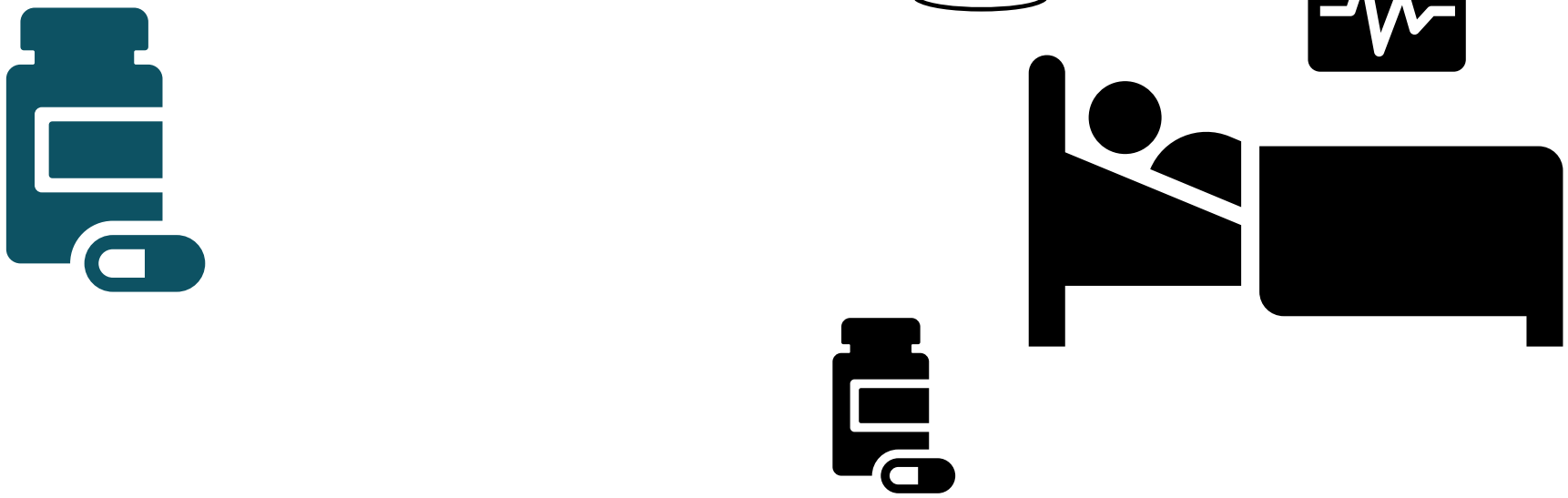


Environmental sustainability assessment by LCA

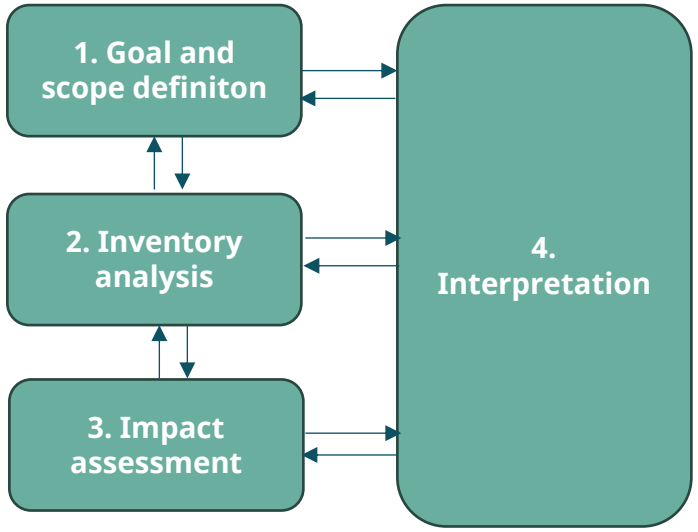
LCA addresses the (potential) environmental impacts of a product or service throughout its lifecycle

Source: Pré., 2020

Environmental sustainability assessment by LCA

LCA addresses the (potential) environmental impacts of a product or service throughout its lifecycle

ISO standards



Source: ISO 14040 (2009)

Life cycle assessment – key advantages

- ✓Quantitative, standardized assessment method
- ✓Can help to identify **hotspots** within the system under study
- ✓Considering of multiple impact categories and full life cycle to **avoid burden shifting**
- ✓Can help in **comparing** products / services

But...

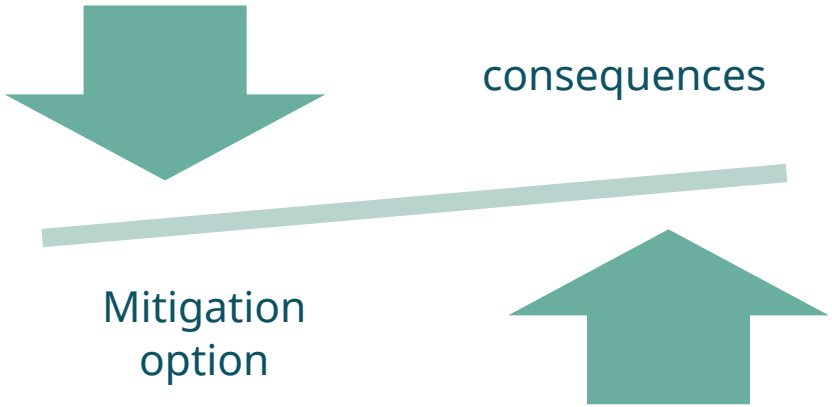
- Provides information for **decision-support** but not the final answer
- Cannot calculate impacts for topics for which numerical models do not exist (yet)
- Quantitative => a lot of **data** is needed
- **Prospective** assessment is important but challenging
- Many methodological choices affect the result so the need for **harmonization** is high

Some small steps forward

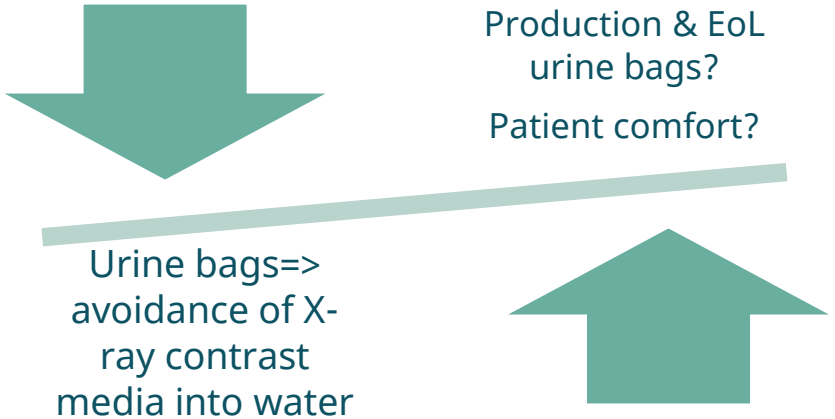
Making choices has implications

Eco-pharma dilemma: Navigating environmental sustainability trade-offs within the lifecycle of pharmaceuticals – A comment

Caroline T.A. Moermond [a,*], Neele Puhlmann [b], Lowik Pieters [c], Avtar Matharu [d], Lieselot Boone [e], Maarten Dobbelaere [f], Héloïse Proquin [a], Klaus Kümmerer [b], Ad M.J. Ragas [g], Rodrigo Vidaurre [h], Bastiaan Venhuis [i,1], Delphine De Smedt [j]

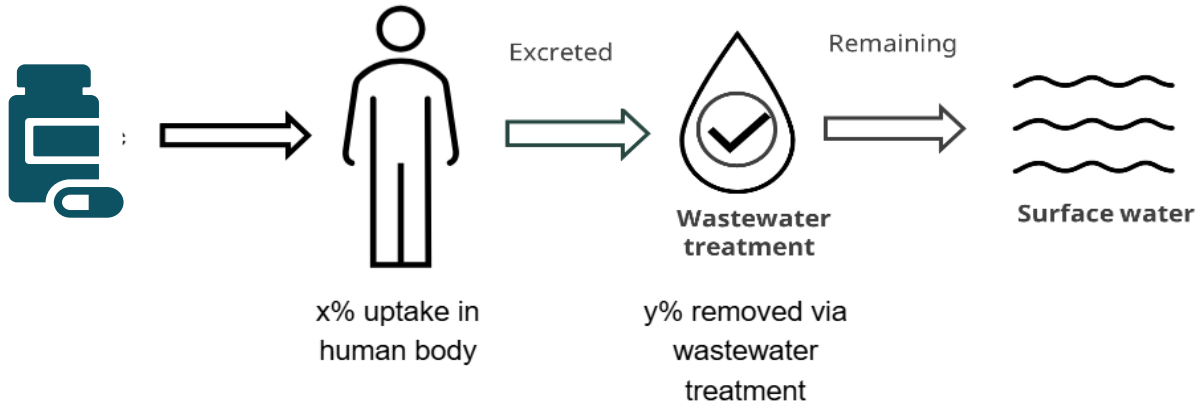


For example:



