

Upcycling of Brewer's Spent Grain: Life Cycle Sustainability Assessment of the CHEERS Biorefinery

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Brewer's spent grain (BSG): a side stream from brewing process

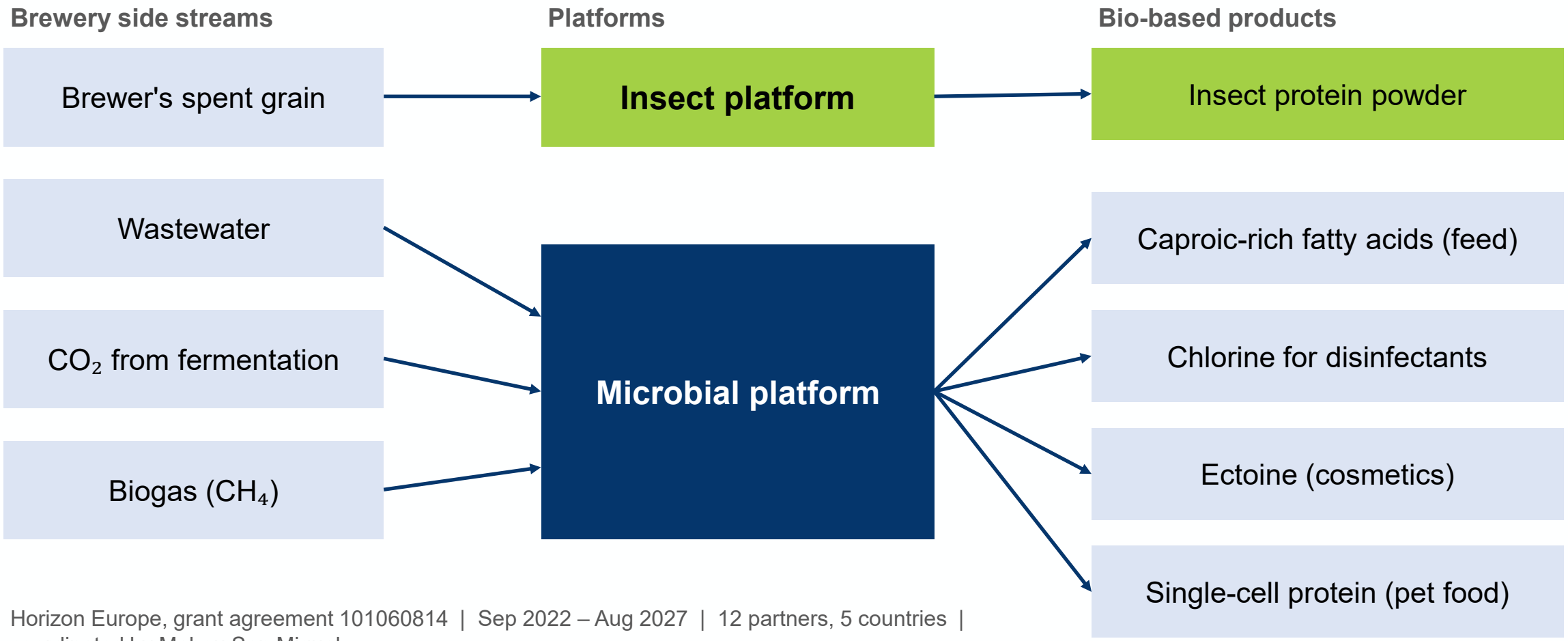
- The bioeconomy is essential for the EU Green Deal to reach its climate and energy goals by 2030 and climate neutrality by 2050, while combating biodiversity loss and pollution
- One key opportunity within the bioeconomy is the valorisation of under-utilised side streams.

CHEERS

CHEERS valorises under-utilised brewery by-streams into five high value-added bio-products through a biorefinery approach

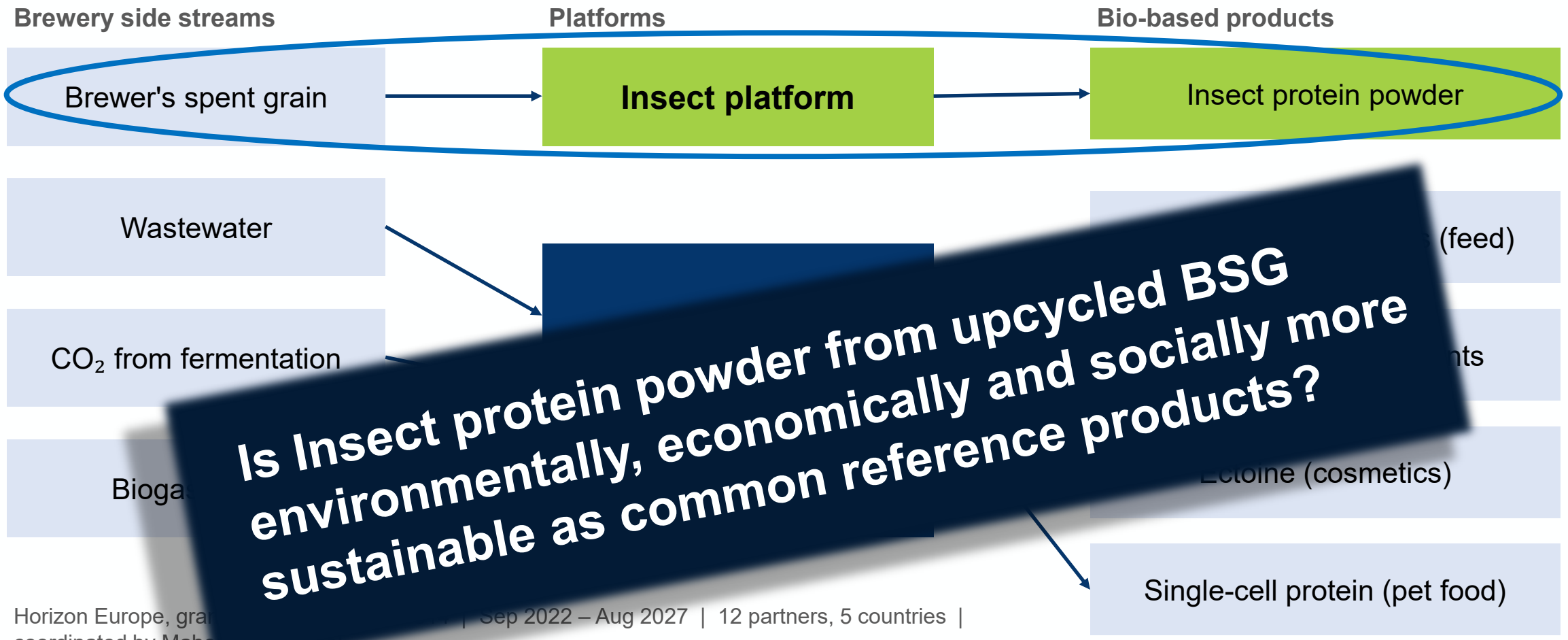


CHEERS: four brewery side streams, two platforms, five products



Horizon Europe, grant agreement 101060814 | Sep 2022 – Aug 2027 | 12 partners, 5 countries | coordinated by Mahou San Miguel

CHEERS: four brewery side streams, two platforms, five products



Is Insect protein powder from upcycled BSG environmentally, economically and socially more sustainable as common reference products?

Horizon Europe, gra | Sep 2022 – Aug 2027 | 12 partners, 5 countries |
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System boundary: from brewer's spent grain to defatted protein powder

Foreground system (cradle-to-gate)



BSG from the Brewery

40 % of feed dry matter



Wheat bran

60 % of the Feed

Beetle maturing tray (CHEERS)



Larvae production

Rearing, blanching, drying, ES

Screw press (CHEERS)



Defatting and milling

Screw press, jet mill, PT

Oil → Co-Product
(Economic Allocation)

Insect protein powder (CHEERS)

