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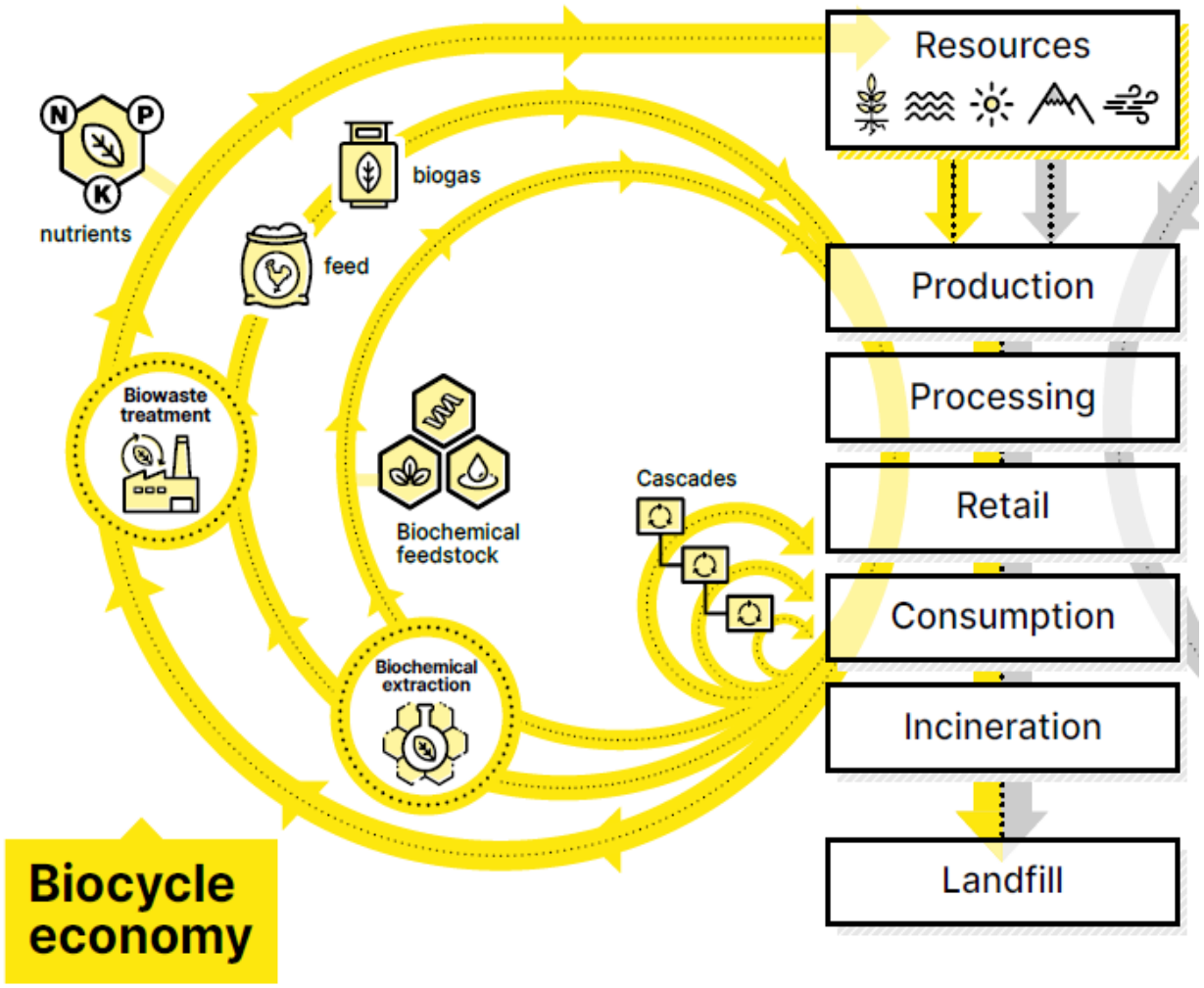
Comparative Screening LCAs of Okara Valorisation Scenarios

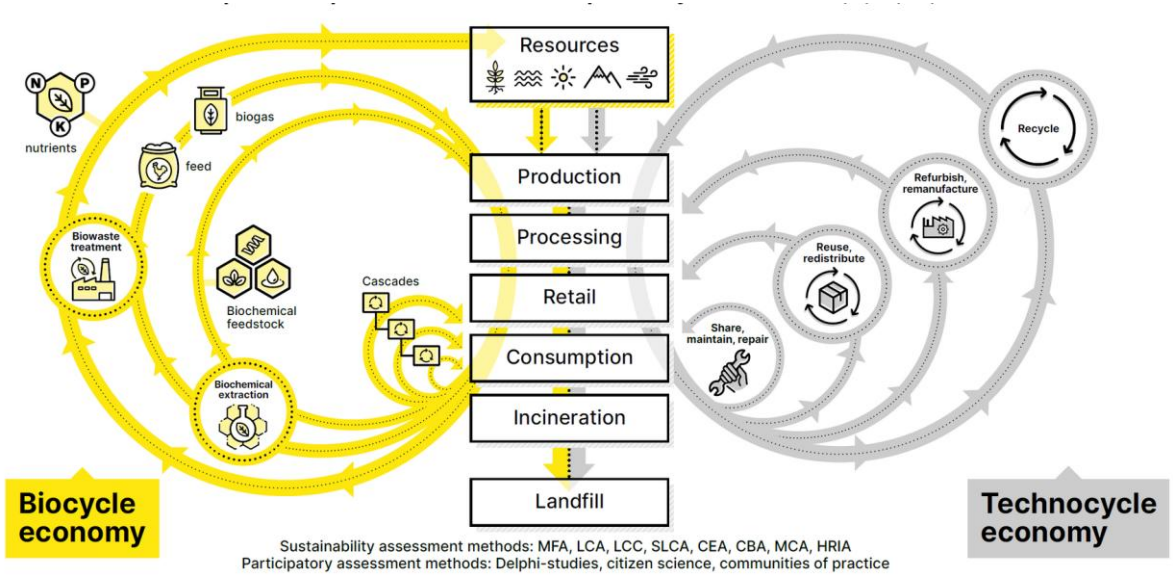
94th LCA Discussion Forum
Session 3: Case studies
ZHAW Wädenswil



Karina Rohrer, Fabian Whitfield, **Lena Breitenmoser**

6 November 2026

Group: **Sustainable Resource Management**



1. **Circular economy of bioresources**
2. **Systems modelling**
3. **Sustainability assessment**