Moermond et al. (2024)
https://doi.org/10.1016/j.scp.2024.101893

Accounting for the impact of pharmaceuticals in the environment by LCA



Need for characterization factors to “translate” emissions into freshwater ecotoxicity impact

USEtox™

3104 chemicals

Only **67 pharmaceuticals**

New freshwater ecotoxicity characterization factors

The International Journal of Life Cycle Assessment (2026) 31:36
https://doi.org/10.1007/s11367-026-02574-8

LCI METHODOLOGY AND DATABASES

Characterization factors for freshwater ecotoxicity of pharmaceuticals

Tolga Ayeri[1] · Jiaqi Wang[1] · Rosalie van Zelm[1] · Ad M. J. Ragas[1]

Received: 8 September 2025 / Accepted: 22 January 2026 / Published online: 16 March 2026
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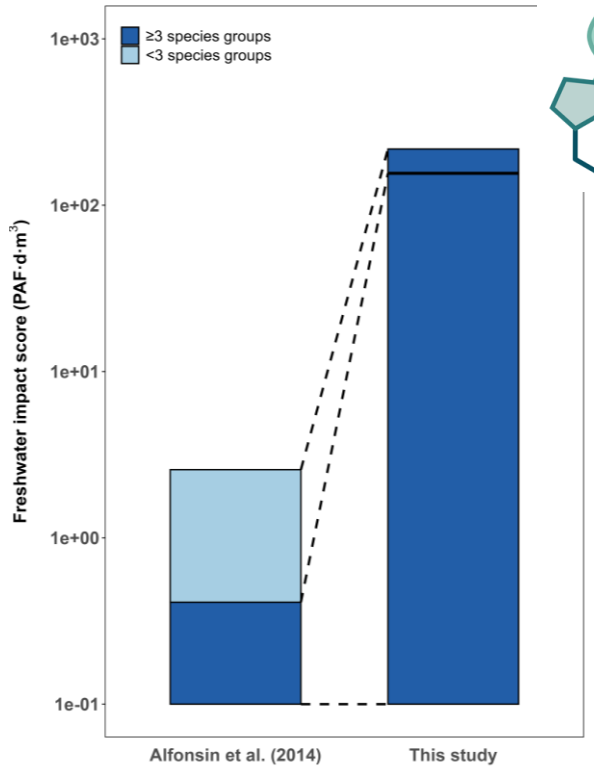


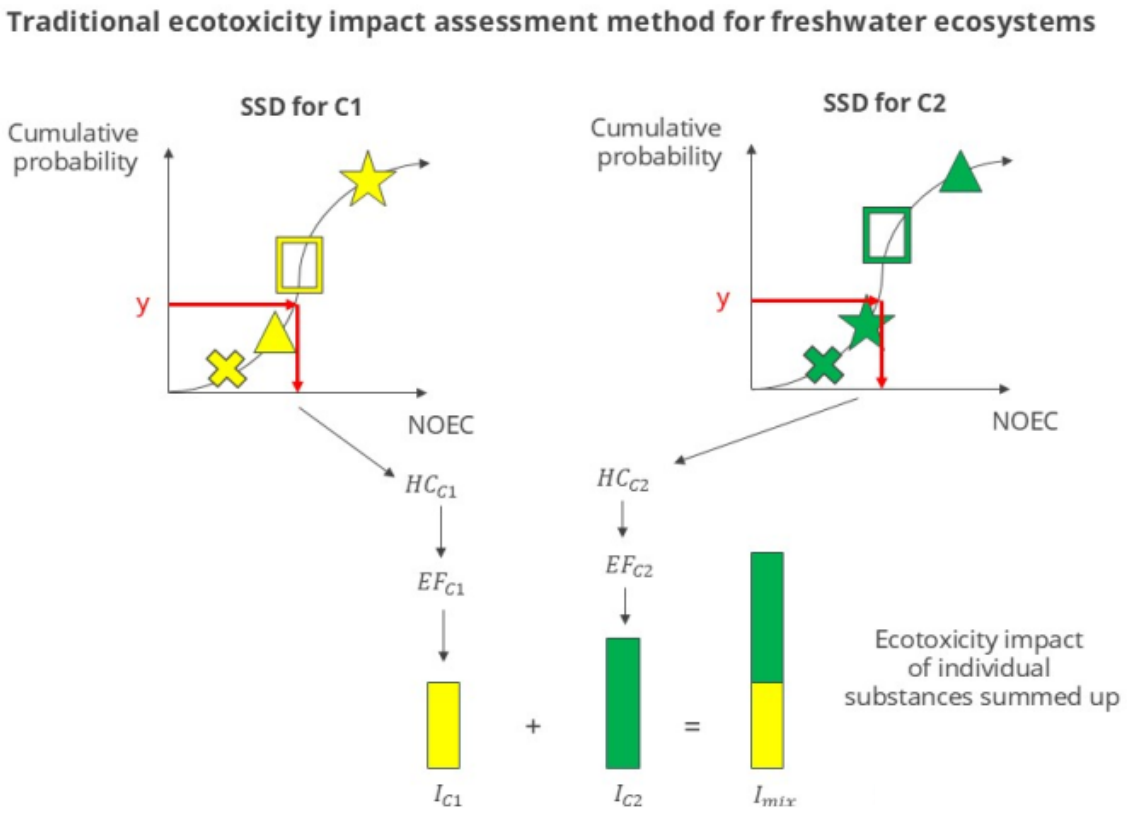
Characterization factors derived for **271 pharmaceuticals**

For 6 pharmaceuticals, the total impacts were **two orders of magnitude** higher!

Ayeri et al. (2026)
https://doi.org/10.1007/s11367-026-02574-8

There is more than 1 product in the environment

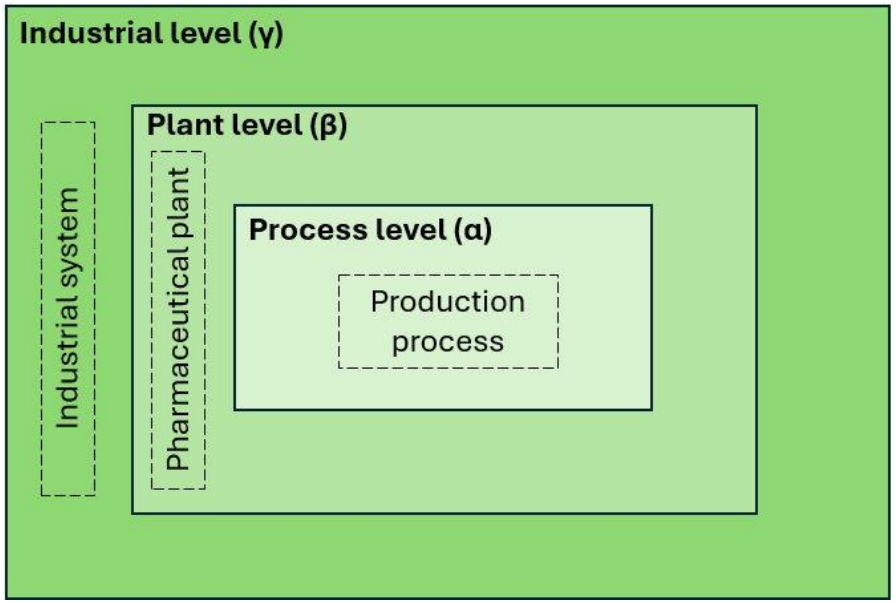
Need for methodology to consider the effect of chemical mixtures in the wastewater on freshwater ecotoxicity impact



- Binairy interactions
- Species impact distribution towards overall freshwater ecotxocity impact

Motte et al. (under review) - Improving the ecotoxicity impact assessment methodology for chemical mixtures: a case study on antibiotics

Data collection is challenging



α level - $LCI_α$
Product & Technology specific
(e.g., consumption of raw materials, reagents, catalysts, energy, water etc.)