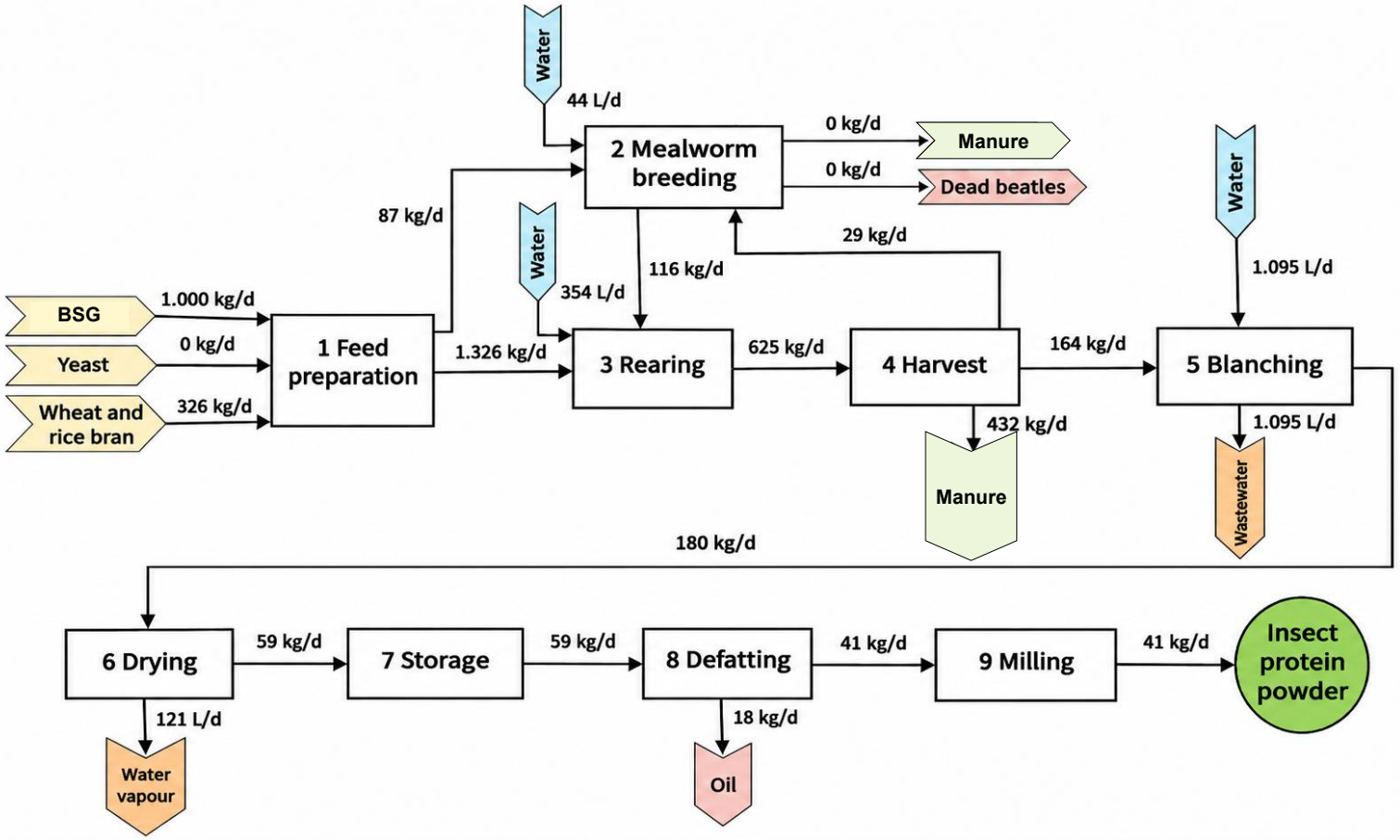


Insect protein powder

FU: 1 kg, ~80 % protein content*

*final lab confirmation pending

Insect platform: process flow used for inventory



Process flow diagram, bagasse diet, flows per day (23 Oct 2026)

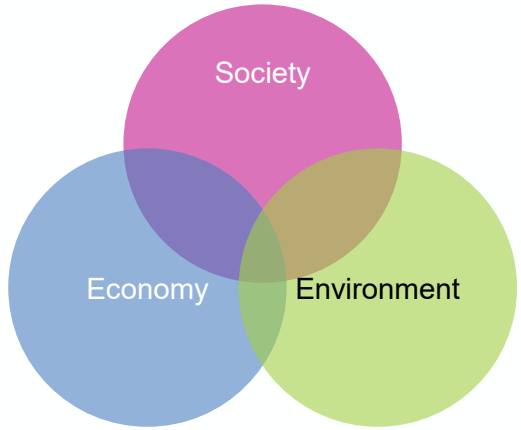
- Larvae production at pilot plant in Spain; defatting and milling in Portugal
- Feed: BSG with wheat bran, second option with spent yeast currently in validation
- Inventory & Energy use extrapolated from one producing module over 155 days

From LCA to LCSA to HILCSA

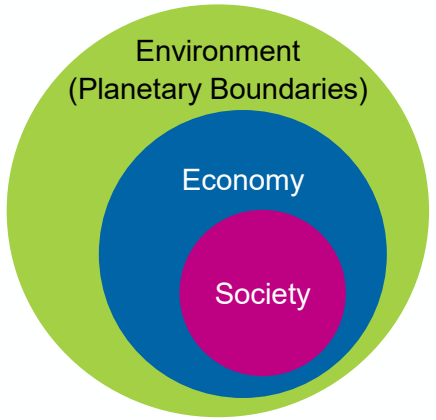
Life Cycle Assessment (LCA)	Life Cycle Sustainability Assessment (LCSA)	Holistic and Integrated Life Cycle Sustainability Assessment (HILCSA)
Assessment of the **environmental** impacts of products and services	Assessment of the **environmental, economic and social impacts** of products and services	**Integrated and holistic assessment** of the environmental, economic and social impacts of products and services



Environment only



Three-pillar model



Humans and nature in relation

Adapted from Kasper & Pfundstein (2026)

HILCSA: one model, one impact assessment, three dimensions

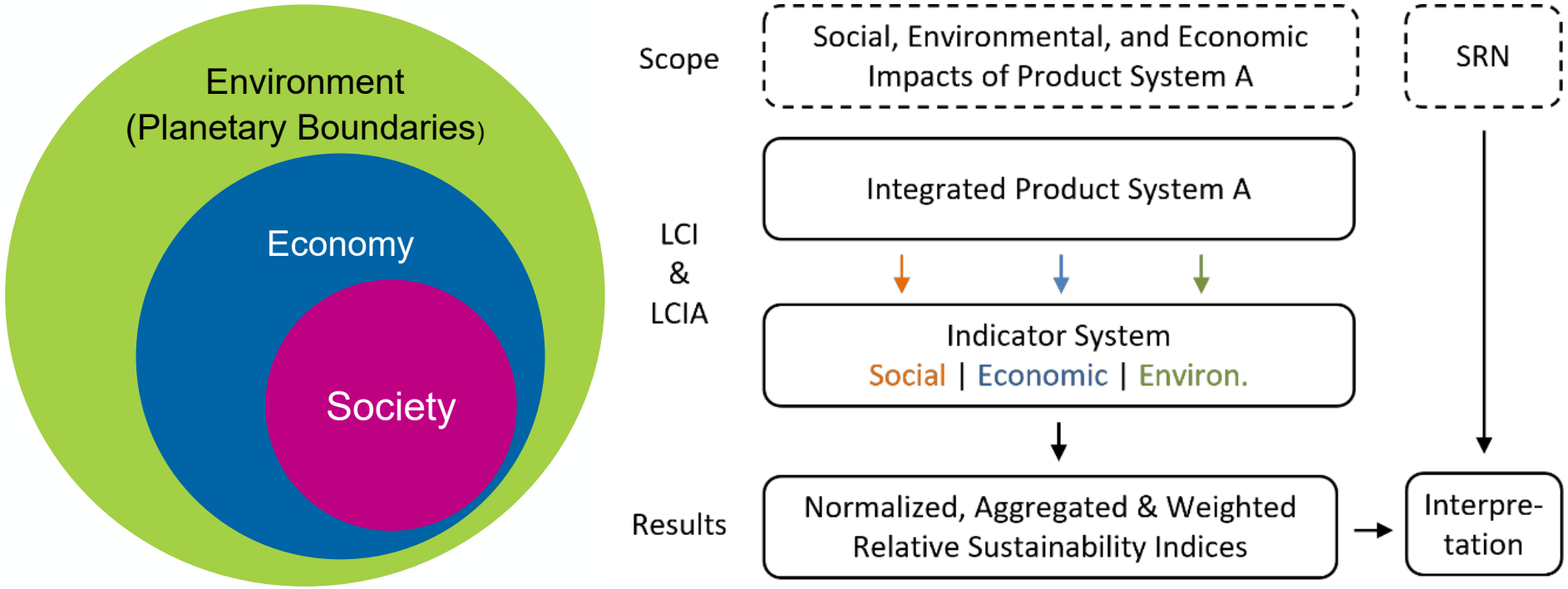


Figure adapted from Zeug et al. (2023); method: Zeug et al. (2021); Pries & Zeug (2026)