Christoph Hugi


Lena Breitenmoser


Thomas Gross

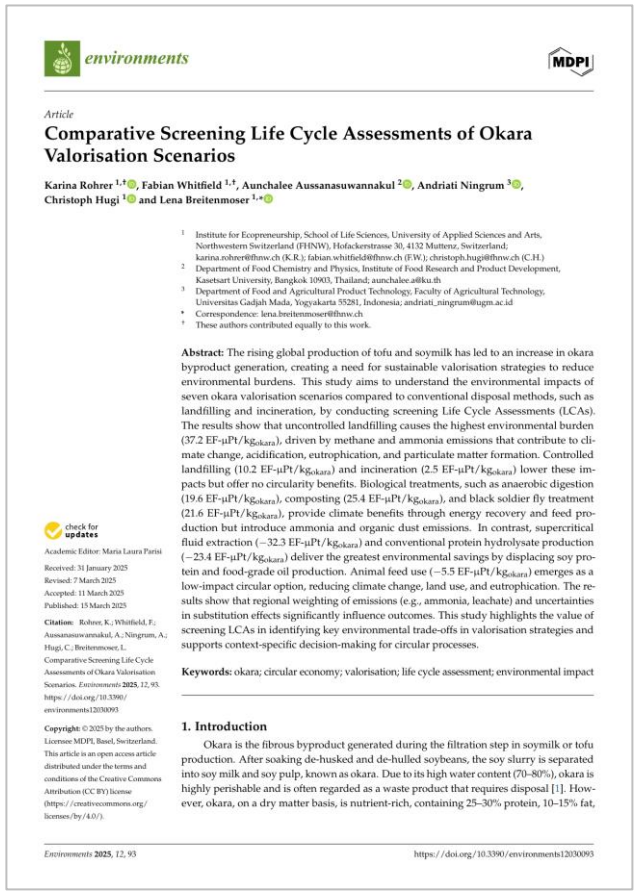

Dirk Hengevoss


Karina Rohrer


Andreina Schweizer


Fabian Whitfield

Today: **Comparative screening LCA of okara valorisation**



environments

MDPI

Article

Comparative Screening Life Cycle Assessments of Okara Valorisation Scenarios

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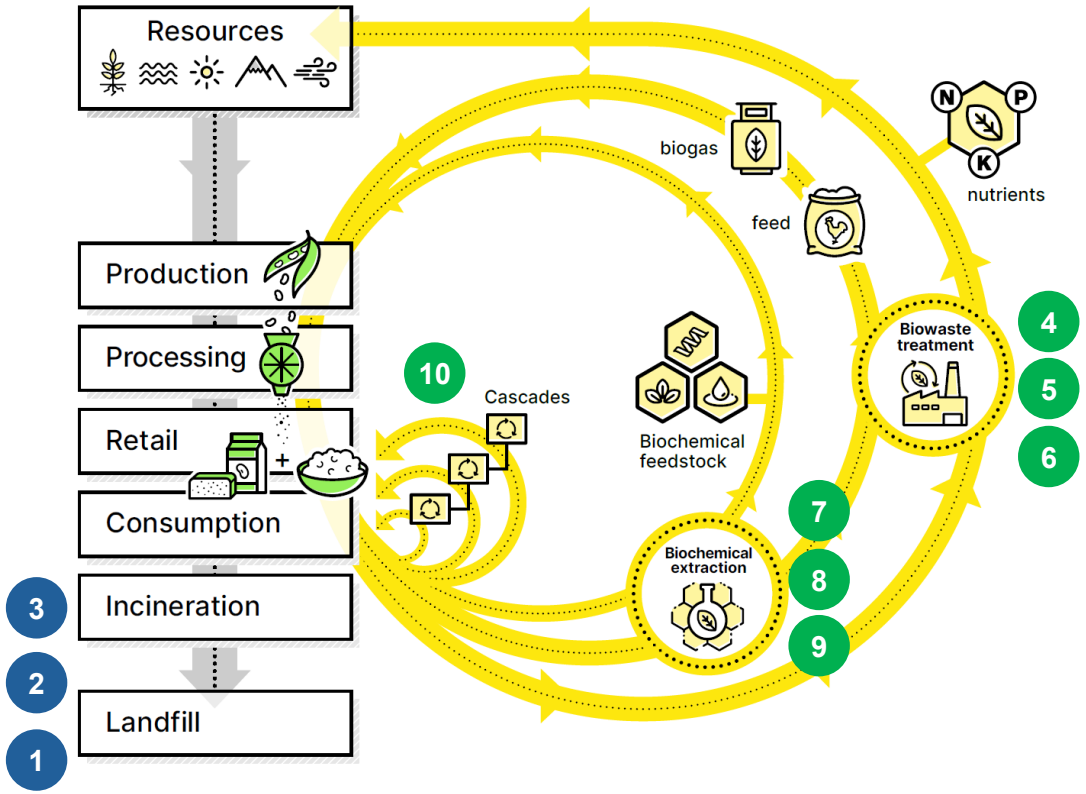
Abstract: The rising global production of tofu and soymilk has led to an increase in okara byproduct generation, creating a need for sustainable valorisation strategies to reduce environmental burdens. This study aims to understand the environmental impacts of seven okara valorisation scenarios compared to conventional disposal methods, such as landfilling and incineration, by conducting screening Life Cycle Assessments (LCAs). The results show that uncontrolled landfilling causes the highest environmental burden (37.2 EF-μPt/kg_{okara}), driven by methane and ammonia emissions that contribute to climate change, acidification, eutrophication, and particulate matter formation. Controlled landfilling (10.2 EF-μPt/kg_{okara}) and incineration (2.5 EF-μPt/kg_{okara}) lower these impacts but offer no circularity benefits. Biological treatments, such as anaerobic digestion (19.6 EF-μPt/kg_{okara}), composting (25.4 EF-μPt/kg_{okara}), and black soldier fly treatment (21.6 EF-μPt/kg_{okara}), provide climate benefits through energy recovery and feed production but introduce ammonia and organic dust emissions. In contrast, supercritical fluid extraction (−32.3 EF-μPt/kg_{okara}) and conventional protein hydrolysate production (−23.4 EF-μPt/kg_{okara}) deliver the greatest environmental savings by displacing soy protein and food-grade oil production. Animal feed use (−5.5 EF-μPt/kg_{okara}) emerges as a low-impact circular option, reducing climate change, land use, and eutrophication. The results show that regional weighting of emissions (e.g., ammonia, leachate) and uncertainties in substitution effects significantly influence outcomes. This study highlights the value of screening LCAs in identifying key environmental trade-offs in valorisation strategies and supports context-specific decision-making for circular processes.

Keywords: okara; circular economy; valorisation; life cycle assessment; environmental impact

1. Introduction

Okara is the fibrous byproduct generated during the filtration step in soymilk or tofu production. After soaking de-husked and de-hulled soybeans, the soy slurry is separated into soy milk and soy pulp, known as okara. Due to its high water content (70–80%), okara is highly perishable and is often regarded as a waste product that requires disposal [1]. However, okara, on a dry matter basis, is nutrient-rich, containing 25–30% protein, 10–15% fat,



1 Uncontrolled landfill
2 Controlled landfill
3 Incineration
4 Anaerobic digestion
5 Composting
6 Black soldier fly
7 Supercritical CO_2 oil
8 Protein hydrolysate, conv.
9 Protein hydrolysate, exp.
10 Silage feed

Rohrer et al. (2025), *Environments* 12(3), 93
doi.org/10.3390/environments12030093

Access the paper

Project: **Okara Valorization**



Switzerland

FHNW, Institute for Ecopreneurship



Thailand

Kasetsart University, IFRPD



Indonesia

Universitas Gadjah Mada

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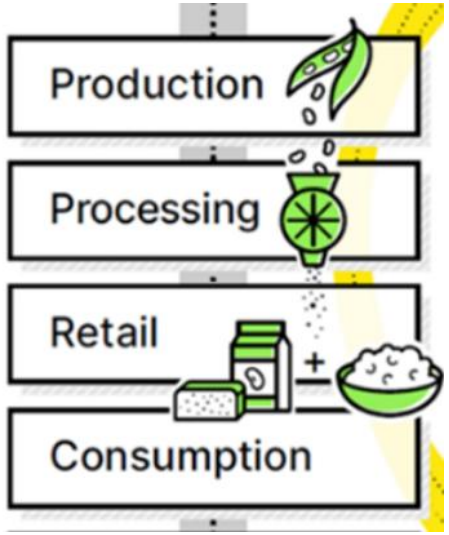
What is okara?













Soaking, grinding Cooking Pressing **Soymilk** → tofu **Okara**

Photos and clip: © Lena Breitenmoser, Karina Rohrer

1.1 kg
okara per kg of soymilk or tofu

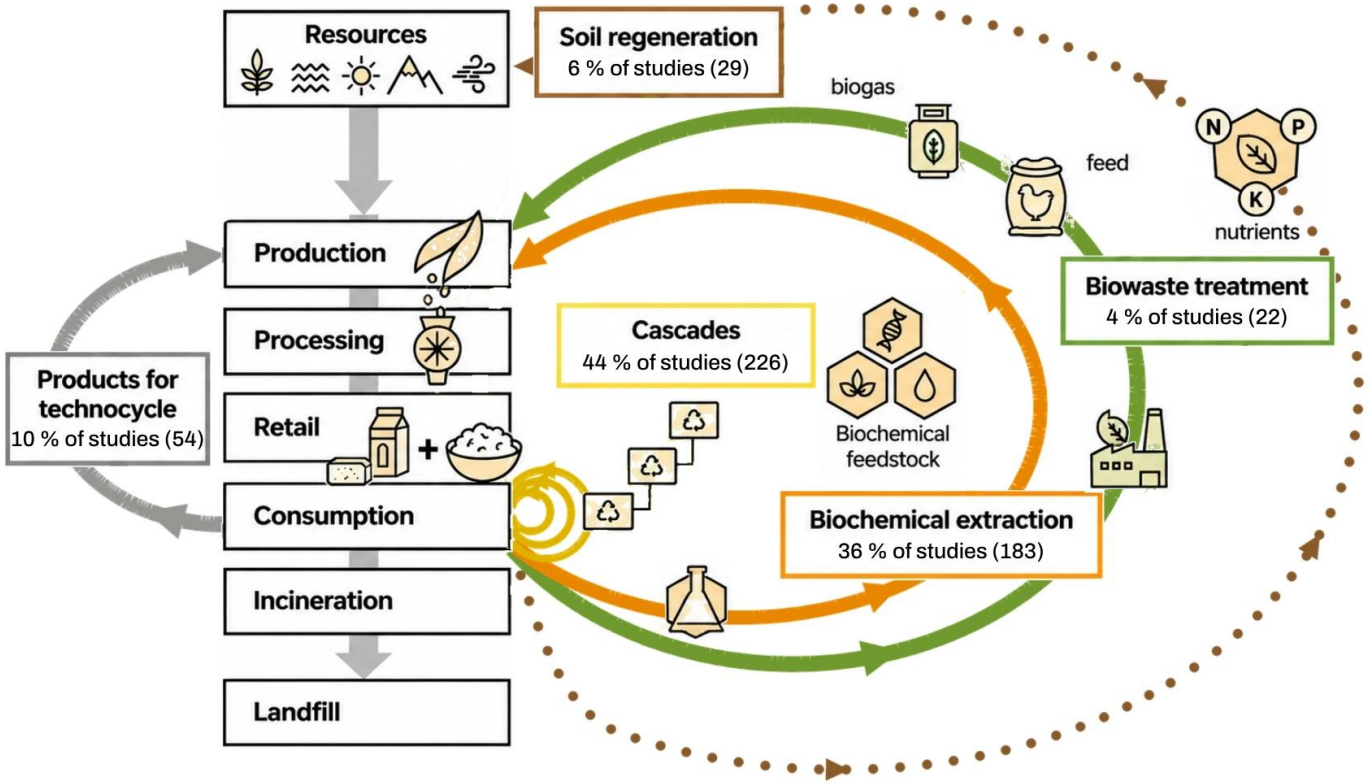
14 Mt
okara per year worldwide

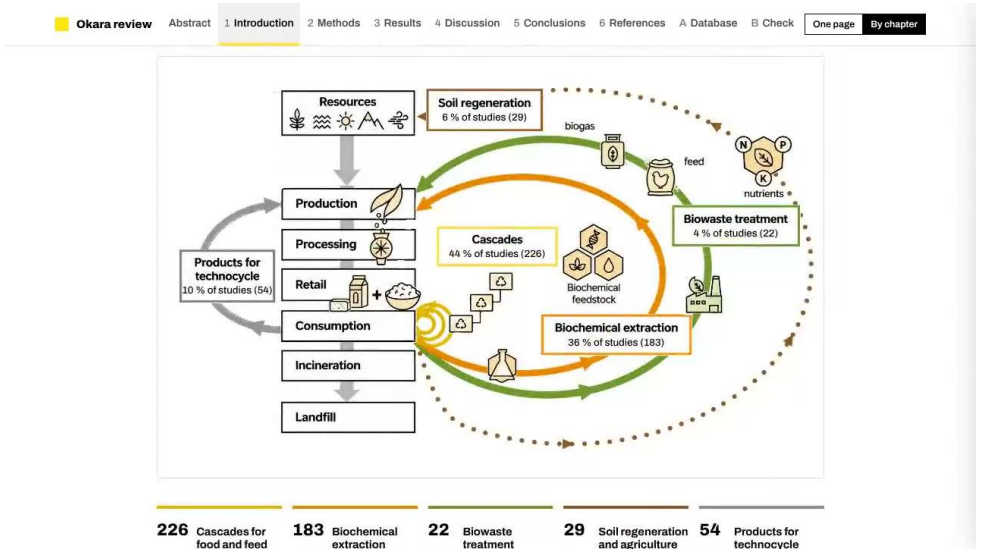
80%
water: spoils within days

½ · ¼ · ⅕
fibre · protein · fat in the dry matter

Rohrer et al. (2025), Figure 1 (icons); Voss et al. (2021); Vong & Liu (2016); O'Toole (2016); Koptelova et al. (2024).