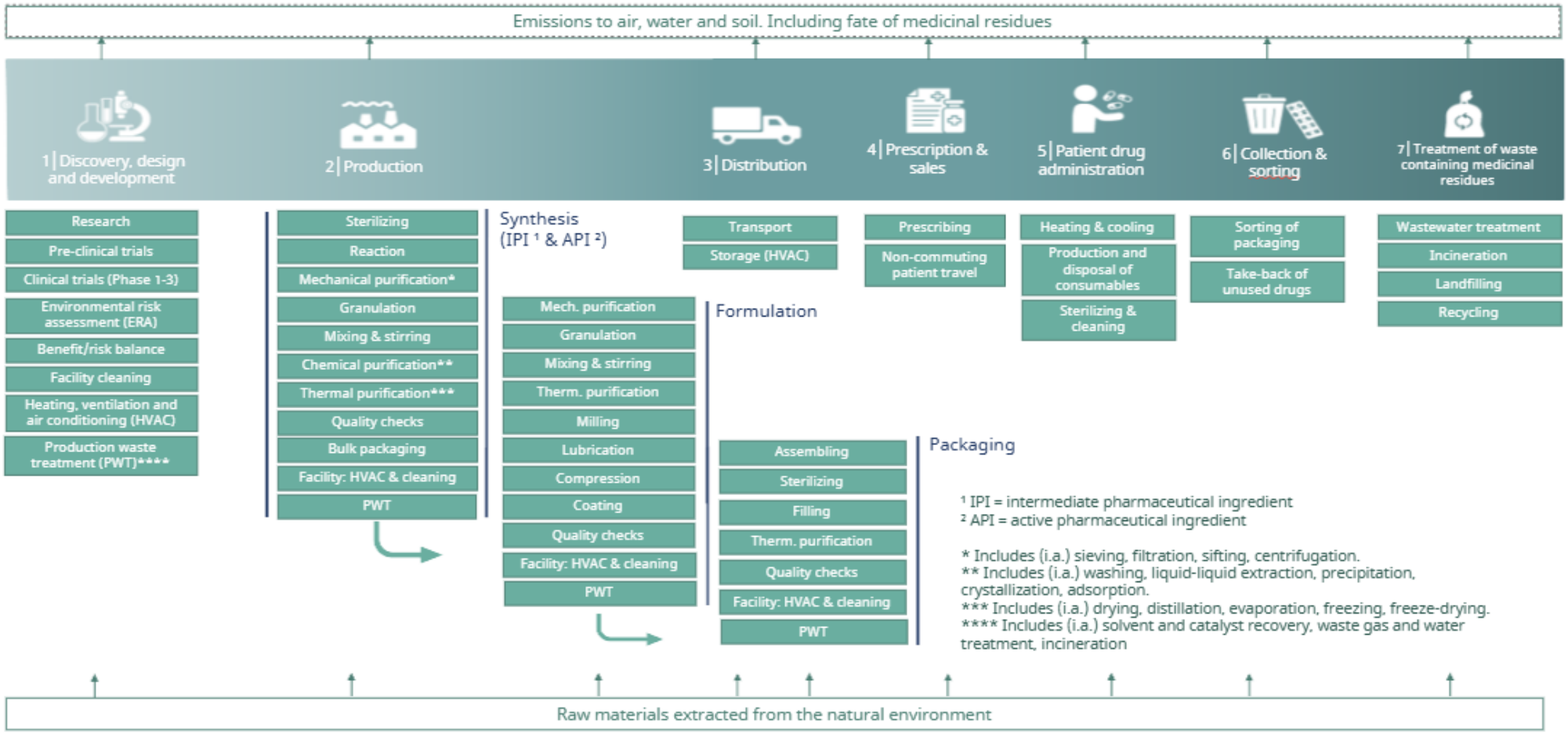
β level - $LCI_β$
Company or plant specific
(e.g., utilities production, on-site solvent recycling etc.)

ϒ level - $LCI_ϒ$
Location & time specific
(e.g., electricity production, material sourcing, waste treatment etc.)

- Data availability?
- Confidentiality?
- Using patent data: how to upscale?

Based on Van der Vorst et al. (2009)

LCA of pharma: data needs



- Include unit processes rather than exclude them
- report data quality

Pieters et al. (2025) Methodologies to fill LCI data gaps for prospective and retrospective assessments

Upscaling energy use from lab to industry scale: batch production

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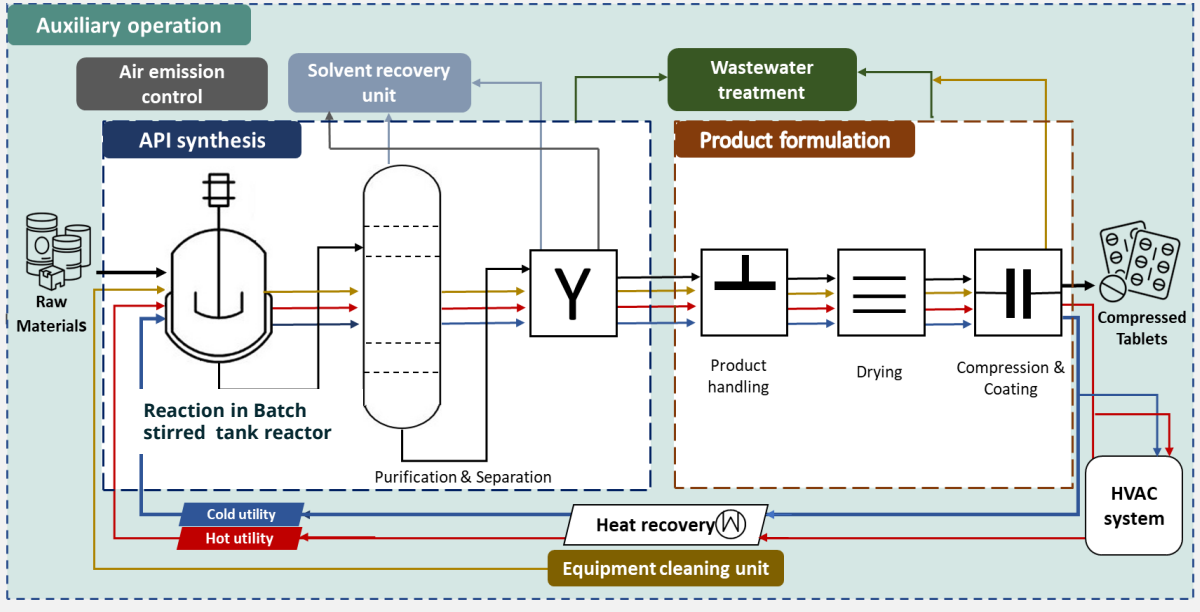
1. Data extraction → **2. Scaling up** → **3. LCI estimation**

Input

Accessible lab data



Guidelines

$E = k \cdot A \cdot \Delta T \cdot t_r$

Derived equations

Supporting tool

Output

Estimated energy use

ACS Sustainable Chemistry & Engineering
pubs.acs.org/journal/ascecg
Open Access
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Research Article

Closing Data Gaps for LCA of Pharmaceutical Production: Estimating Energy Usage by Upscaling Laboratory Data