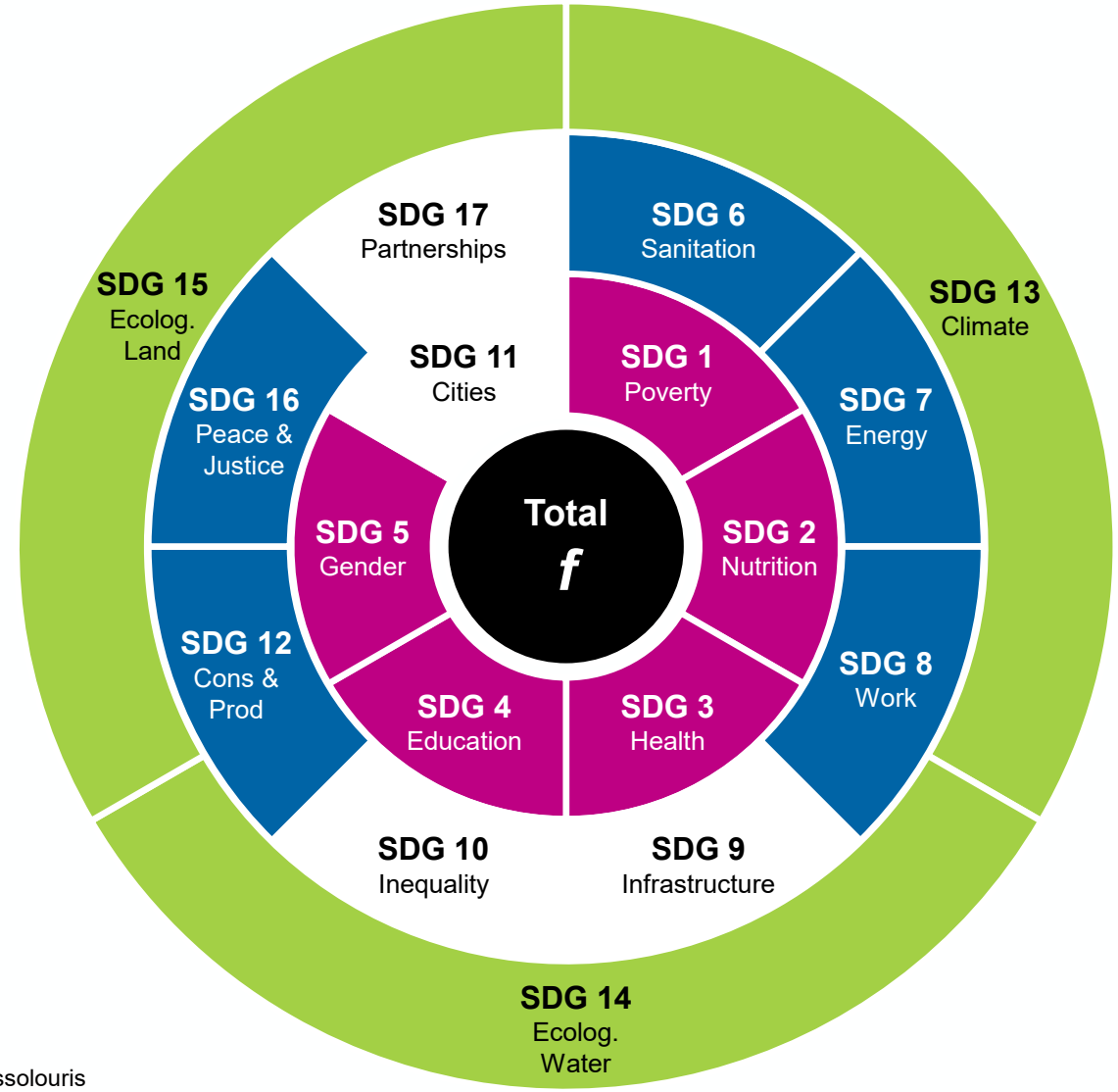
80 indicators covering 13 of 17 SDGs

1 LCIA method in openLCA: HILCSA v2.3

Database: soca v3
Hamed & Ciroth (2024)

A/B **CHEERS Result (A) relative to a reference product (B)**

HILCSA: one model, one impact assessment, three dimensions



80 Indicator
f = A_CHEERS / B_Ref.

↓

SDG
Mean of x Indicators

↓

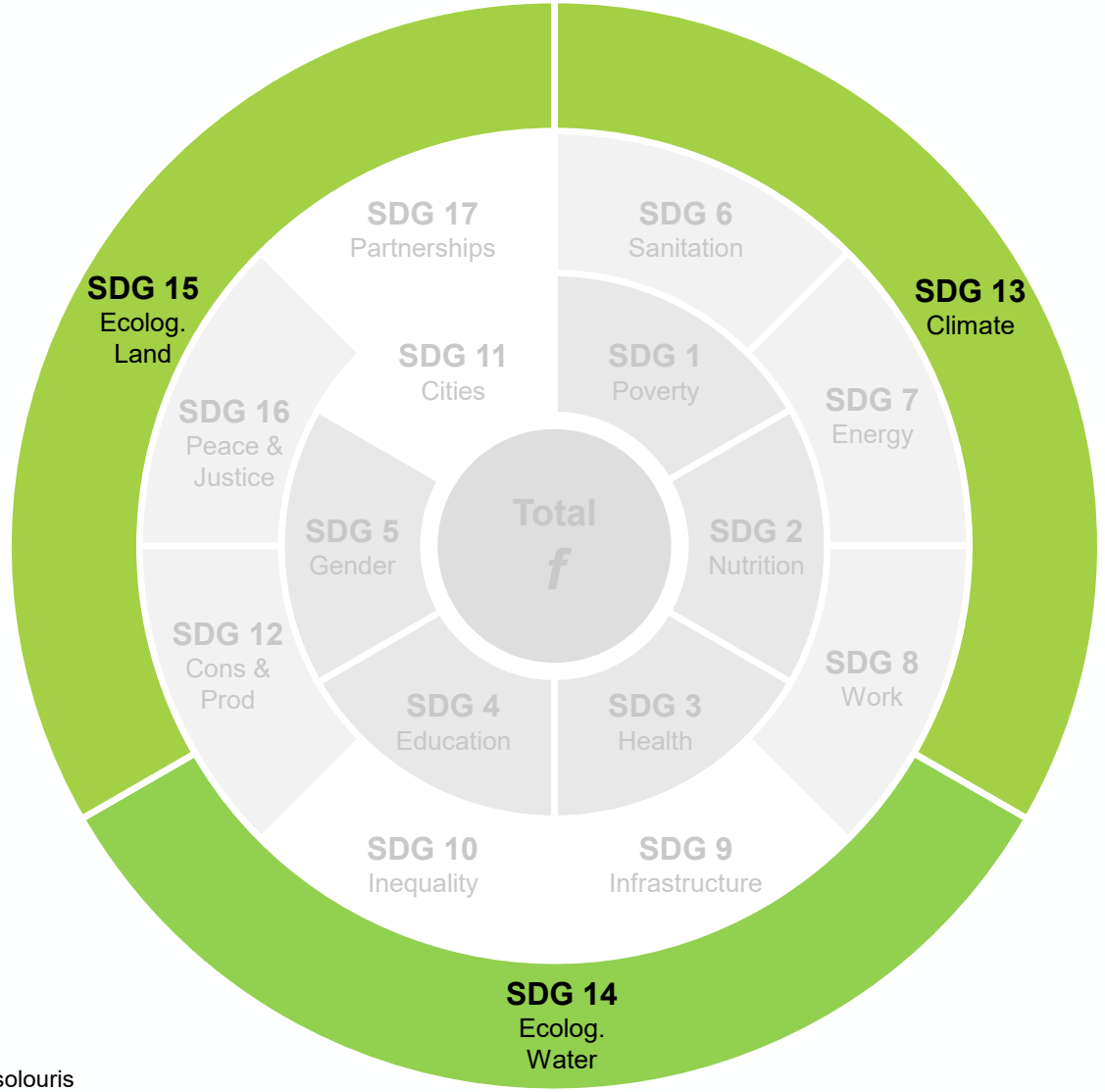
Dimensions
Planetary Boundaries, Economy, Society

↓

Total f
Substitution Factor of Impact

HILCSA: one model, one impact assessment, three dimensions

Outer ring – Planetary Boundaries
SDG 13–15



18 of 80 Indicator
f = A_CHEERS / B_Ref.