Okara research: **a fast-growing library**





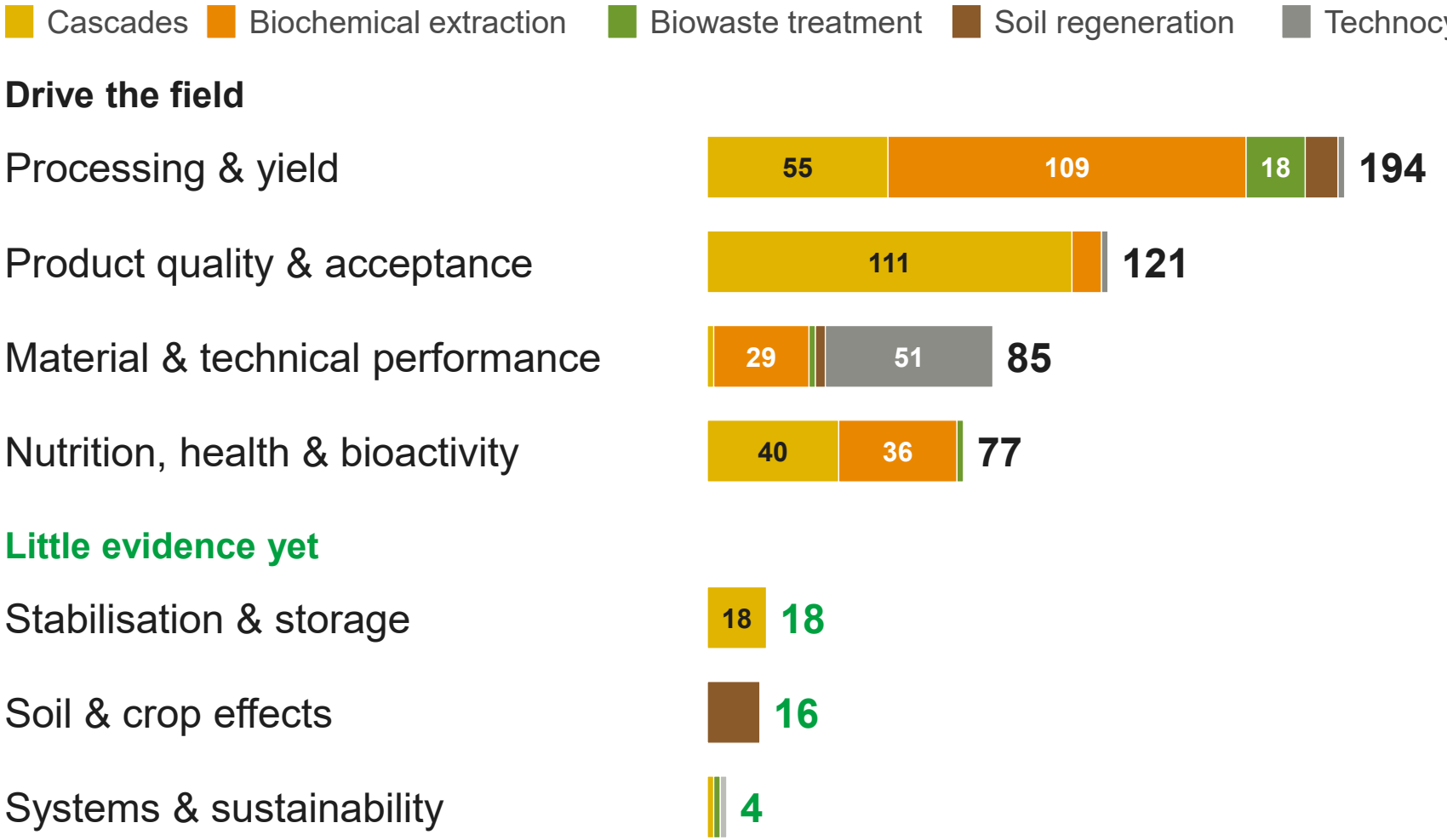
515 articles

on okara valorisation since 2000

Interactive library: scoping review in preparation

Breitenmoser et al., scoping review in preparation (preliminary data).

Okara research: **products first, sustainability rarely**

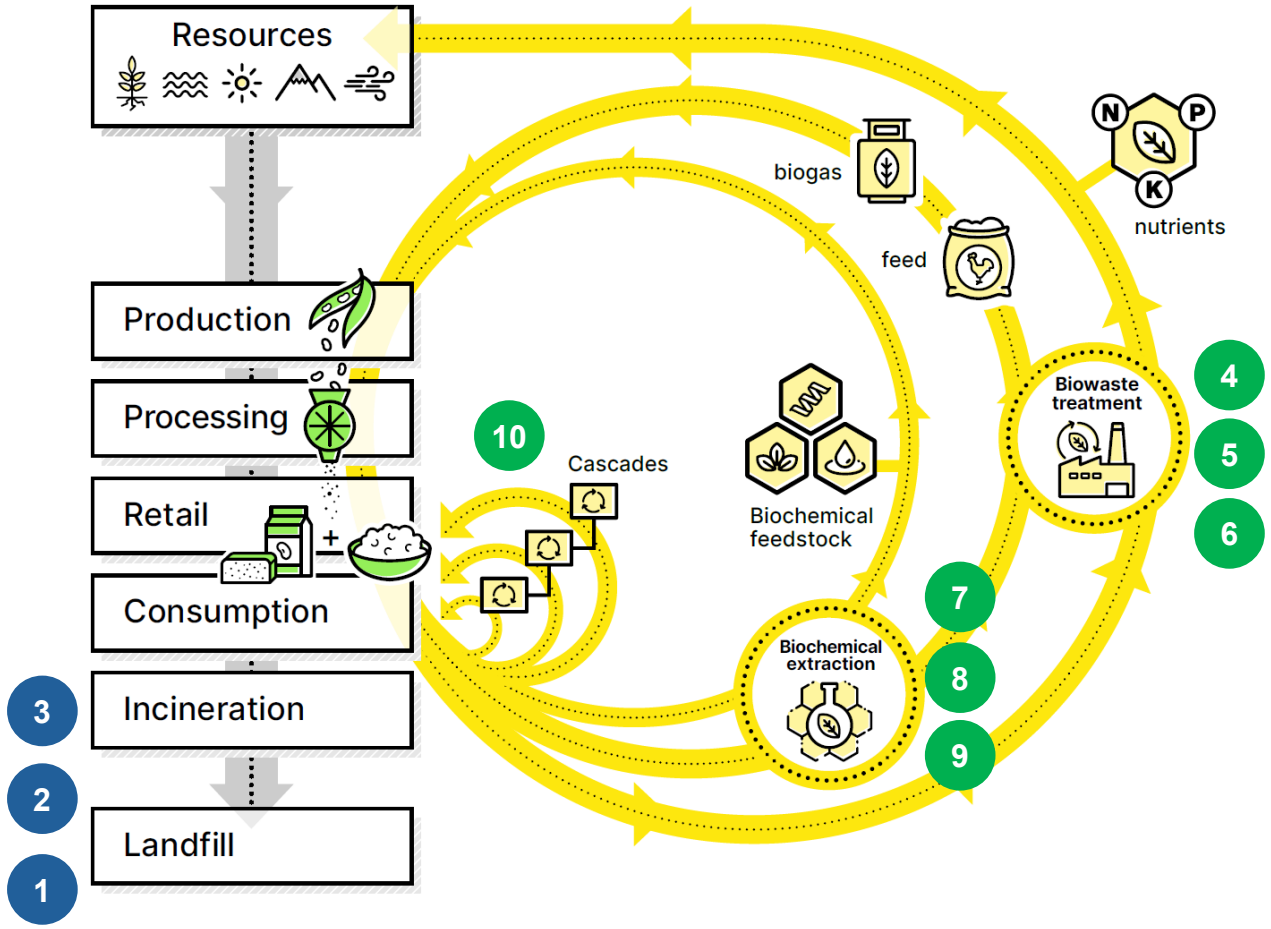


4 of 515

articles assess sustainability, one is our LCA

Breitenmoser et al., scoping review in preparation (preliminary data).

Study design: **ten scenarios for 1 kg of okara**



1. Uncontrolled landfill
2. Controlled landfill
3. Incineration
4. Anaerobic digestion
5. Composting
6. Black soldier fly
7. Supercritical CO_2 oil
8. Protein hydrolysate, conv.
9. Protein hydrolysate, exp.
10. Silage feed

Research questions

Q1 How do circular routes compare with landfill and incineration?

Q2 Which processes and emissions are the hotspots?

Q3 Can a screening LCA guide process development early?

Adapted from Rohrer et al. (2025), Figure 1.