Muhammed Ayaj Ansar,* Rosalie van Zelm, and Ad M. J. Ragas

Ansar et al. (2025)
https://doi.org/10.1021/acssuschemeng.5c04708

GreenSpeed tool: making use of available data within the company

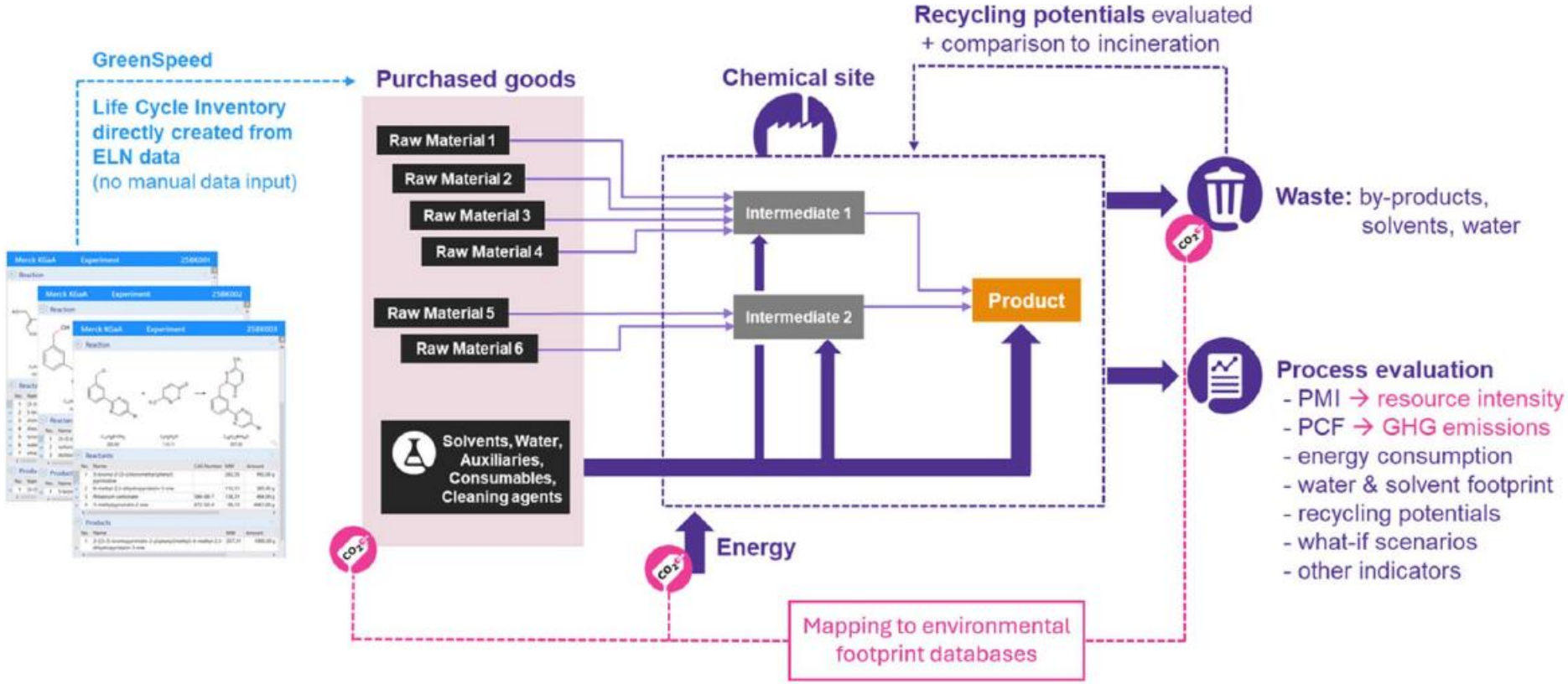


Fig. 1 Interconnectivity between GreenSpeed and ELNs, automated life cycle inventory creation and overview on the main three contributors used for calculating the PCF: purchased goods, energy, and waste treatment.

Dauth et al. (2026)
10.1039/d5su00636h

Need for harmonization: PAS2090

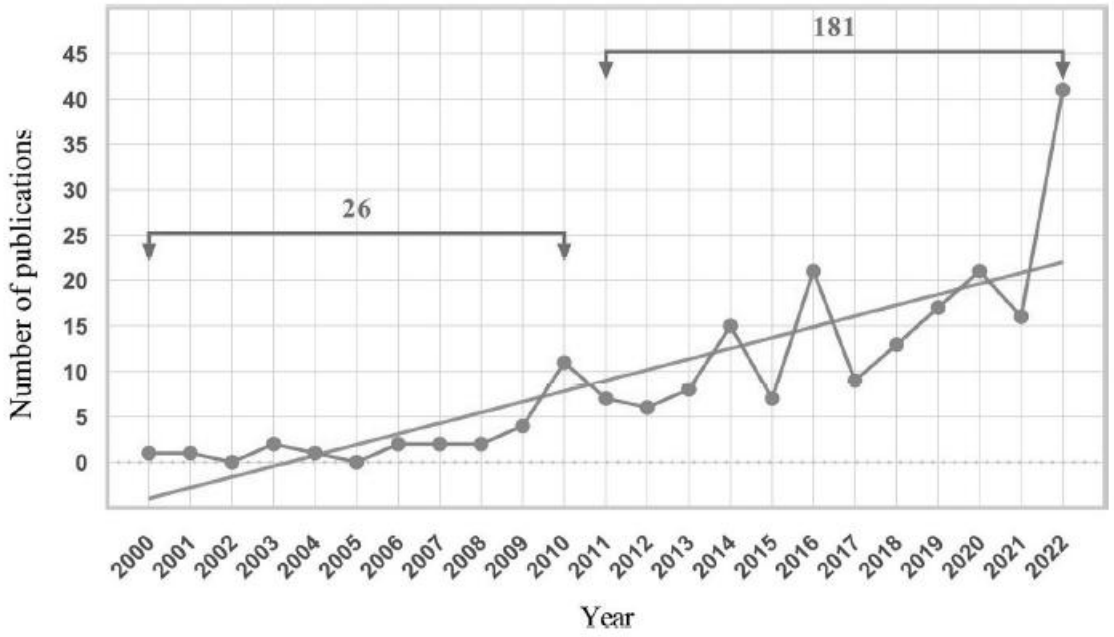
- Development of PAS 2090:2025 – Pharmaceutical Products: Product Category Rules