↓

SDG 13, 14 and 15
Geometric Mean

↓

Dimension
Planetary Boundaries

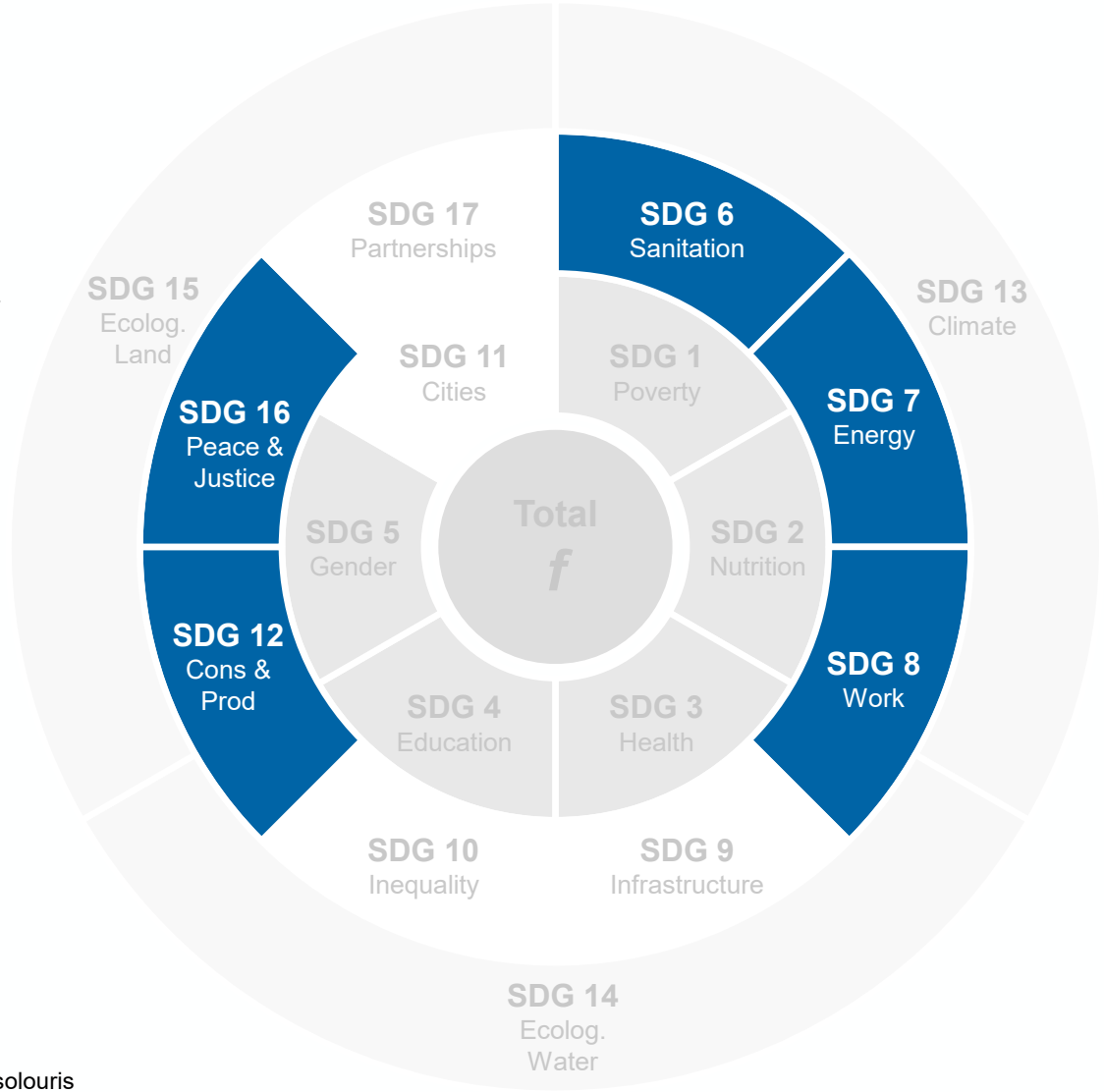
↓

Dimension f
Substitution Factor of Impact

HILCSA: one model, one impact assessment, three dimensions

Outer ring – Planetary Boundaries
SDG 13–15

Middle ring – Economy
SDG 6–10, 12, 16 and 17



42 of 80 Indicator
f = A_CHEERS / B_Ref.

↓

SDG 6, 7, 8, 12 & 16
Geometric Mean

↓

Dimension
Economy

↓

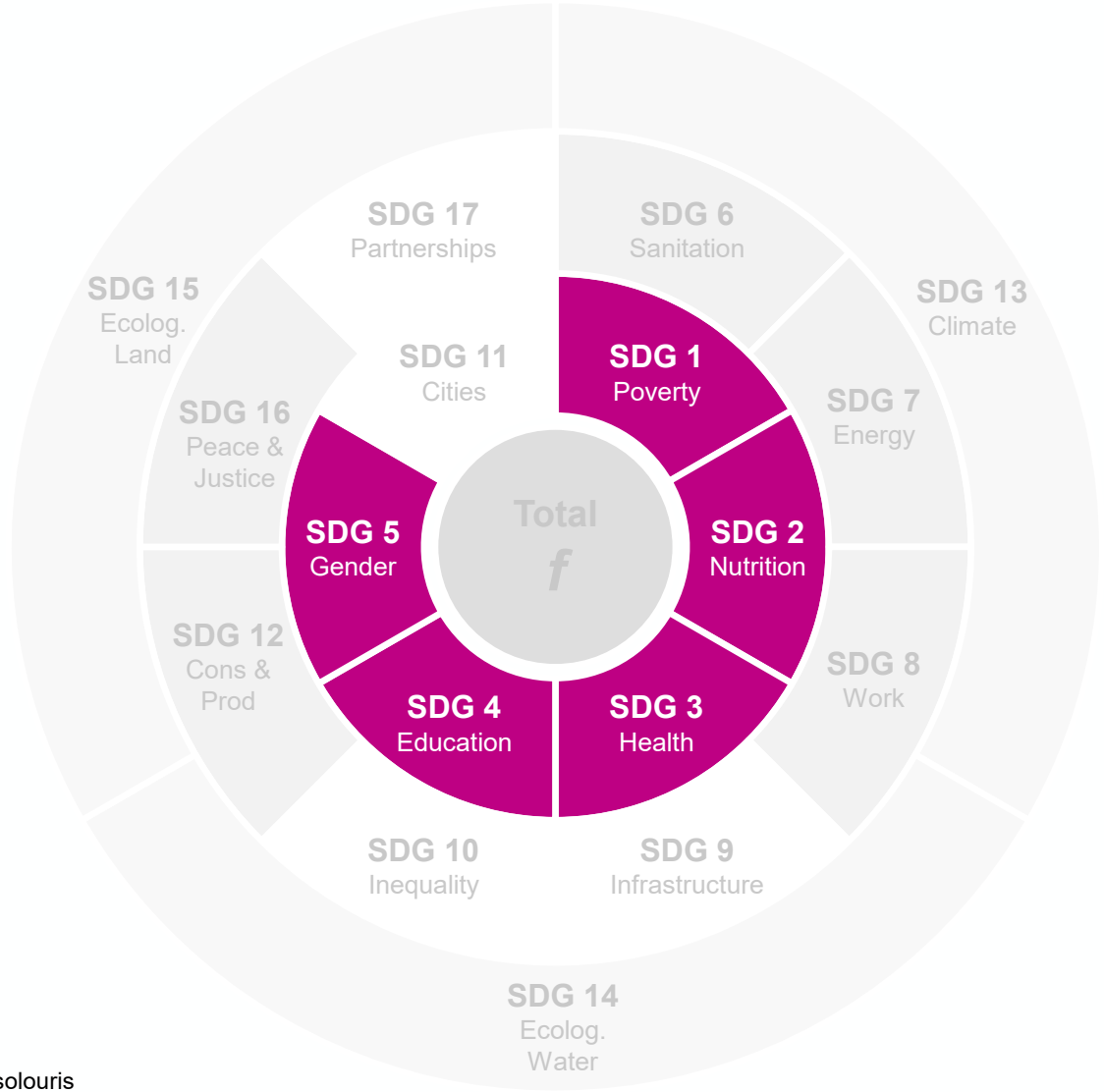
Dimension f
Substitution Factor of Impact

HILCSA: one model, one impact assessment, three dimensions

Outer ring – Planetary Boundaries
SDG 13–15

Middle ring – Economy
SDG 6–10, 12, 16 and 17

Inner ring – Society
SDG 1–5 and 11



20 of 80 Indicator
f = A_CHEERS / B_Ref.