Goal and scope: **Screening LCA** for 10 valorisation

Inventory

LCI

- SimaPro 9.6, ecoinvent 3.1
- Global data, no specific region
- Partners in Switzerland, Thailand, Indonesia
- Literature emission factors (NH_3, N_2O, CH_4)

Impact assessment

LCIA

- EF 3.1, 16 impact categories
- Global normalisation and weighting
- Single score: µPt per kg fresh okara

Sensitivity check

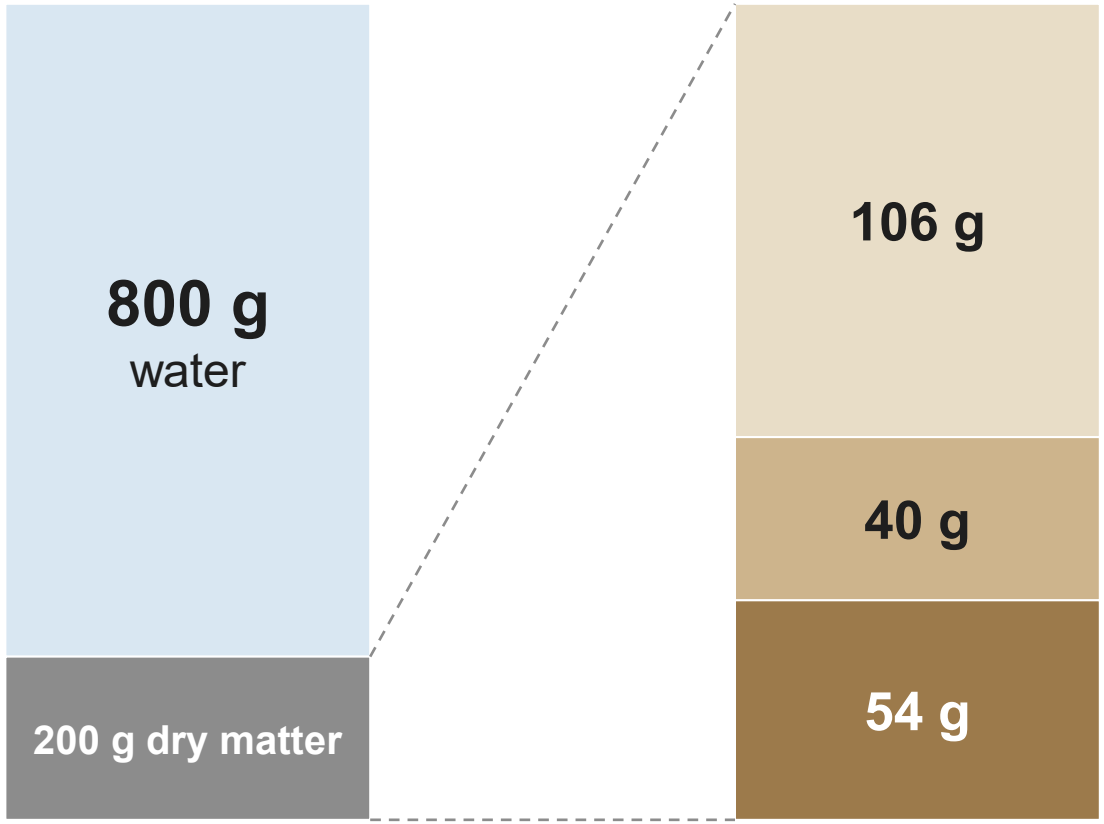
Interpretation

- Same inventory, second method
- Ecological Scarcity 2021 (UBP)
- Does the ranking hold?

European Commission JRC (2023); Sala et al. (2018); FOEN (2021).

Goal and scope: **functional unit**

1 kg
fresh okara
functional unit



Nutrients
contained in the dry matter

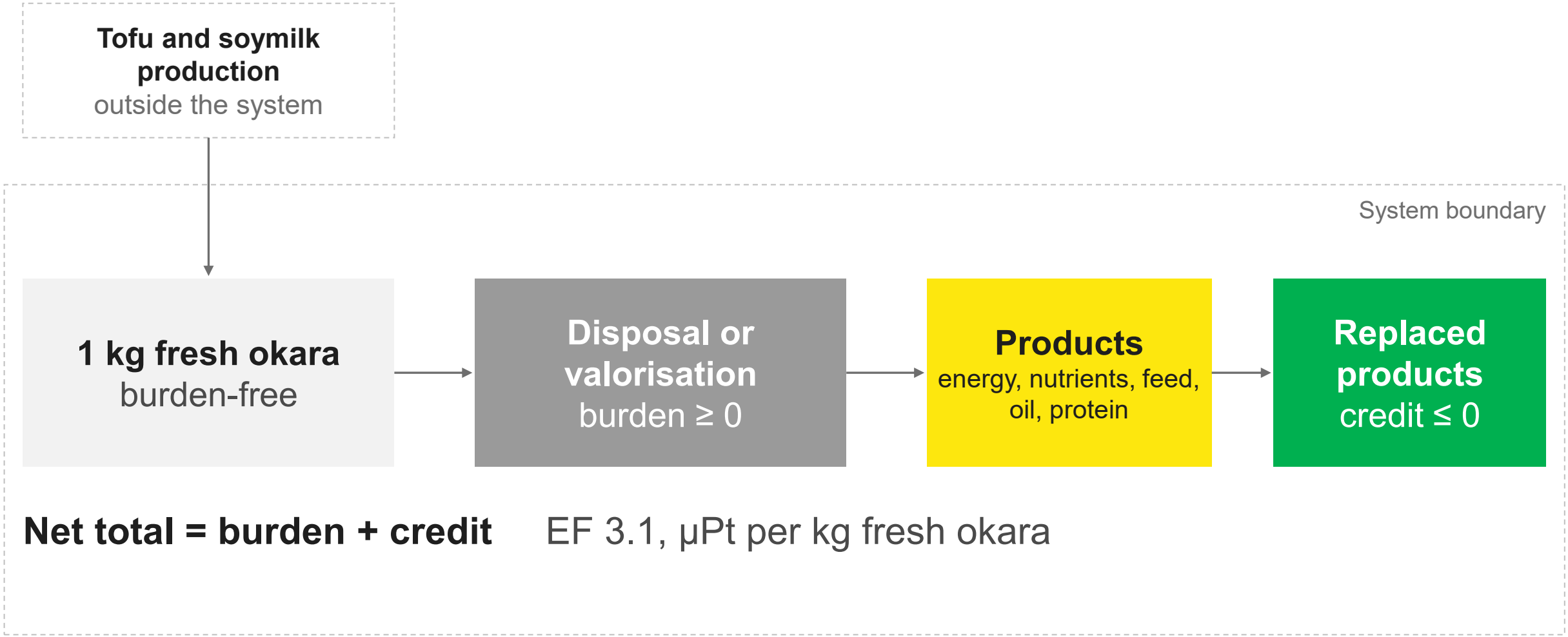
9.1 g N
4.55% DM, mostly in protein

0.6 g P
0.29% DM

1.7 g K
0.84% DM

Rohrer et al. (2025), Table 1; O'Toole (2016); Aussanasuwannakul et al. (2023); Li et al. (2012); Choy et al. (2015).

Goal and scope: **system boundary and system expansion**



Net total = burden + credit EF 3.1, µPt per kg fresh okara

Goal and scope: **scenarios and data quality**

Scenario		Why chosen	Process data	Emissions	Credit	Replaced product
S1	Uncontrolled landfill	Current practice	🟡	🟡	–	none
S2	Controlled landfill	Current practice	🟢	🟡	🟢	natural gas
S3	Incineration	Current practice	🟢	🟢	–	none
S4	Anaerobic digestion	Established biowaste route	🟢	🔴	🟡	natural gas, NPK fertiliser
S5	Composting	Established biowaste route	🟢	🔴	🟡	NPK fertiliser
S6	Black soldier fly	Established biowaste route	🟡	🔴	🔴	fishmeal, fish oil, fertiliser
S7	Supercritical CO_2 oil	Partner process, pilot (KU)	🟡	🟡	🔴	sesame oil, soybean meal
S8	Protein hydrolysate, conv.	Industrial reference	🟡	🟡	🔴	soy protein, pea residues
S9	Protein hydrolysate, exp.	Partner process, lab (UGM)	🔴	🟡	🔴	soy protein hydrolysate
S10	Silage feed	Simplest direct reuse	🟡	🟡	🟡	soybean meal