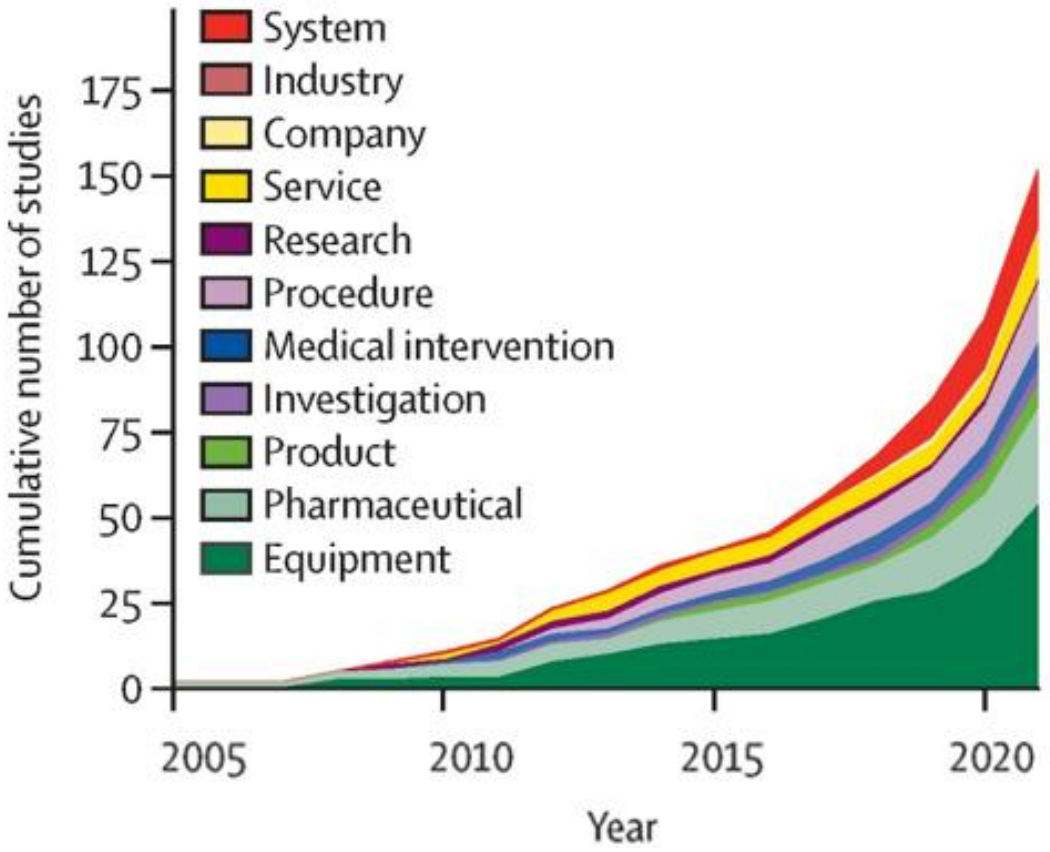
TECHNICAL GUIDANCE TO PAS 2090:2025 - VERSION 1.1

LCA in healthcare sector

Trends in pharma-LCA studies

Publications in pharma-LCA research

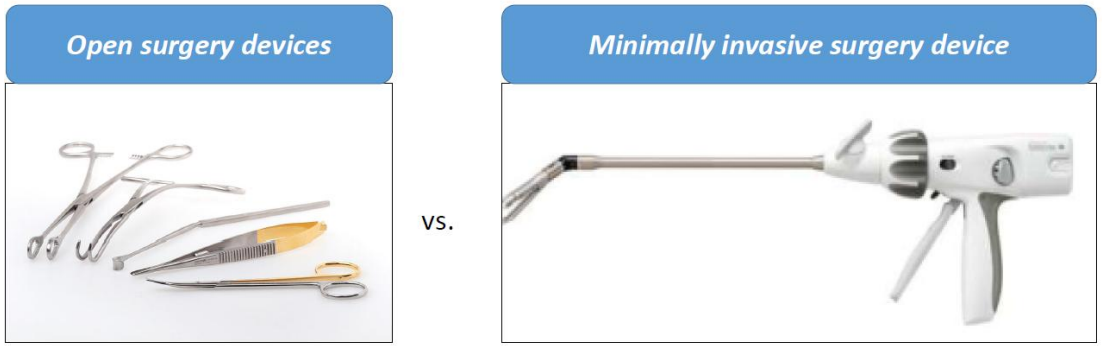


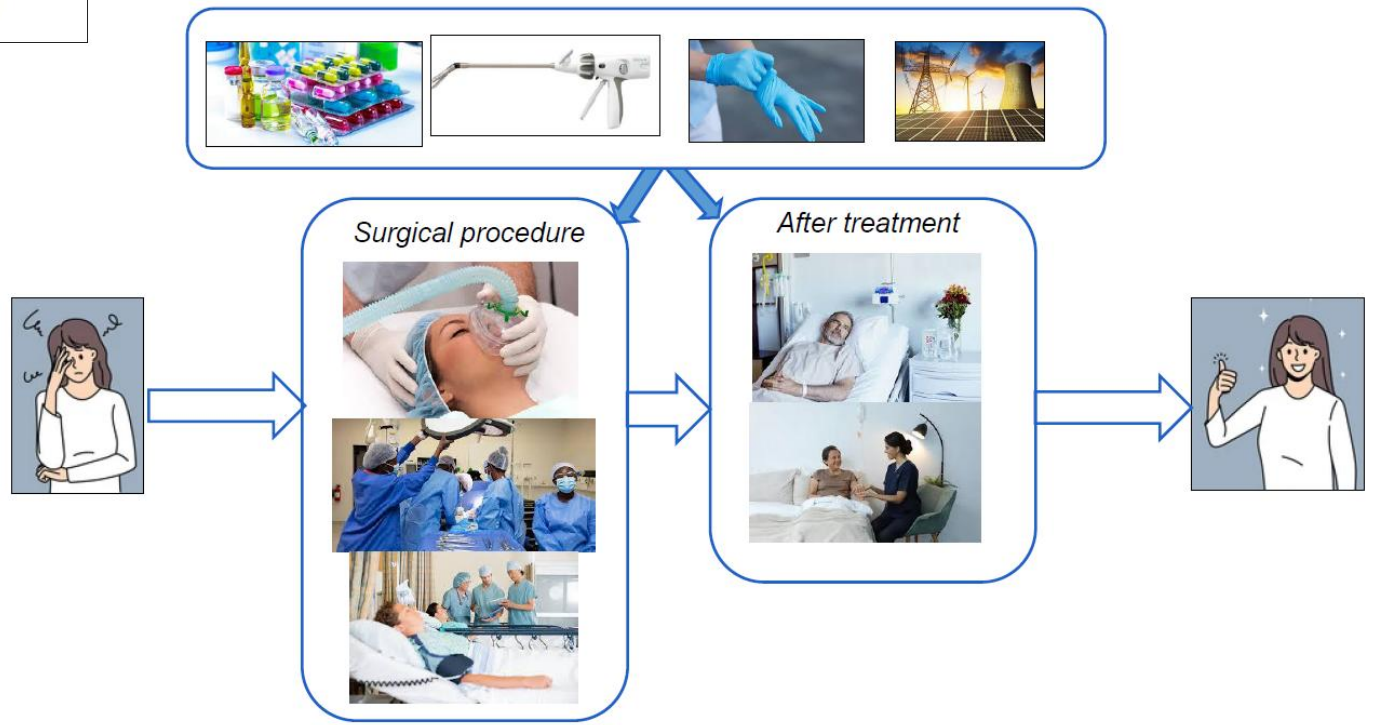


Sabour et al. (2023)
https://doi.org/10.1007/s13762-023-05103-4

Drew et al. (2022)
https://doi.org/10.1016/S2542-5196(22)00257-1

From product to system evaluation

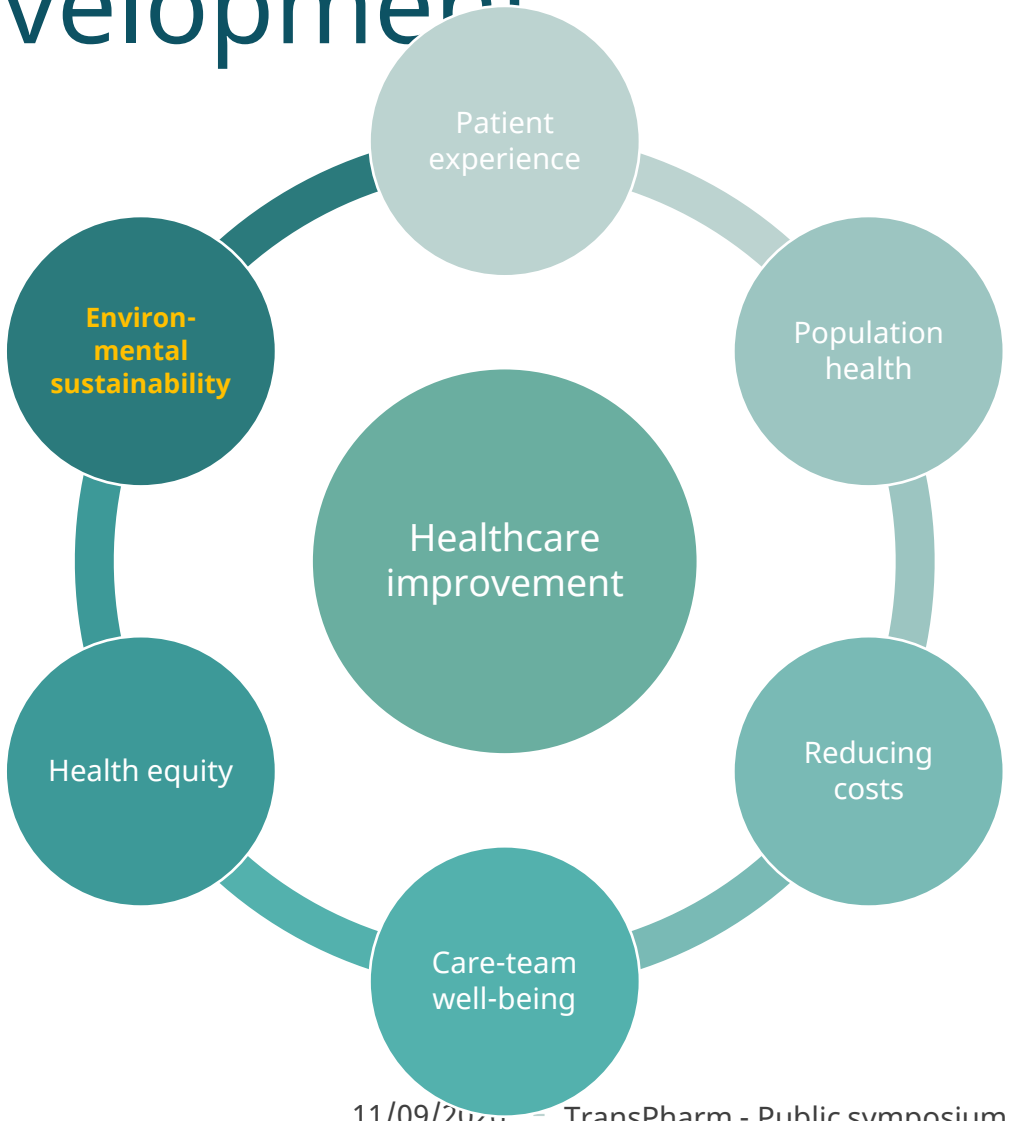




Digital Health in the Circular Economy

Muindi et al. (2025)
https://doi.org/10.1007/s11367-024-02415-6

LCA in healthcare: sustainable healthcare development



Sextuple aim

to care for patients, costs, providers, population equity and the planet

Based on Alami et al. (2023) 10.1002/hpm.3616

Beyond “only LCA”

- Linking LCA with health technology assessment (HTA)