↓

SDG 1, 2, 3, 4 & 5
Geometric Mean

↓

Dimension
Society

↓

Dimension f
Substitution Factor of Impact

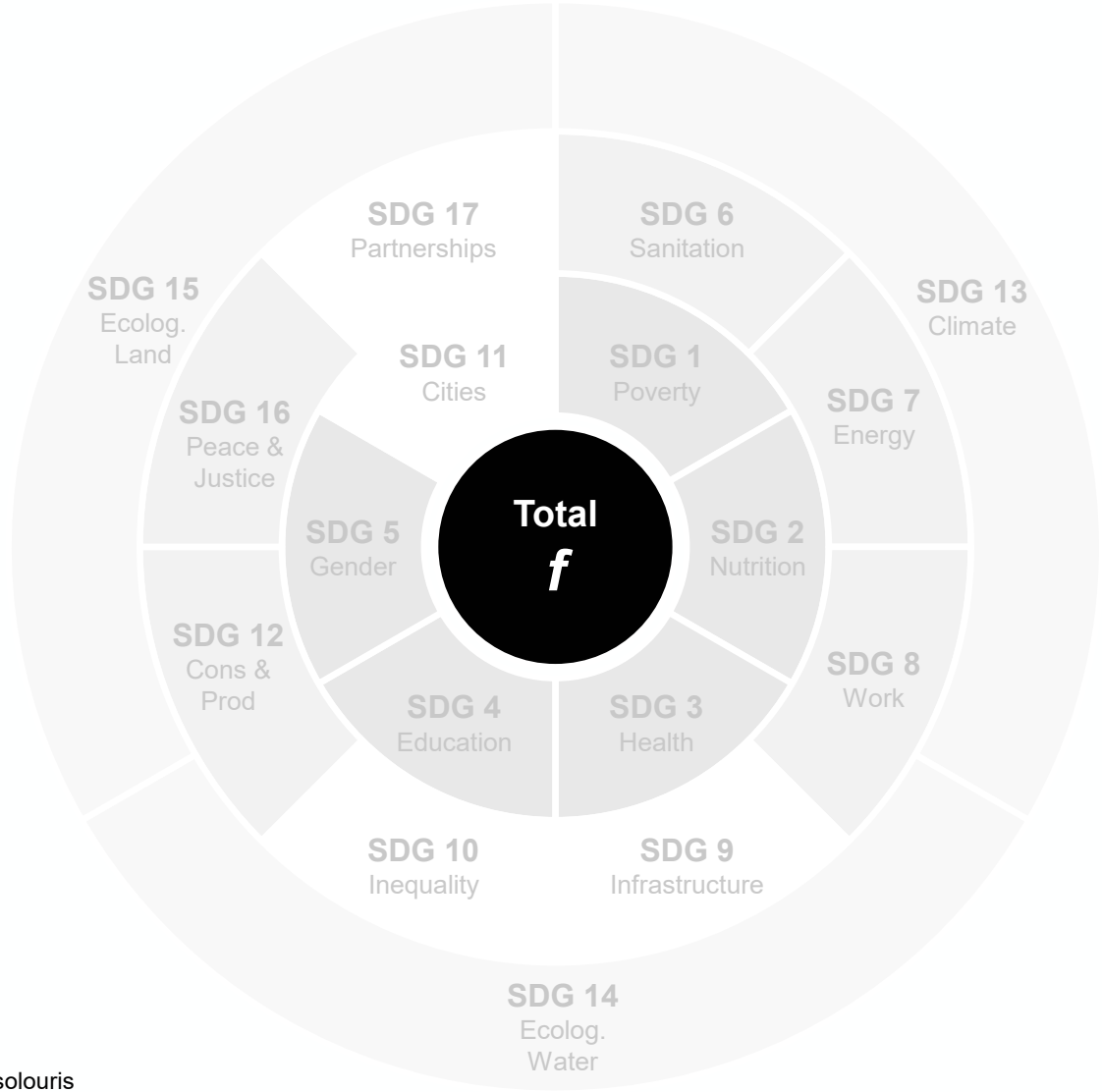
HILCSA: one model, one impact assessment, three dimensions

Outer ring – Planetary Boundaries
SDG 13–15

Middle ring – Economy
SDG 6–10, 12, 16 and 17

Inner ring – Society
SDG 1–5 and 11

Centre
Total substitution factor f (all SDGs combined)



All 80 Indicator
f = A_CHEERS / B_Ref.

↓

All SDG
Geometric Mean

↓

Dimensions
Planetary Boundaries, Economy, Society

↓

Total f
Substitution Factor of Impact

HILCSA: one model, one impact assessment, three dimensions

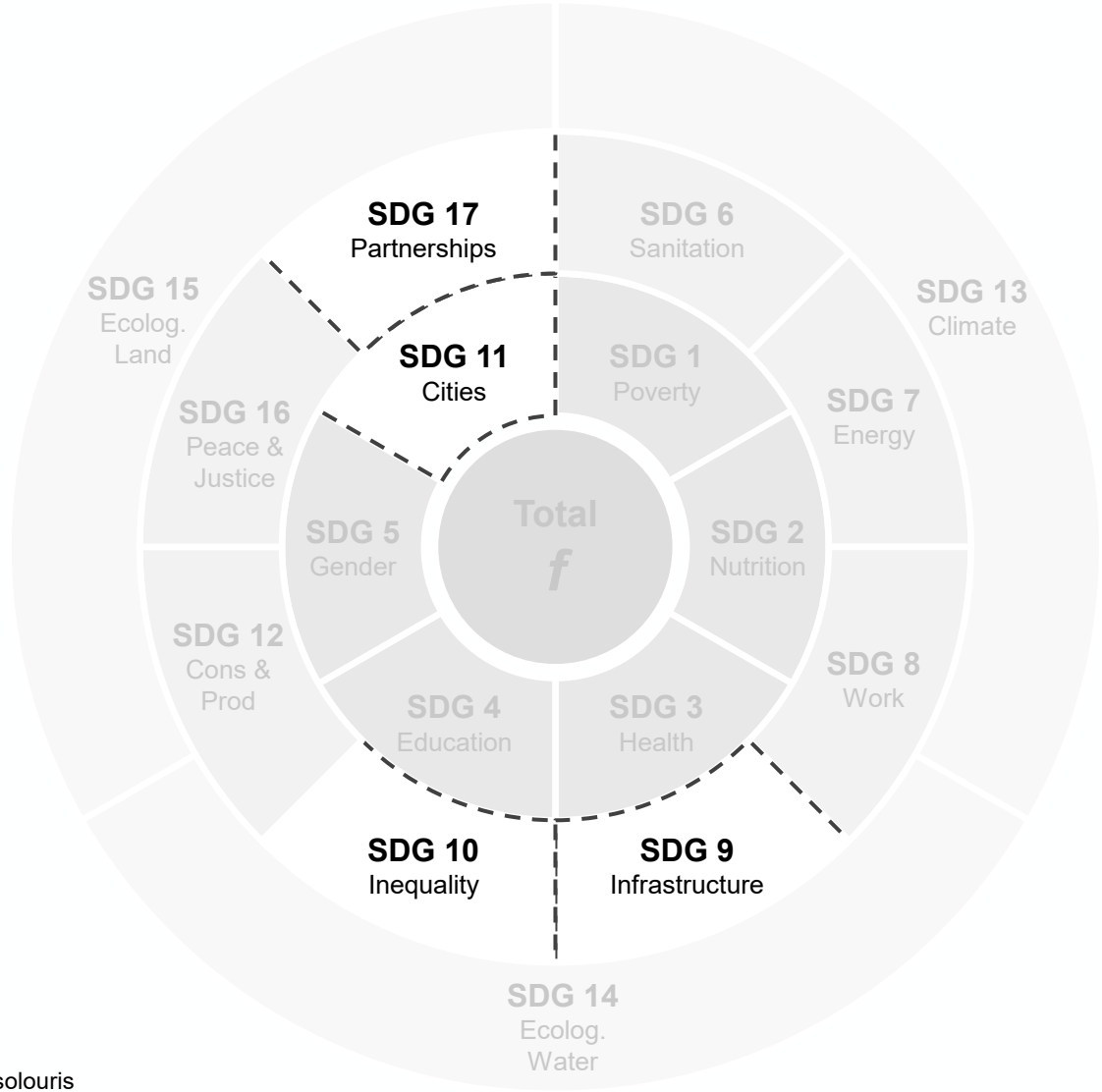
Outer ring – Planetary Boundaries
SDG 13–15

Middle ring – Economy
SDG 6–10, 12, 16 and 17

Inner ring – Society
SDG 1–5 and 11

Centre
Total substitution factor f (all SDGs combined)

White segments
SDG not addressed by HILCSA



0 of 80 Indicator
f = A_CHEERS / B_Ref.