Data quality: 🟢 robust 🟡 moderate 🔴 uncertain – no credit

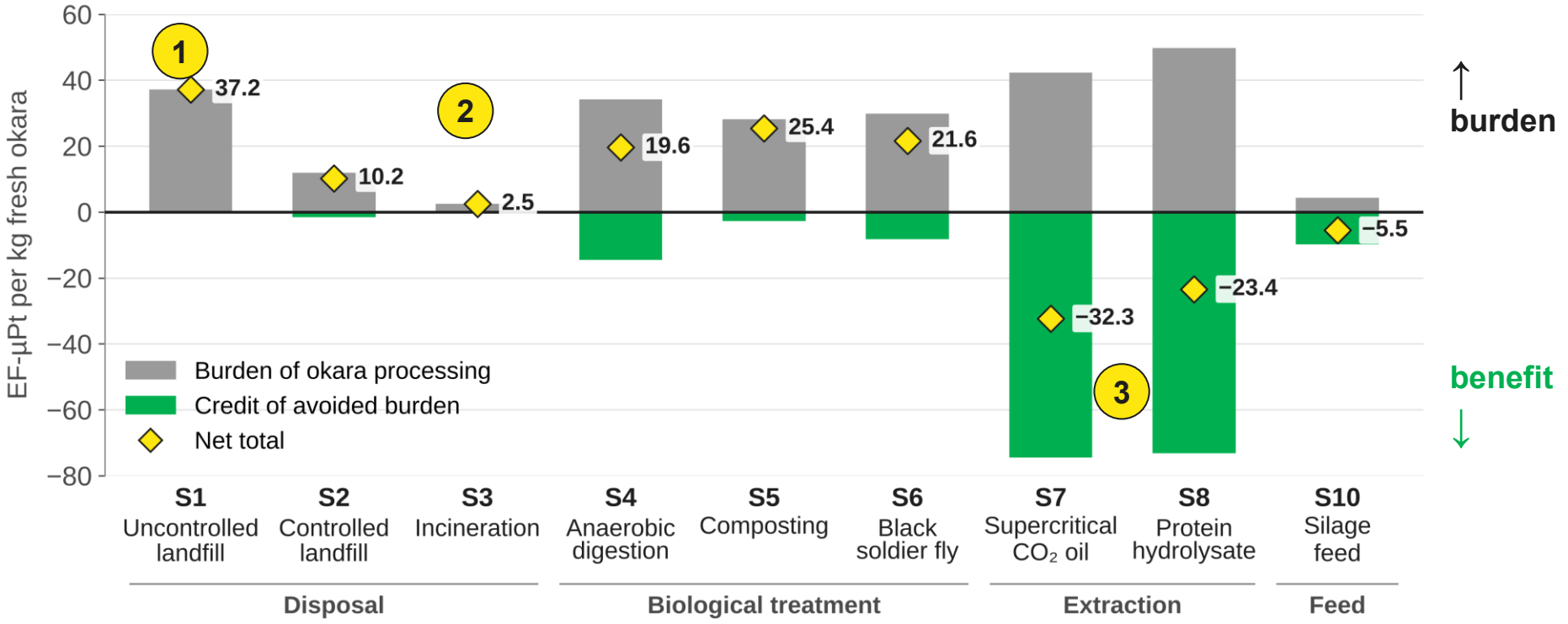
Rohrer et al. (2025), Sections 2.1 and 3.3.

Q1

How do circular routes compare with landfill and incineration?

Aggregated results

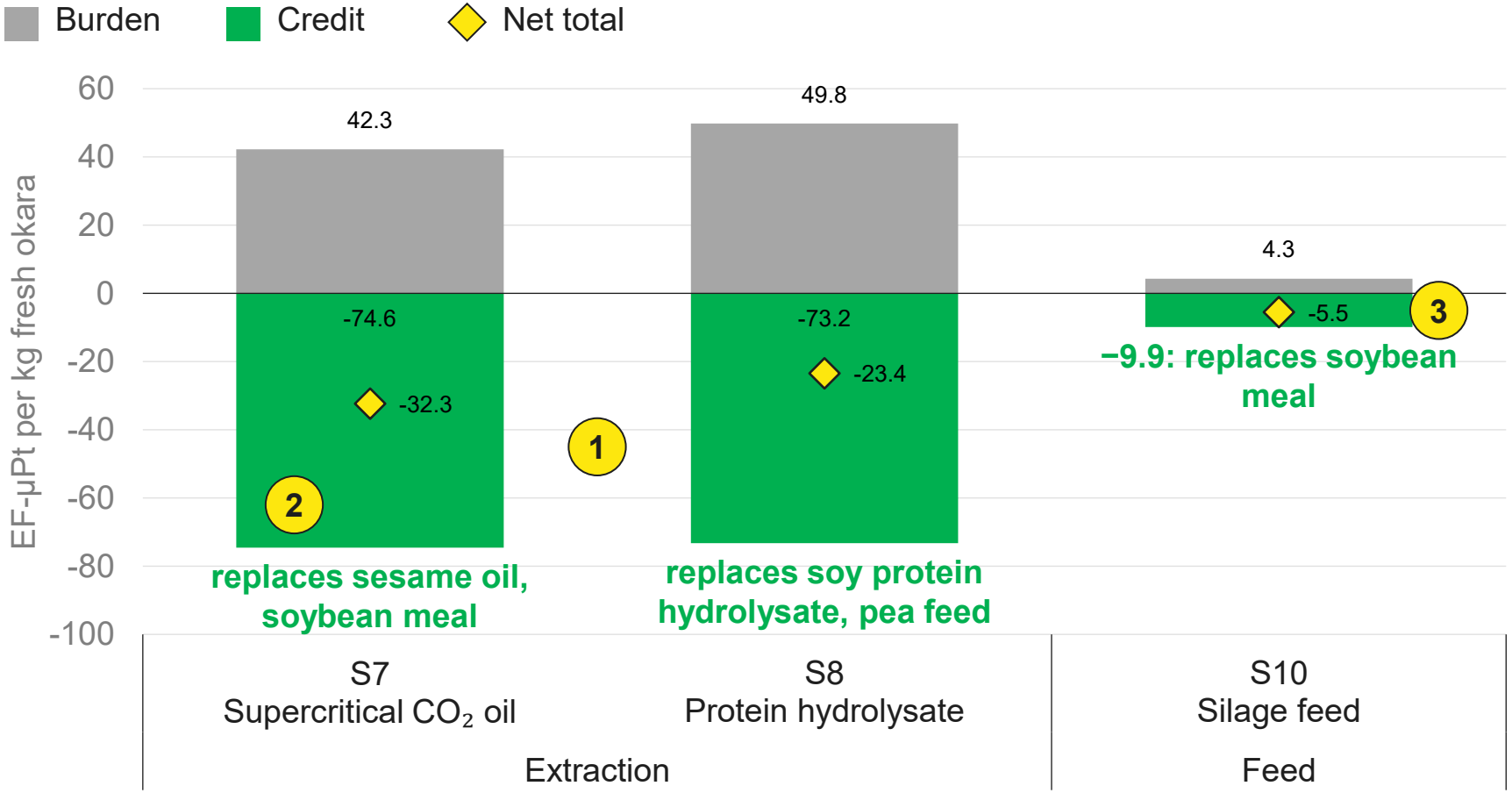
Results: **aggregated Environmental Footprint**

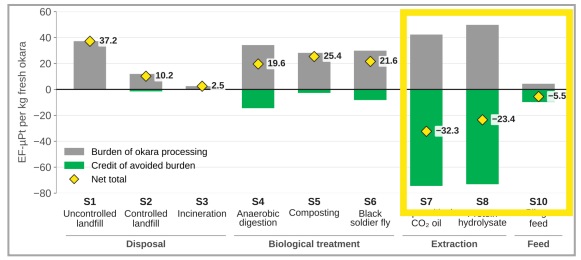


1. **Uncontrolled landfill** is the worst case
2. **Biological routes** above incineration: why?
3. **Extraction and feed** are net negative

Rohrer et al. (2025), Figure 2 (aggregated); S9 not shown (net total 201 EF-µPt).

Results: **for extraction and feed, the credits decide**



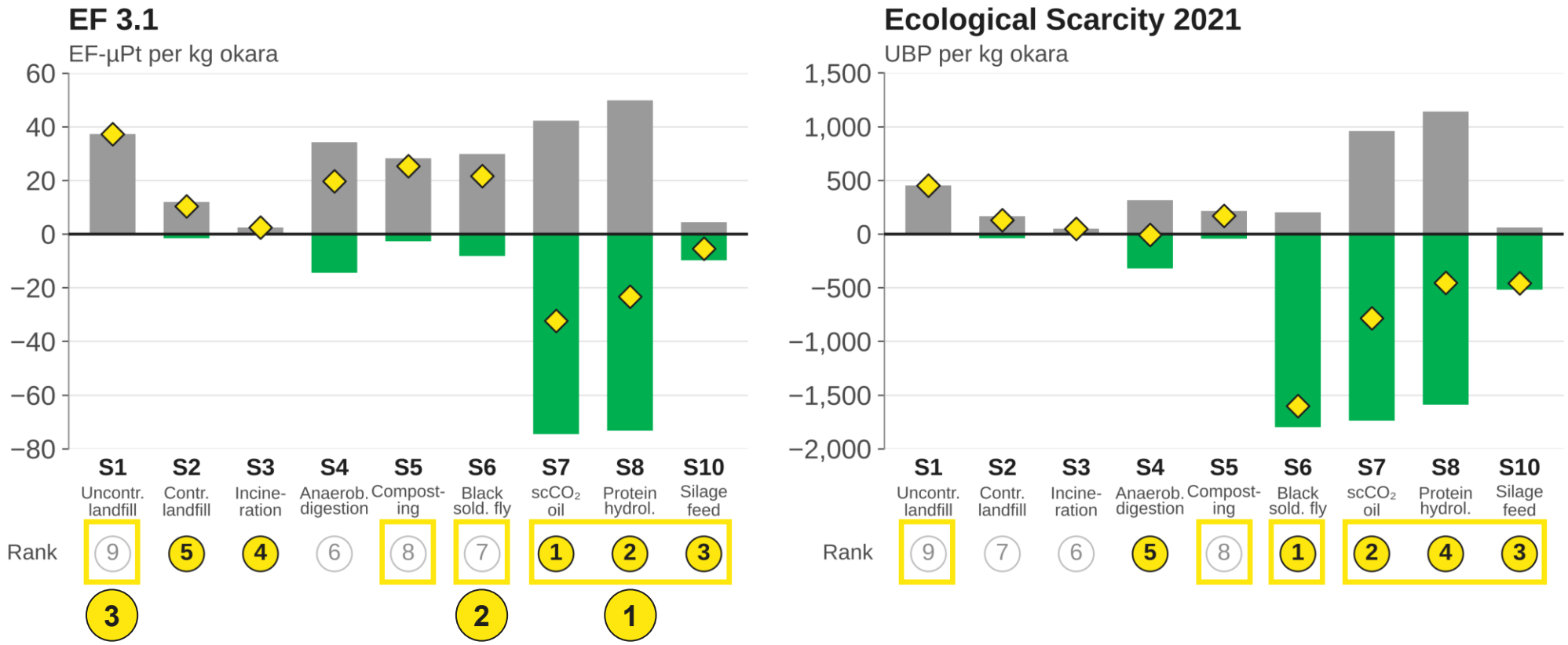


From the overview: S7, S8, S10, credit side

1. **S7, S8** net negative only via credits
2. **Credits** need a market
3. **Direct reuse** earns less credit

Rohrer et al. (2025), Tables 4–5.