ENGAGE WITH US / WORKING GROUPS AND TASK FORCES

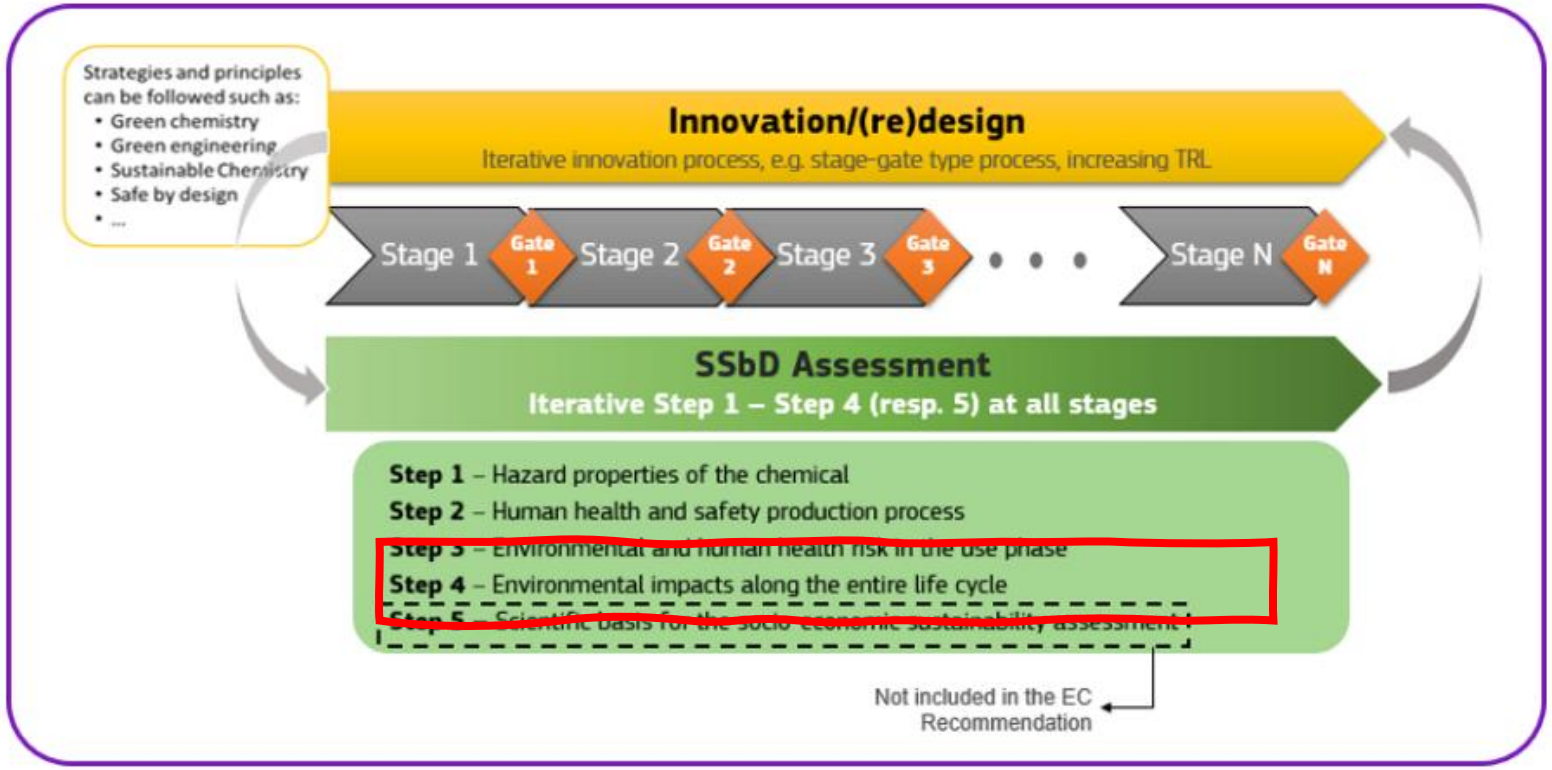
Environmental Sustainability in Health Technology Assessment (ESHTA) Working Group

Incorporating environmental sustainability into HTA is critical to support healthcare sustainable development. The definition of HTA emphasizes the inclusion of environmental aspects, however this domain is still not widely adopted globally.

https://htai.org/engage-with-us/working-groups/htai-eshta/

Beyond “only LCA”

- LCA as part of SSbD

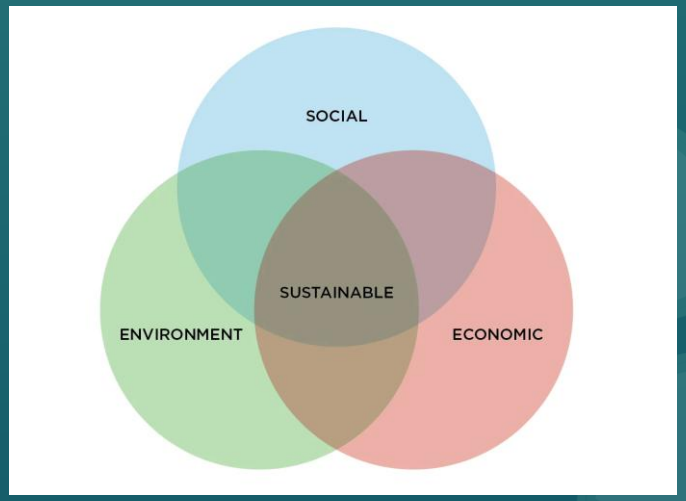


European Commission, Joint Research Centre, Caldeira, C., Farcal, R., Moretti, C. (2022). Safe and sustainable by design chemicals and materials: review of safety and sustainability dimensions, aspects, methods, indicators, and tools, https://data.europa.eu/doi/10.2760/879069

https://joint-research-centre.ec.europa.eu/jrc-news-and-updates/designing-safer-and-more-sustainable-chemicals-and-materials-methodological-guidance-2024-07-11_en