↓

SDG 9, 10, 11 & 17
Geometric Mean

↓

Dimensions
Economy, Society

↓

No f
No Substitution Factor of Impact

CHEERS product vs. Three References

A

CHEERS insect protein powder

Yellow mealworm fed with BSG and wheat bran, defatted and milled

Larvae production ES, processing PT

vs.

B1 Whey protein

Whey protein, Italy (Bacenetti et al., 2018)

Animal protein

B2 Pea protein

80 % protein, Spain (extrapolated soca v3 dataset)

Plant protein

B3 Mealworm protein

Yellow mealworm protein, small-scale, Austria (Dreyer et al., 2021)

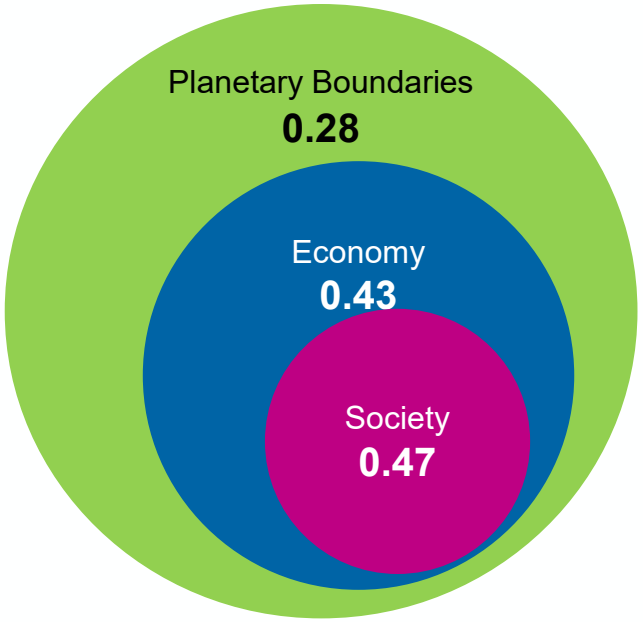
Same species, different feed and scale

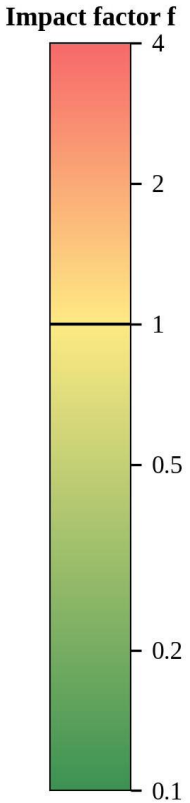
Same basis for all: 1 kg, equal protein content (80 %), cradle-to-gate | f = A / B per indicator | f < 1: A is more sustainable

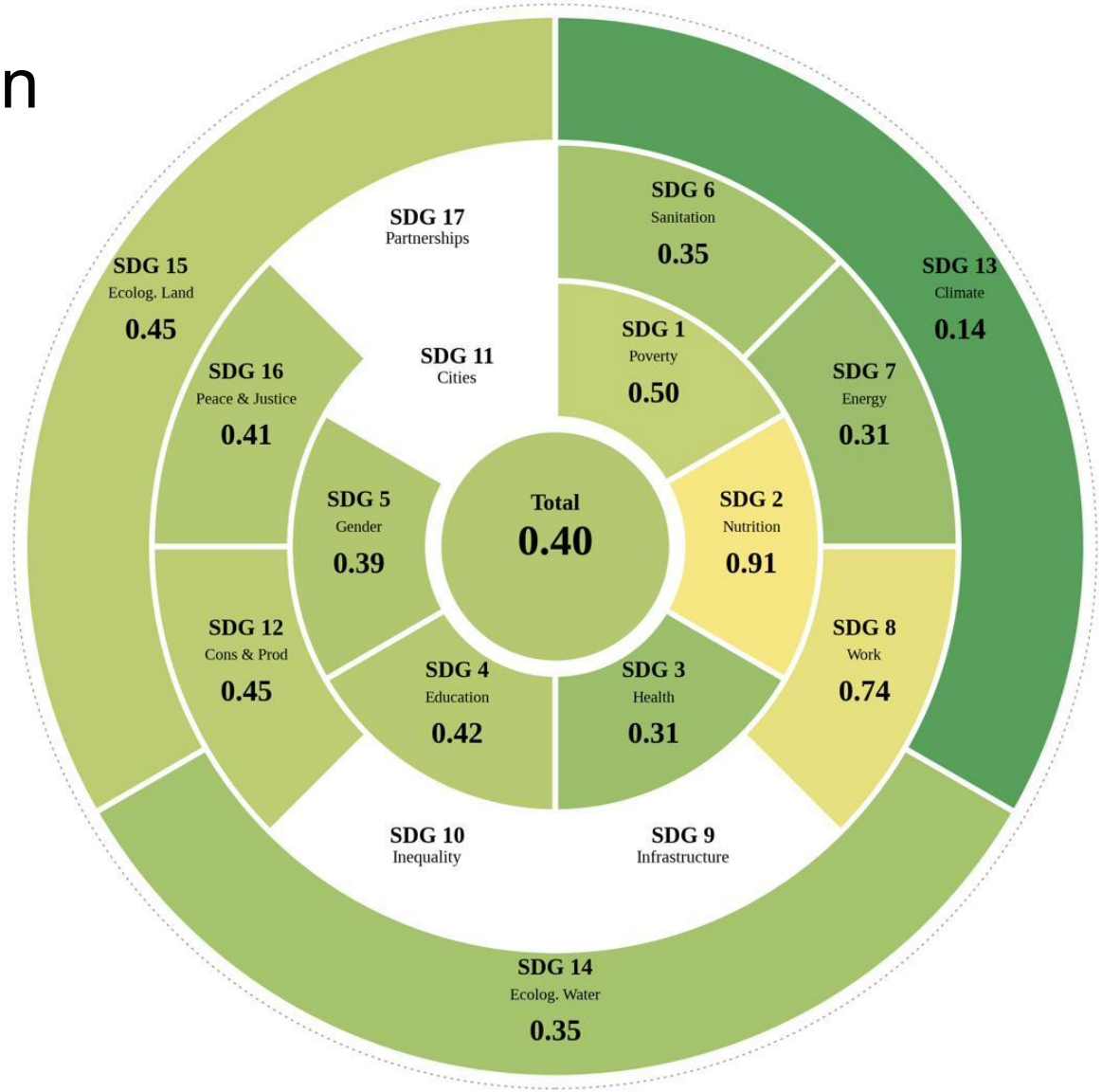
Insect protein powder vs. Whey protein

A: CHEERS insect protein powder (ES/PT)
B1: Whey protein (Bacenetti et al. (2018))

- **Total f = 0.40:** the Insect protein powder causes less than half the impact

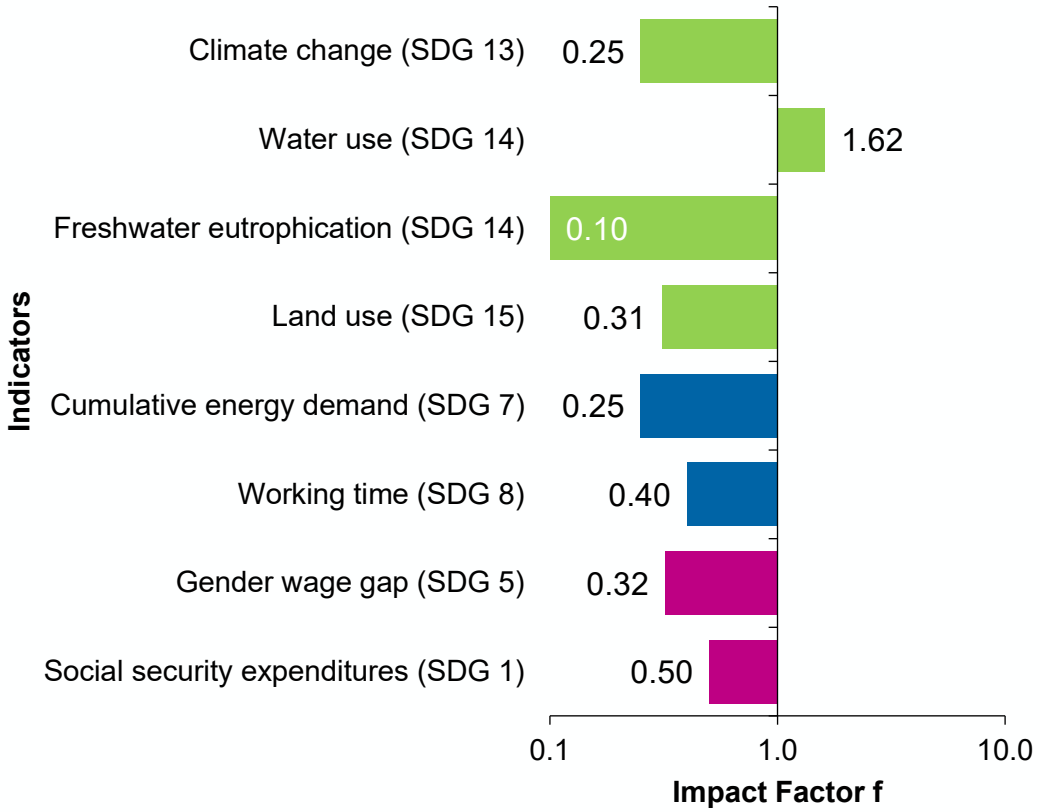






f per SDG = A / B, equal FU; f < 1: A more sustainable. Colour scale 0.1–4 (log), shared by the three comparisons.