Sensitivity: **EF 3.1 vs. Ecological Scarcity 2021**



1 **Robust:** S7, S8, S10 in the top five with both

2 **Answer:** EF amplifies NH_3; BSF jumps 7 → 1

3 **Last with both:** landfill (S1), composting (S5)

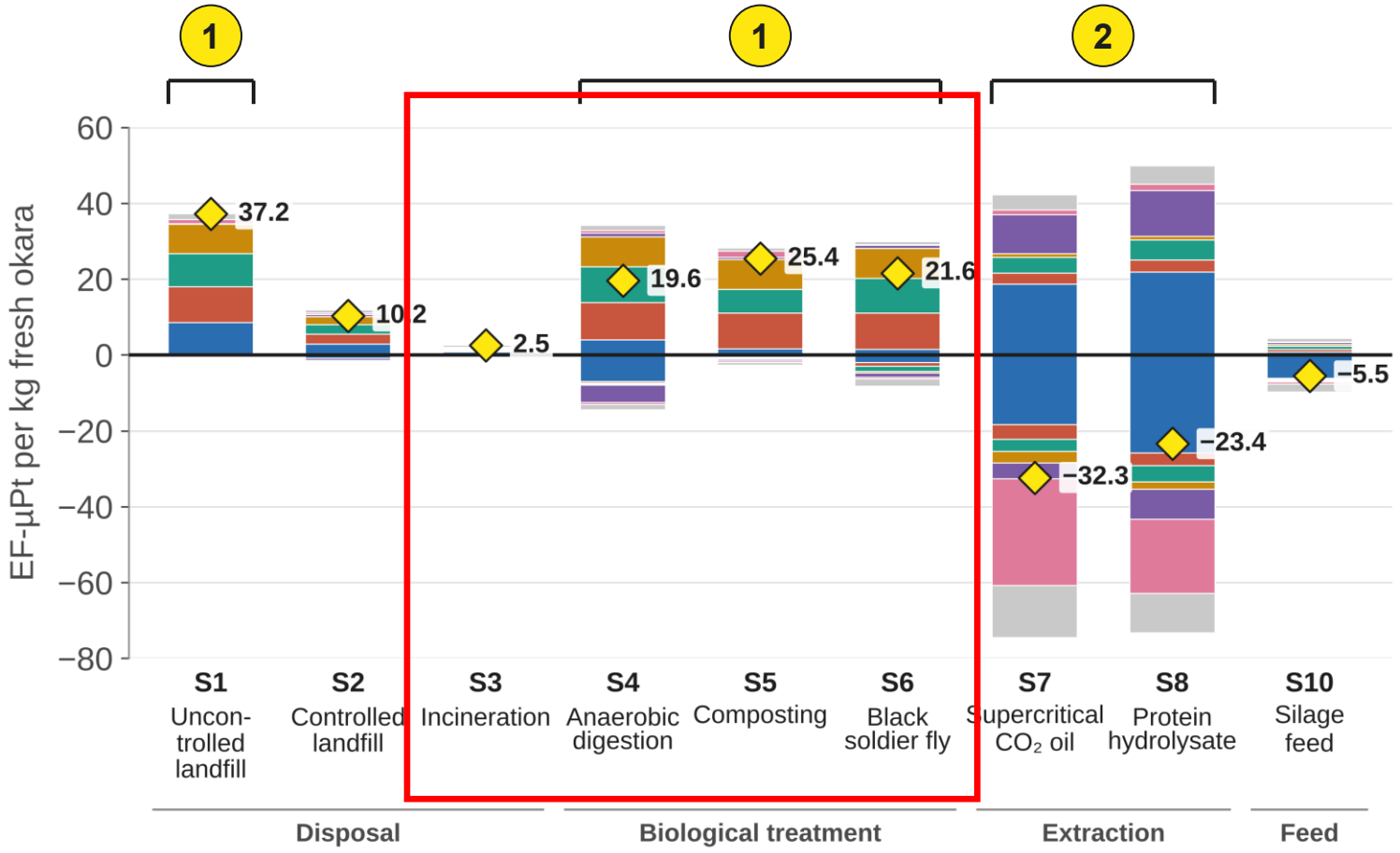
Rohrer et al. (2025), Figure S3. Rank 1 = lowest net impact; S9 excluded (last with both methods).

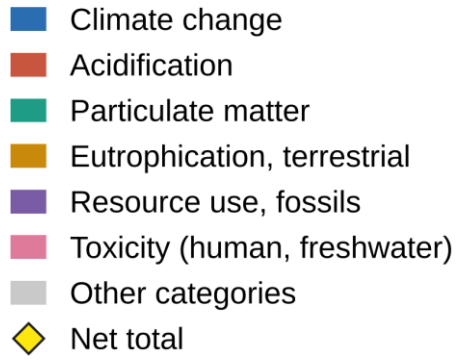
Q2

Which processes and emissions are the hotspots?

Midpoints and characterised results

Results: **contribution of impact categories**



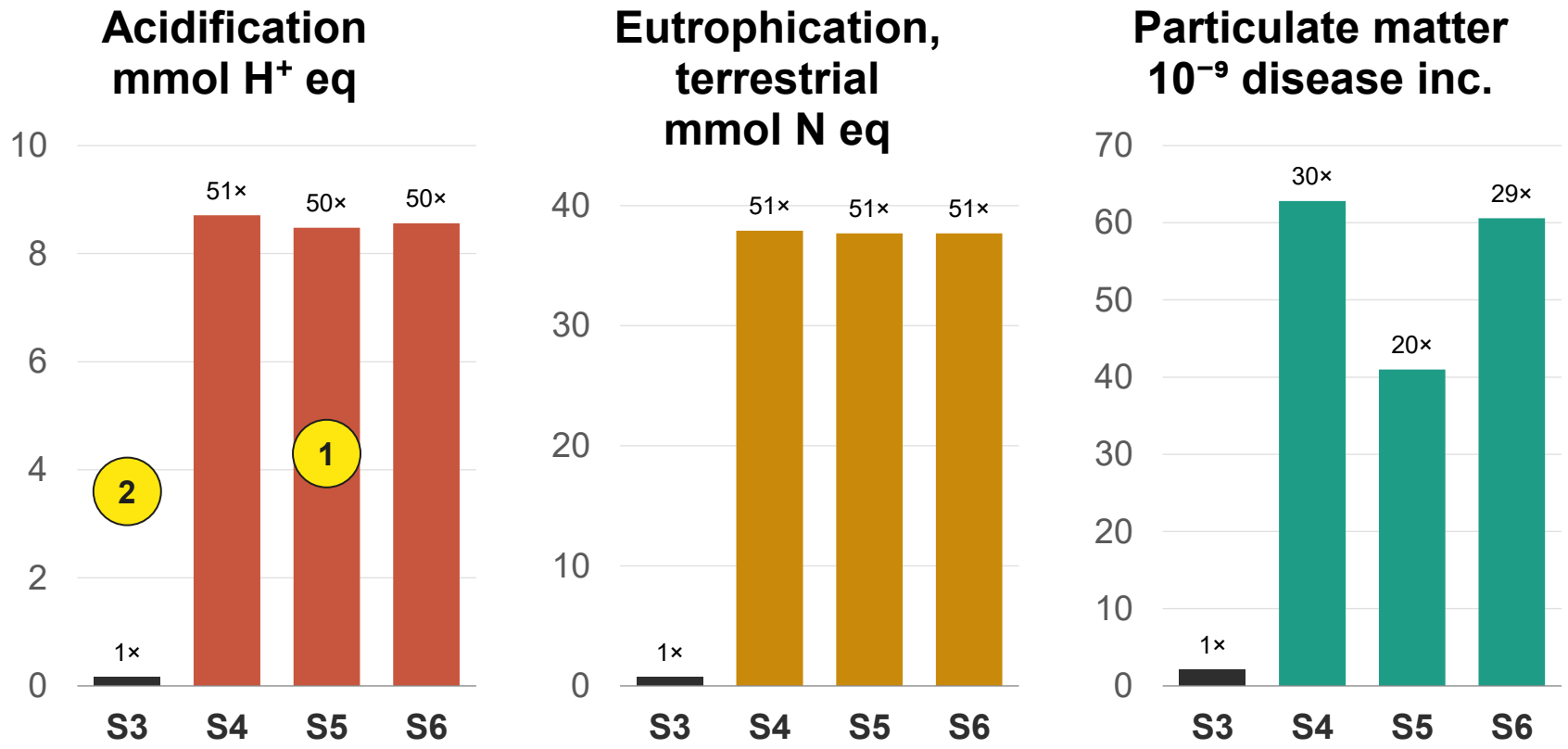


1 **N-related emissions** drive landfill and biological routes

2 **Energy** drives the extraction routes

Rohrer et al. (2025), Tables S1–S4; EF 3.1 normalisation and weighting.