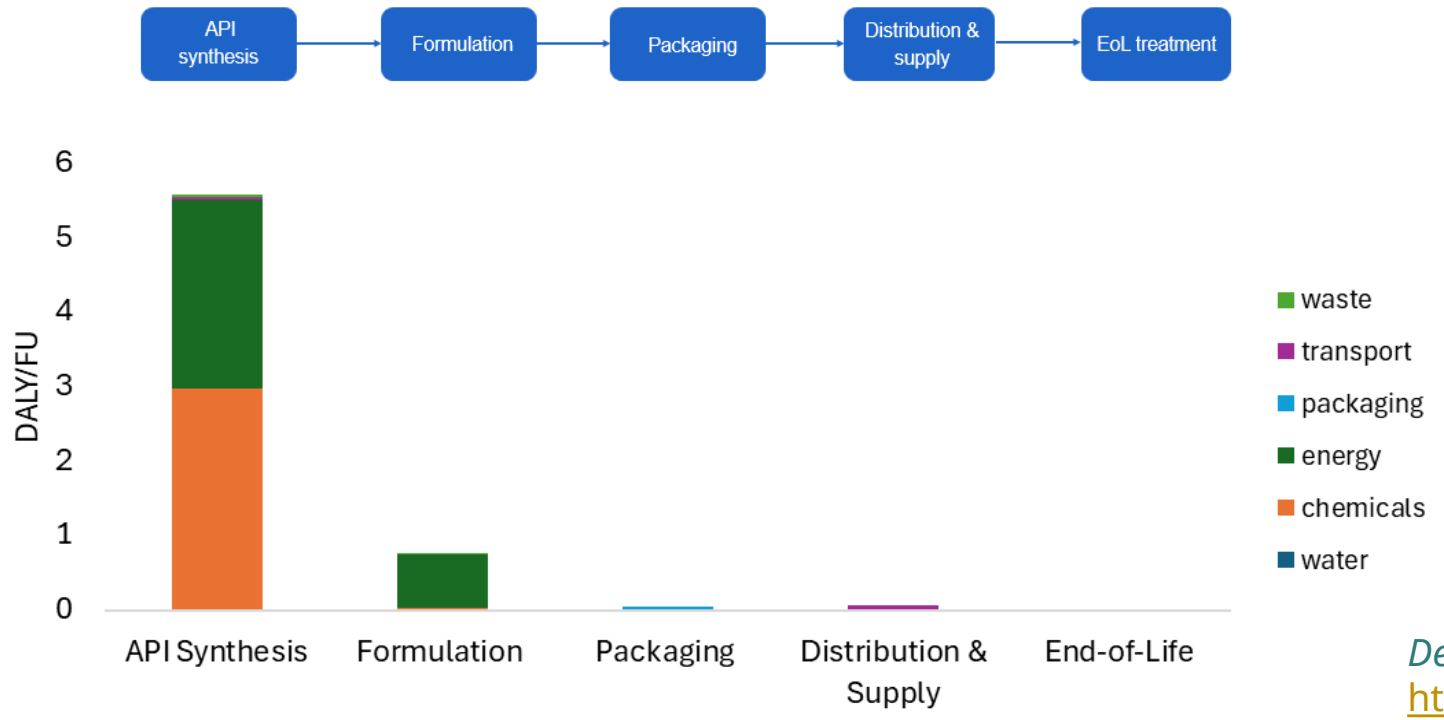
Sustainability of pharmaceuticals

Going beyond the environmental pillar



From environmental burdens (footprint)…

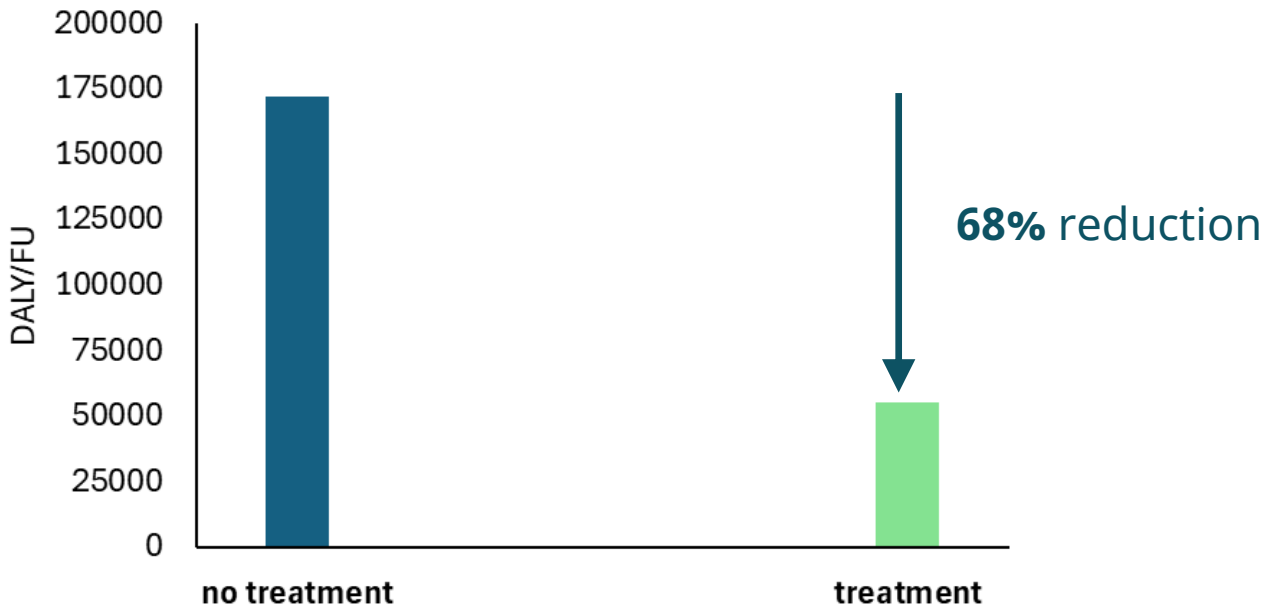
- WHO Program in Vietnam: worm infection treatment
- Treatment: 2 x per year - 8 M children for five years → 64 M tablets
- Results **footprint**: expressed in **DALYs** created by the environmental impact of the treatment
- FU: “the treatment with mebendazole 500 mg tablets every six months for five years of eight million children in Vietnam, aged 5–14, reaching 80% coverage”



Debaveye et al. (2018) - https://doi.org/10.1371/journal.pntd.0006954

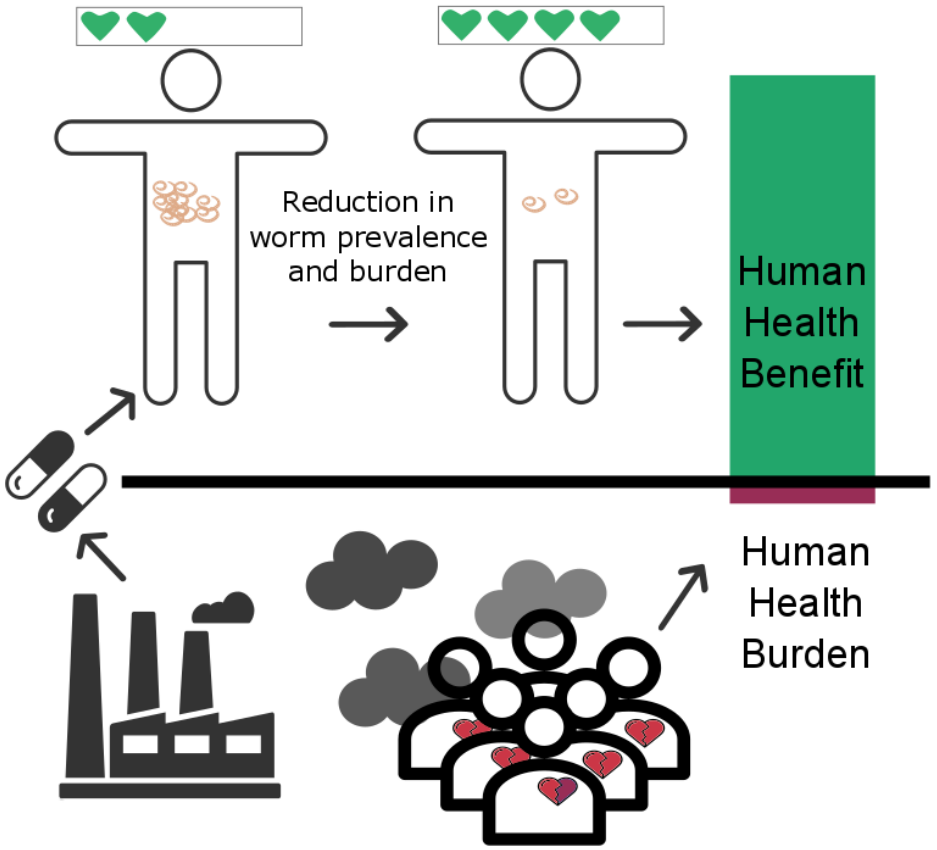
…to the benefits (handprint) of pharmaceuticals

- Comparison No Treatment ⇔ Treatment 2x/year in 8 M children for 5 years
- Calculating avoided DALYs (disability-adjusted life years)
- **Results handprint** expressed in **DALYs avoided** because of the treatment of the children