Insect protein powder vs. Whey protein



Planetary Boundaries Economy Society

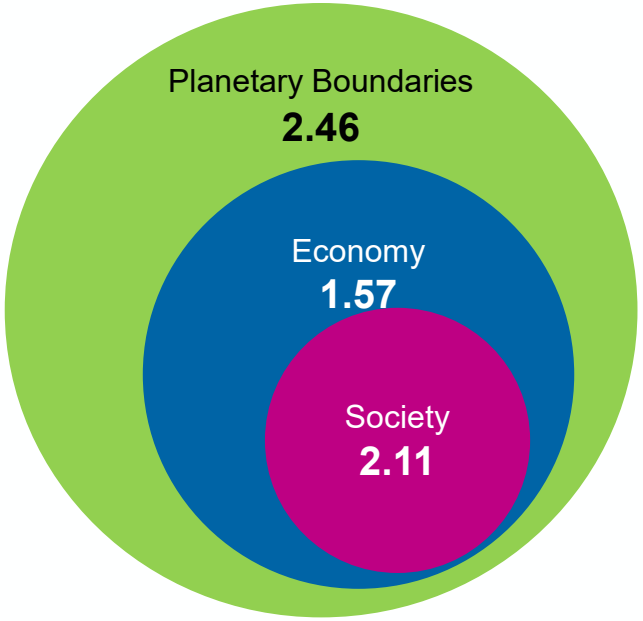
f < 1: CHEERS powder more sustainable; scale 0.1–10

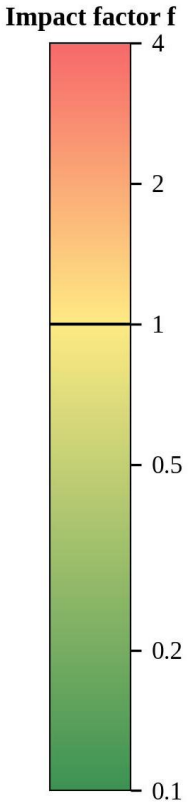
Indicator	A: CHEERS powder	B: Whey protein
Climate change	Wheat bran	European electricity, cheese and milk
Water use	Wheat bran irrigation, barley for beer	Hydropower reservoirs, Polish electricity
Freshwater eutrophication	Wheat farming, coal mining spoil	Lignite mining spoil
Land use	Wheat bran	Milk production
Cumulative energy demand	Spanish electricity	French nuclear fuel chain
Working time	Indian hard coal	European electricity, Indian hard coal
Gender wage gap	South African coal	South African coal
Social security expenditures	Indian hard coal	Indian hard coal, European electricity

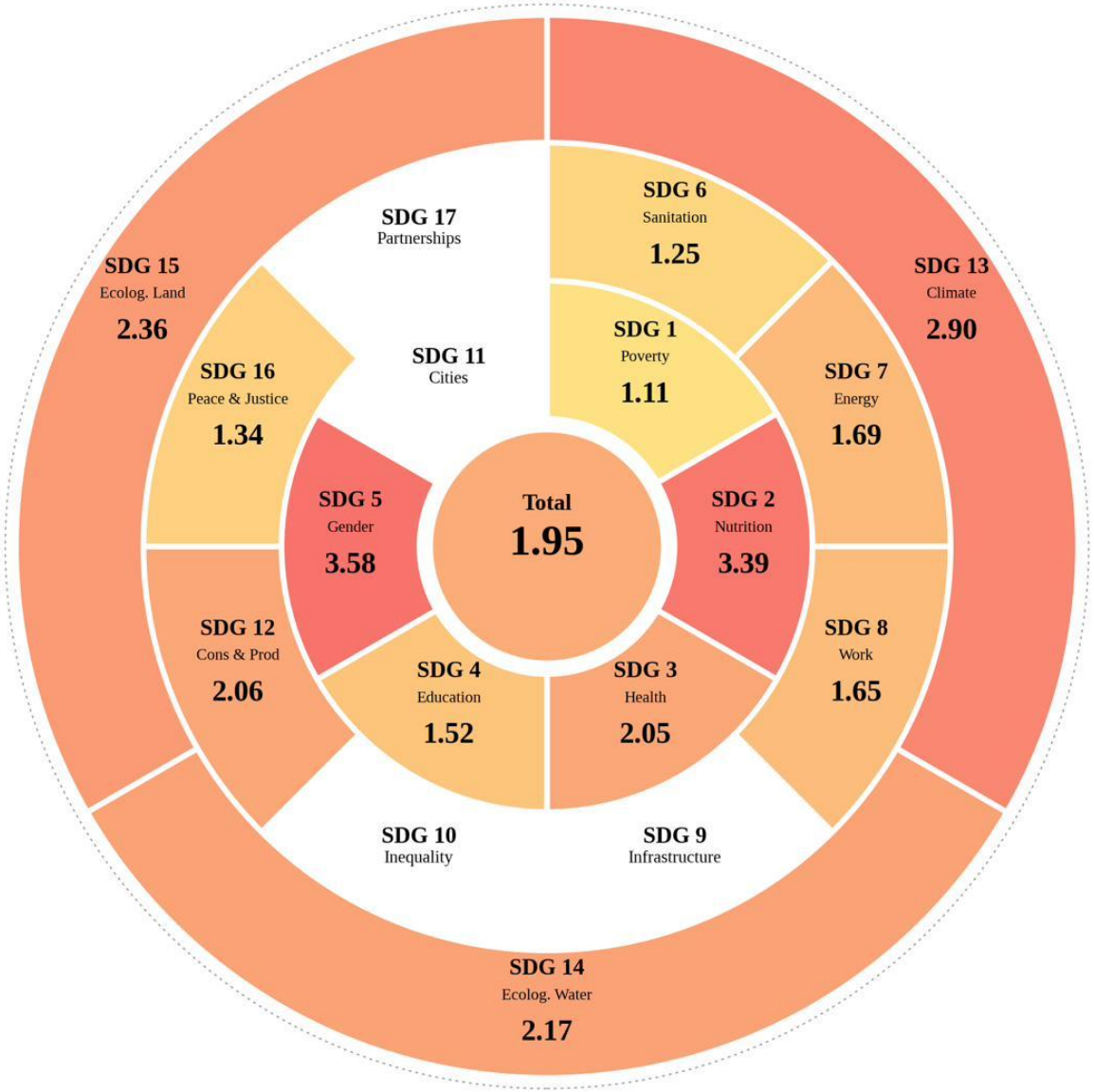
Insect protein powder vs. Pea protein

A: CHEERS insect protein powder (ES/PT)
B2: Pea protein (extrapolated soca v3 dataset)