Results: **incineration lower than biological treatment**



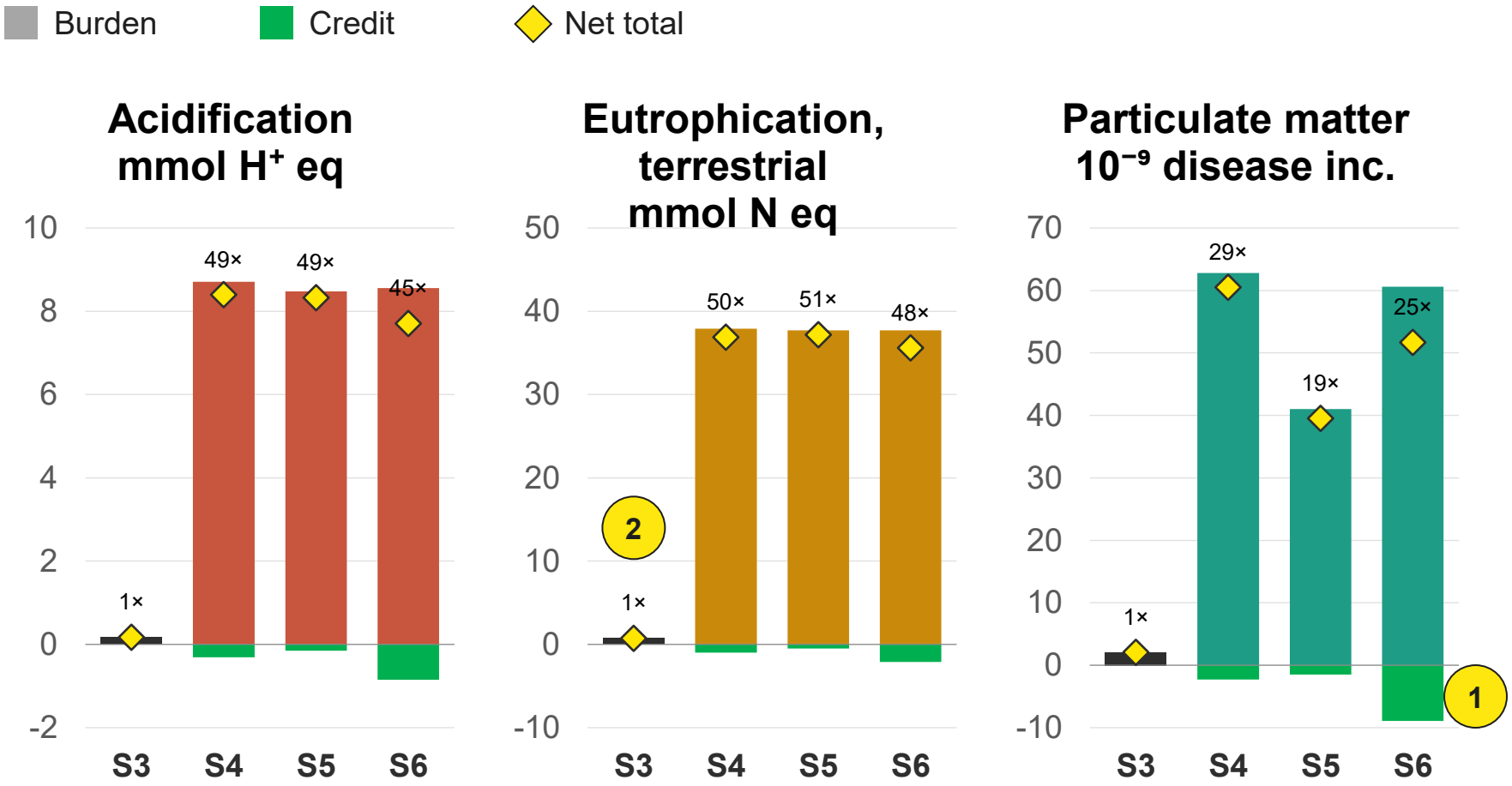
S3 Incineration **S4** Anaerobic digestion **S5** Composting **S6** Black soldier fly

1 **S4–S6:** 20–50× more than S3, as NH_3 escapes in open decomposition

2 **S3:** closed combustion, flue gas cleaning

Rohrer et al. (2025), Tables S1–S2 (burden without credits); factor = scenario / S3.

Results: **with credits, the gap stays**



S3 Incineration **S4** Anaerobic digestion **S5** Composting **S6** Black soldier fly

1 **Credits:** only 1–15% off for S4–S6 (energy, fertiliser, fishmeal replaced)

2 **Gap stays:** net still about 20–50× above S3

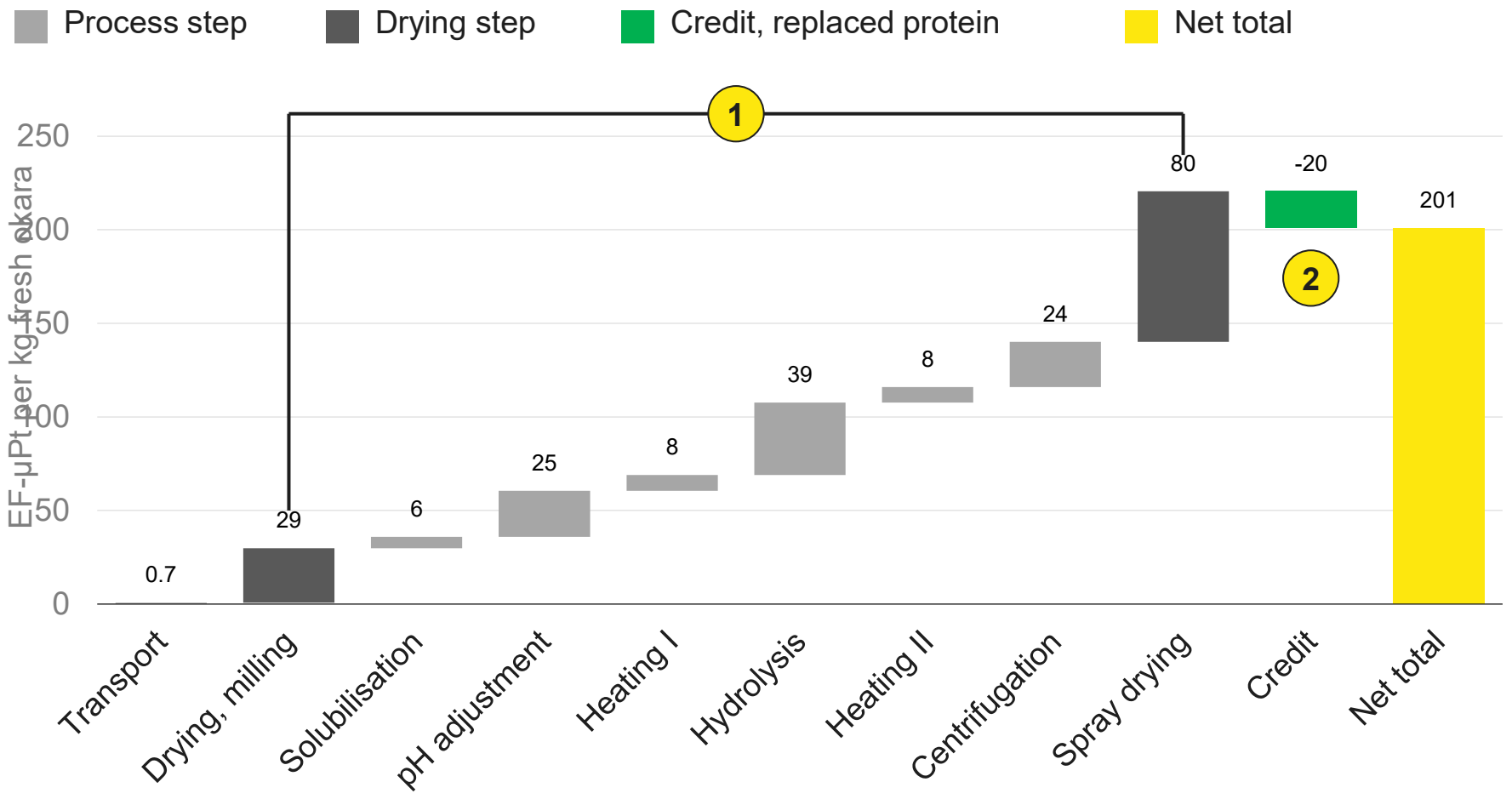
Rohrer et al. (2025), Tables S1–S2 (burden and net with avoided burden); factor = net / net S3.

Q3

Can a screening LCA guide process development early?