Debaveye et al. (2018) - https://doi.org/10.1371/journal.pntd.0006954

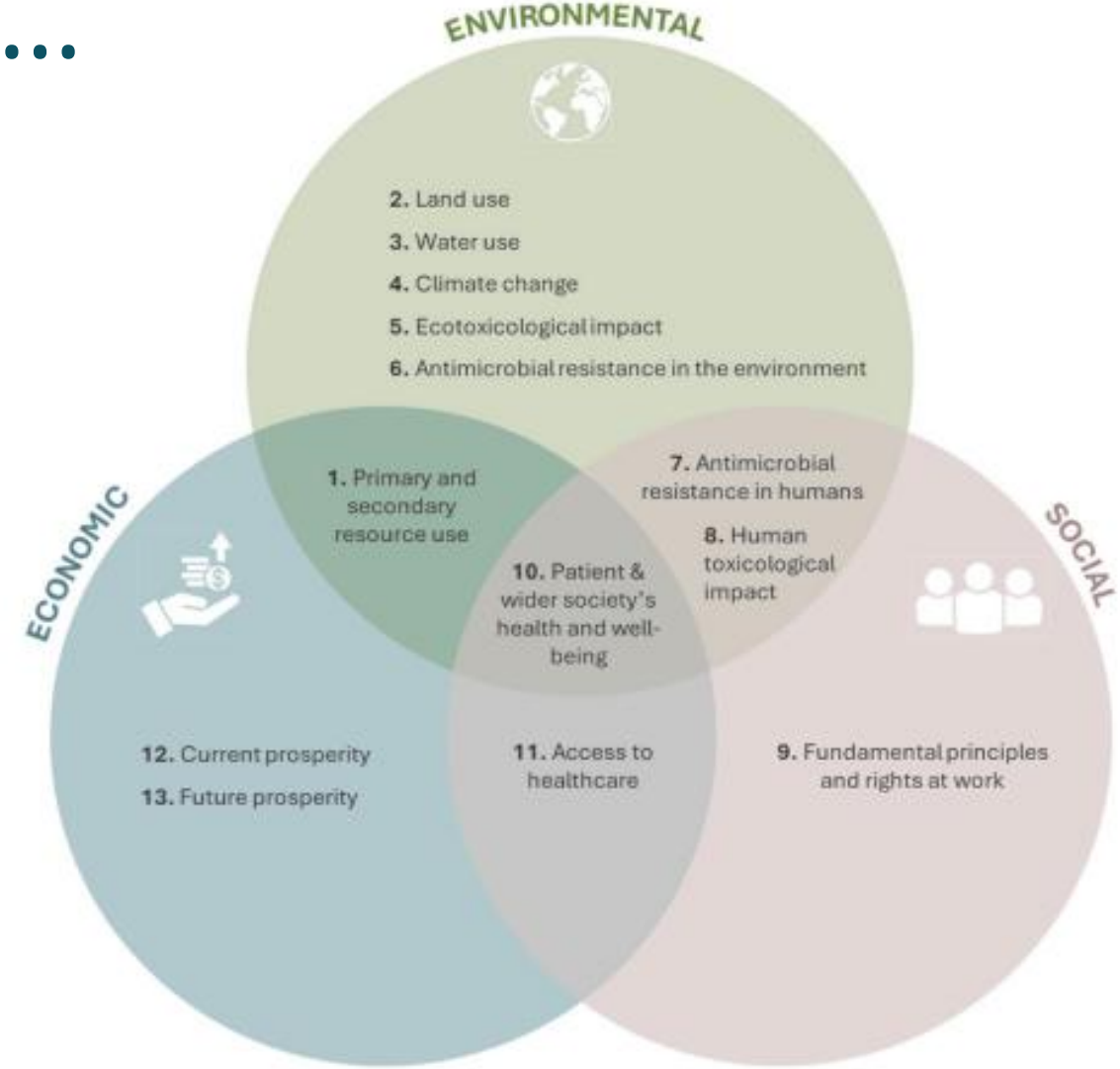
Mebendazole



18,000 x more DALYs averted than created

Debaveye et al. (2018) - https://doi.org/10.1371/journal.pntd.0006954

Integrated sustainability assessment
From theory…

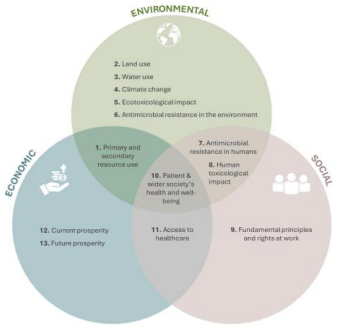


Van Wilder et al. (2024)
10.1016/j.jclepro.2024.142978

...towards operationalisation

Top down

- Literature
- Existing frameworks



Bottom up

- Project partners' feedback
- Stakeholder input

Van Wilder et al. (2024)
10.1016/j.jclepro.2024.142978

Top down

- Systematic literature review
  - 267 potential indicators

From social impact categories to a final set of 34 indicators and associated metrics

Bottom up

- Indicator selection based on stakeholder wishes
  - Materiality assessment
  - Expert consultation through Delphi technique

Van Wilder et al. (2026) - Under review

To conclude

To be continued!

PHARMECO

Advancing Safe and Sustainable by design Practices in Pharmaceutical Manufacturing

Addressing the urgent need for sustainability in the healthcare industry

Funded by the European Union and the private members of the IHI JU. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the aforementioned parties. Neither of the aforementioned parties can be held responsible for them.

PHARMECO summary

Ötvös et al. (2025) http://doi.org/10.1002/cssc.202501218

- **WHAT:**
  - **Public-private partnership** led by Ghent University and Sanofi, uniting **31 partners** across 14 countries to advance Safe and Sustainable by Design (SSbD) practices in pharmaceutical manufacturing

- **Funding and duration:**
  - 45M €, co-funded by the European Union and the private members of the IHI JU
  - 01/11/2024 – 31/10/2030

- **Mission:**
  - To enhance pharmaceuticals and biologics with sustainable methods, reducing use of water, energy, solvents, waste;
  - Standardized sustainability assessment methodology in healthcare

If you want to know more: www.pharmeco.eu

PHARMECO innovative health initiative COCIR efpia EuropaBio MedTech Europe Vaccines Europe Co-funded by the European Union

Public-private partnership of 31 international collaborators

Uniting expertise to advance PHARMECO's ambitious objectives

18 PUBLIC partners

13 PRIVATE partners

PHARMECO key objectives

- Integration of Safe and Sustainable by Design (SSbD) principles in pharmaceutical manufacturing practices
- Uptake of scalable, eco-friendly manufacturing optimizations and innovations in pharmaceutical manufacturing, focused on reducing greenhouse gases, solvent use, water, and energy consumption
- Development of digital support tools for prospective evaluation to guide sustainable production via process simulation
- Establish standardized environmental assessment systems for (bio)pharmaceuticals, ensuring consistency across the industry

PHARMECO WP7: Sustainability assessment and steering

Three key objectives – 5 tasks

Steering sustainability by design

Tailoring SSbD framework to pharma

Sustainability assessment of technologies / pharmaceuticals

Evaluating environmental sustainability of innovative technologies/ pharmaceuticals

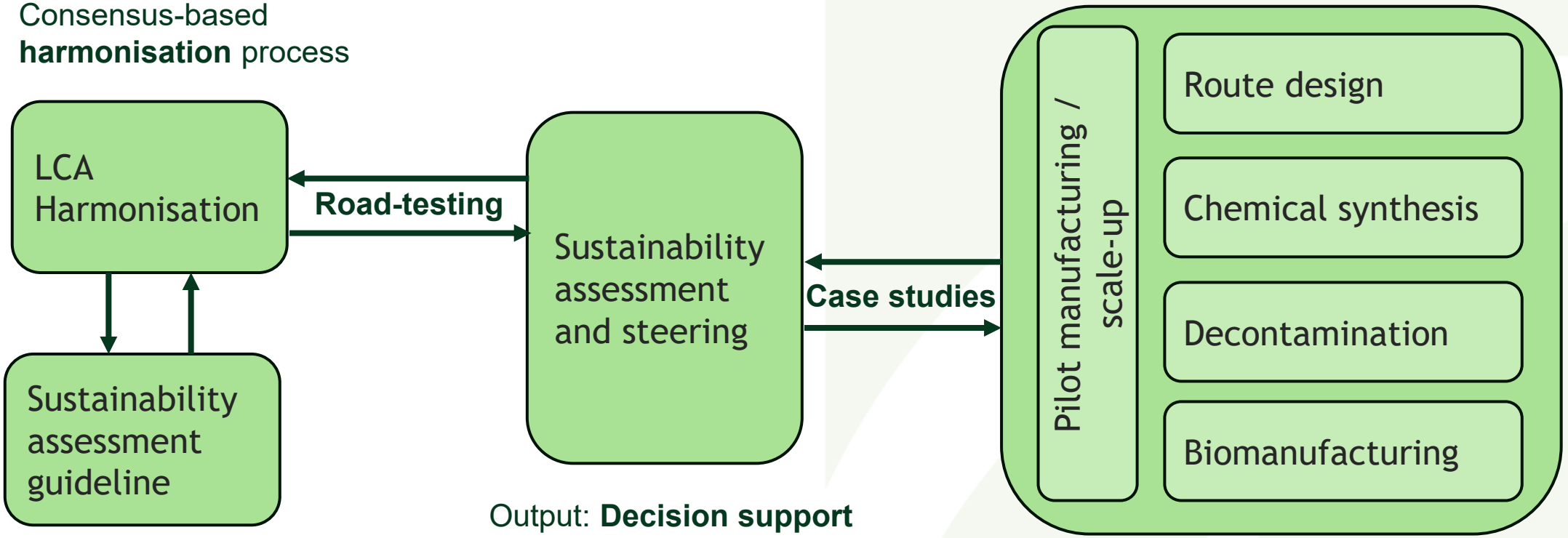
Towards integrated sustainability assessment of pharmaceuticals

Prospective assessment of pharmaceutical production

A guideline for environmental sustainability assessment for **route design**

Development of digital decision support for sustainable pharmaceutical production

PHARMECO WP8: Harmonisation of sustainability assessment



Output: LCA **guideline** for the pharmaceutical sector

Output: **Decision support system** for designing, operating, and evaluating the sustainability of healthcare product manufacturing.

Evaluate the impact of current and innovative **manufacturing practices** on a pharmaceutical product's **full life cycle**

Life cycle thinking approaches as support to move towards more sustainable pharma

- Life cycle thinking brings important insights
- Sustainability assessments are **demanding** ~ quality
- Data is key:
  Efforts on ecotoxicity (PREMIER), LCA related databases (e.g. MedZero) or tools (e.g. GreenSpeed)
- LCA in healthcare is often not “stand-alone” (SSbD, HTA, risk assessment & LCA, …)
- Life cycle thinking toolbox is work in progress:
  Research remains essential

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Thank you

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Contact/Questions?

Lieselot Boone
Ghent University

Lieselot.Boone@ugent.be

0032/9 264 59 54

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