The lab-scale hydrolysate

Results: **lab-scale hydrolysate (S9), drying is the hotspot**

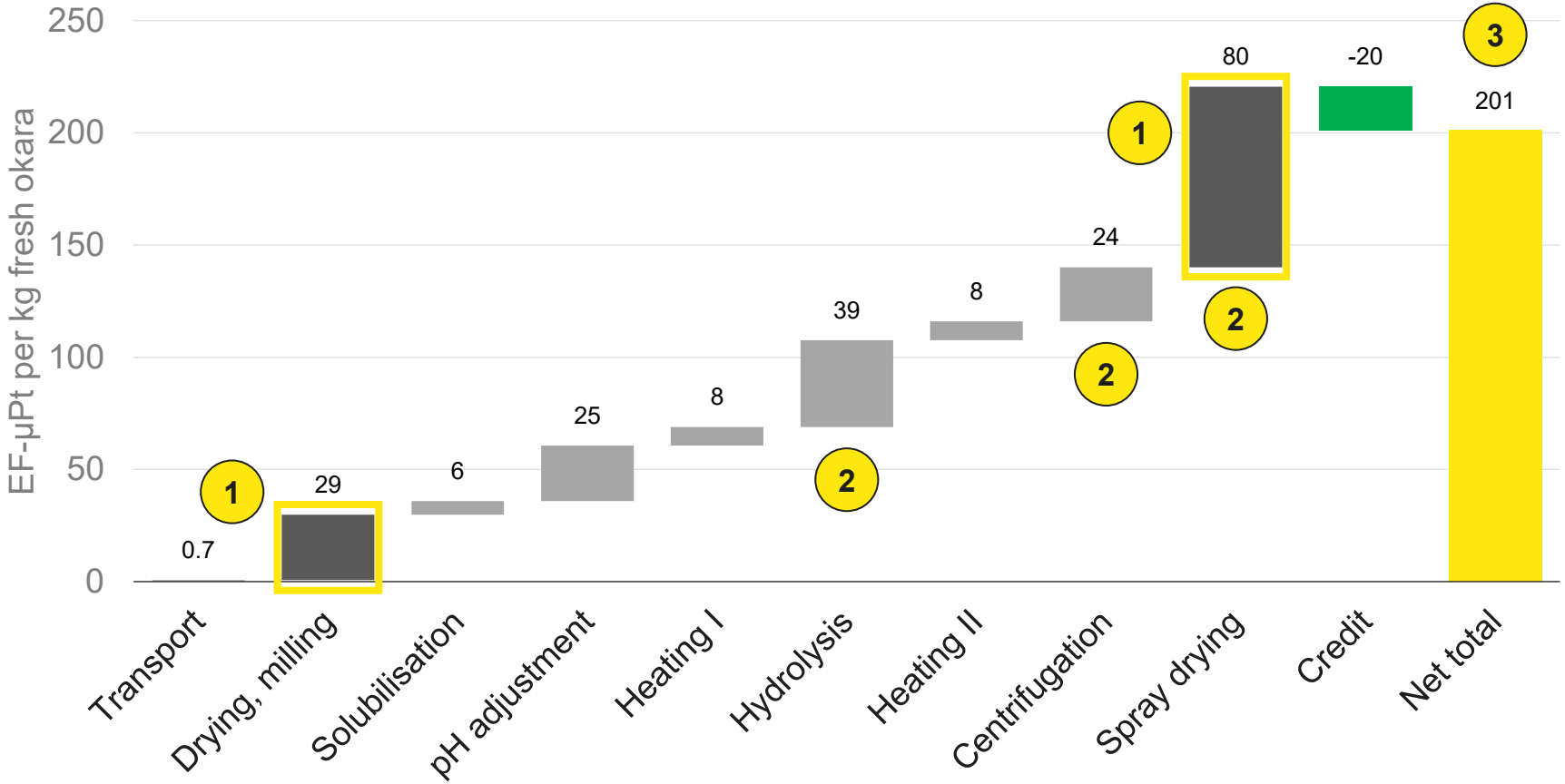


1. **Drying:** 110 of 220 µPt
2. **Recovery:** 24% (S8: 70%)
3. **Fix first:** drying, separation, recovery

Rohrer et al. (2025), Figure 3; Quintana et al. (2023).

Results: **screening points the lab to its levers**

Lab-scale hydrolysate (S9), EF-µPt per kg fresh okara



1 **Hotspot:** drying, 110 of 220 µPt

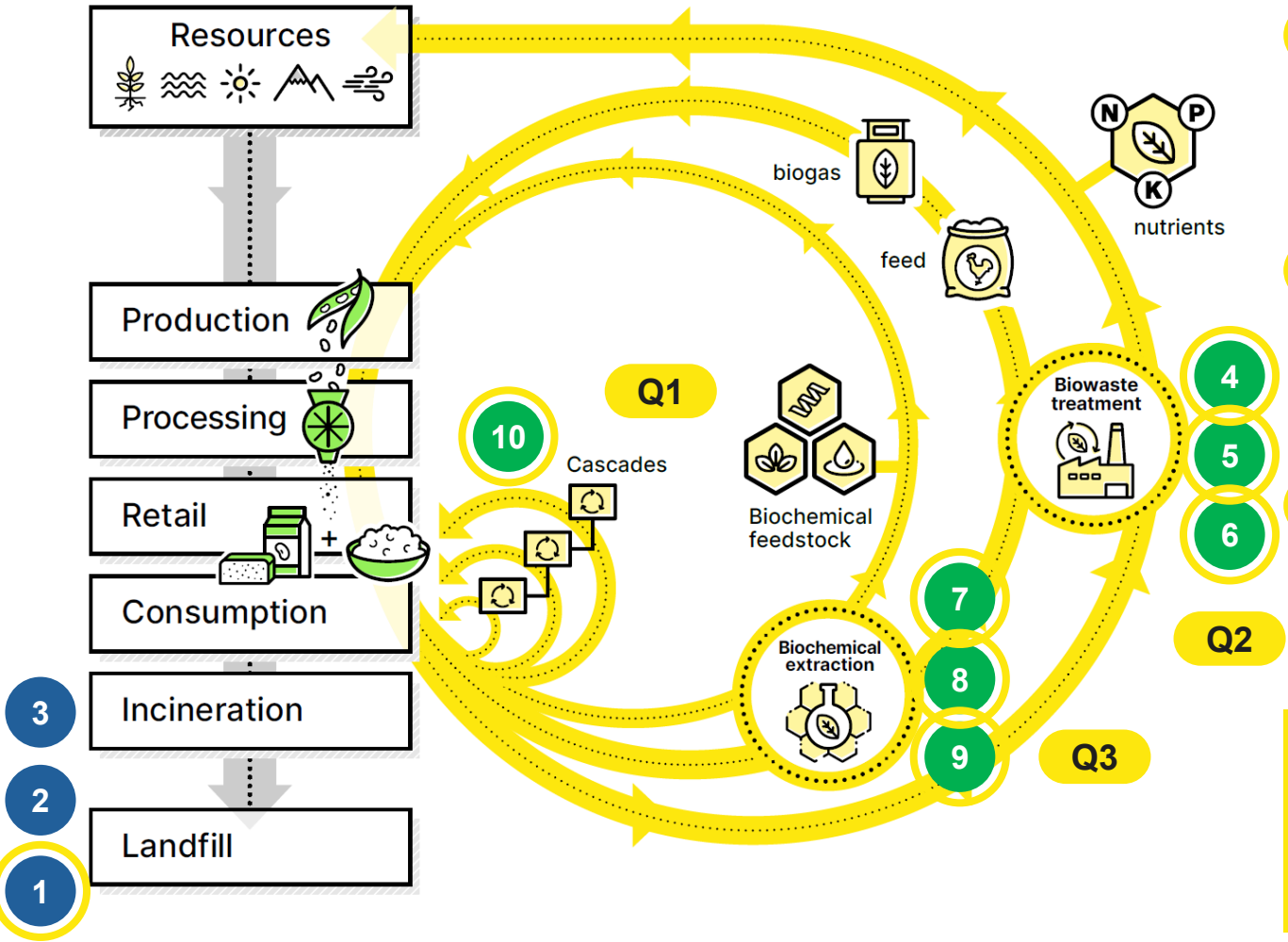
2 **Levers:** lower-energy drying, membrane separation, better enzymes

3 **Screen again:** lower burden, higher recovery, larger credit

Same logic elsewhere: biological, control NH_3 · extraction, cut energy · all routes, secure a market

Rohrer et al. (2025), Sections 3.2 and 4.

Conclusions: **our three questions, answered**



Adapted from Rohrer et al. (2025), Figure 1.

Q1 How do circular routes compare?

Replacing soy products performs best (S7, S8, S10); uncontrolled dumping is worst (S1)

Q2 Where are the hotspots?

Hotspots: ammonia in biological treatment (S4–S6), drying energy in extraction

Q3 Can screening guide development?

Yes: screening showed the lab where to start, drying and recovery (S9)

For side-stream screening LCAs:

- make substitution explicit and report two weighting methods.
- Screening shows direction, not final rankings.

Thank you for your attention



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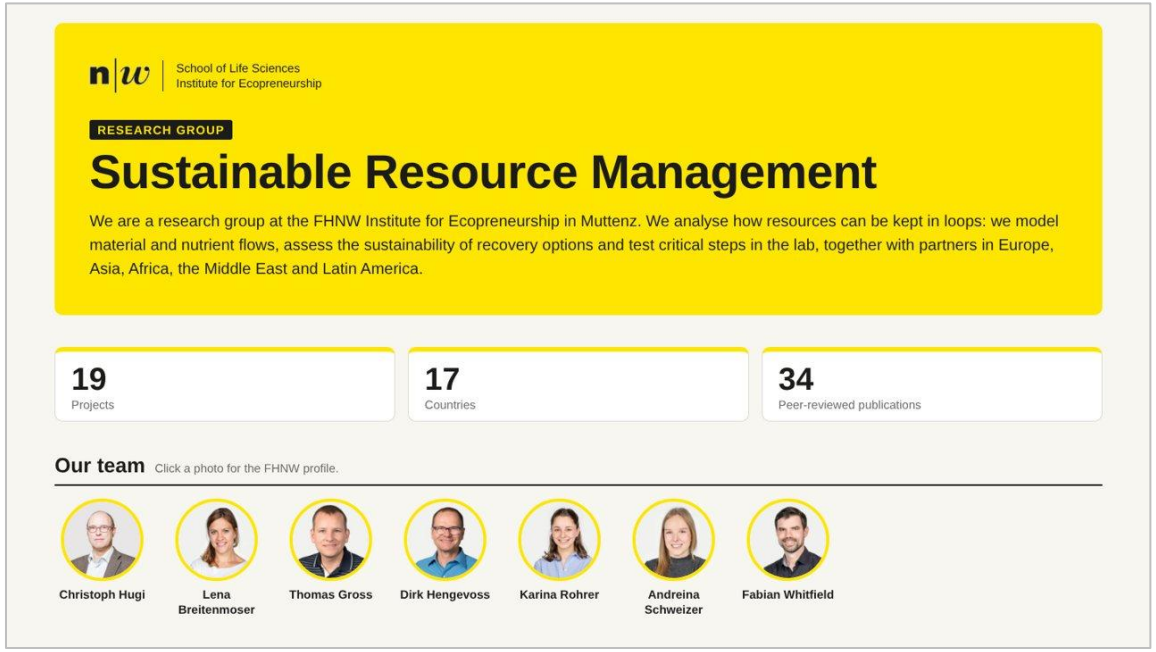

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