- **Total f = 1.95:** the Insect protein powder causes almost double the impact

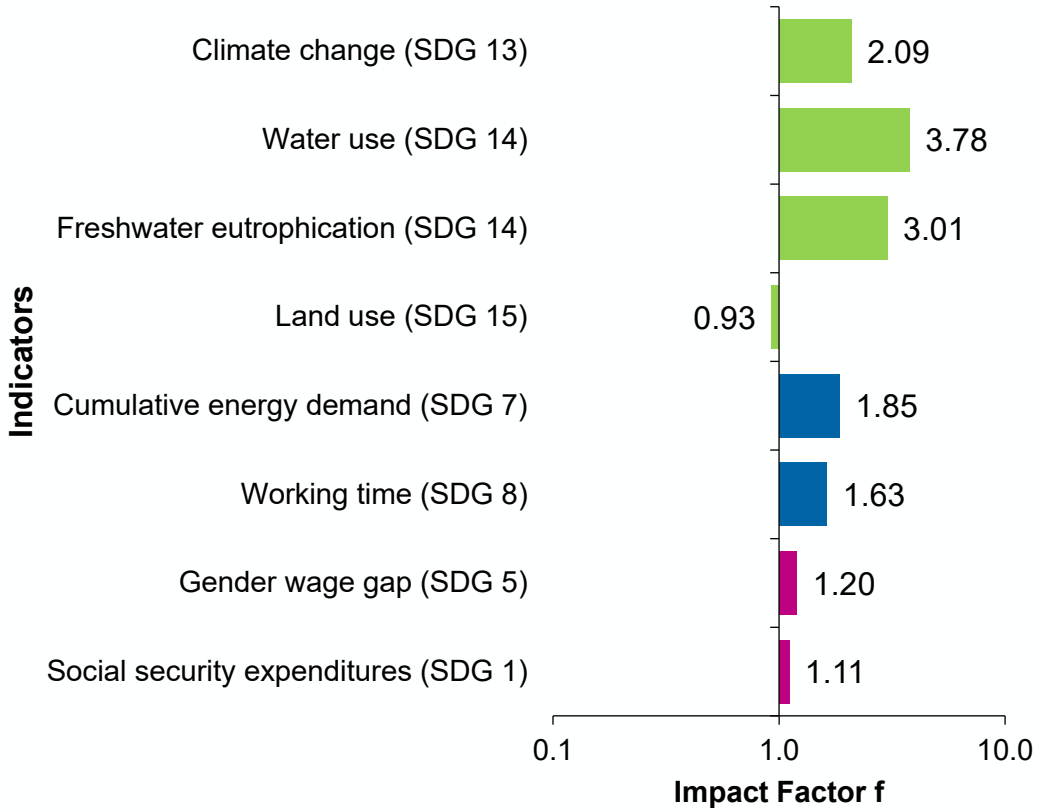






f per SDG = A / B, equal FU; f < 1: A more sustainable. Colour scale 0.1–4 (log), shared by the three comparisons.

Insect protein powder vs. Pea protein



Indicator	A: CHEERS powder	B: Pea protein
Climate change	Wheat bran	Pea farming, process steam
Water use	Wheat bran irrigation, barley for beer	Pea irrigation
Freshwater eutrophication	Wheat farming, coal mining spoil	Pea farming, coal and lignite spoil
Land use	Wheat bran	Pea farming
Cumulative energy demand	Spanish electricity	Pea farming, process steam
Working time	Indian hard coal	Pea farming, Indian hard coal
Gender wage gap	South African coal	South African coal, pea farming
Social security expenditures	Indian hard coal	Pea farming, Indian hard coal

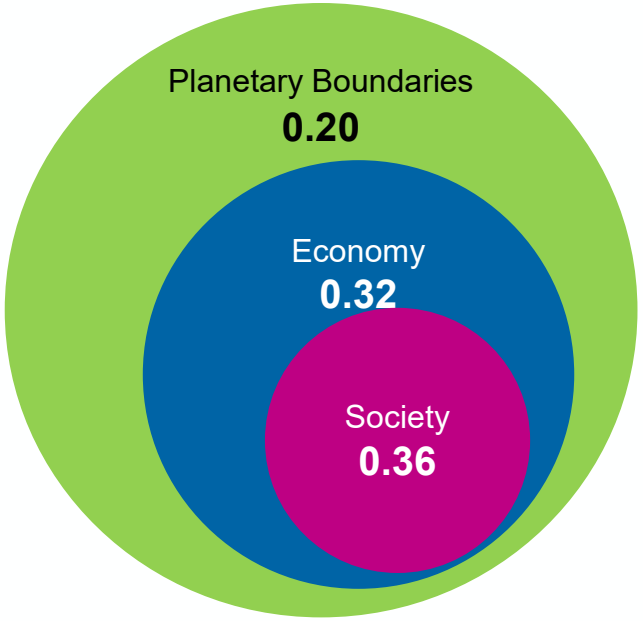
Planetary Boundaries **Economy** **Society**

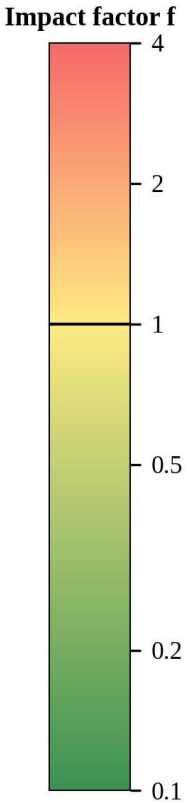
f < 1: CHEERS powder more sustainable; scale 0.1–10

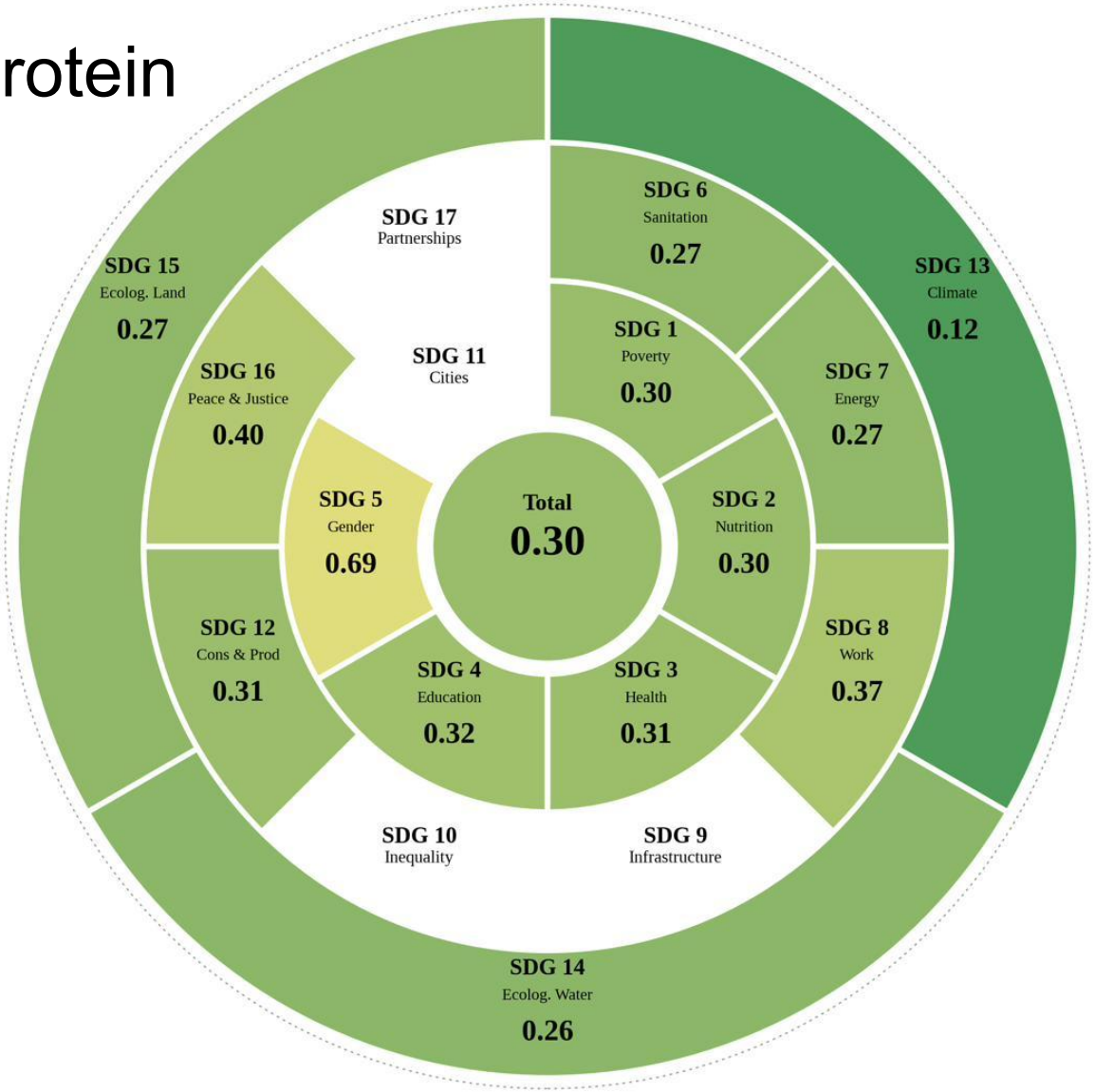
Insect protein powder vs. Mealworm protein

A: CHEERS insect protein powder (ES/PT)
B3: Mealworm protein (AT) (Dreyer et al. (2021))

- **Total f = 0.30:** the Insect protein powder causes less than a third the impact
- the most direct comparison, same species

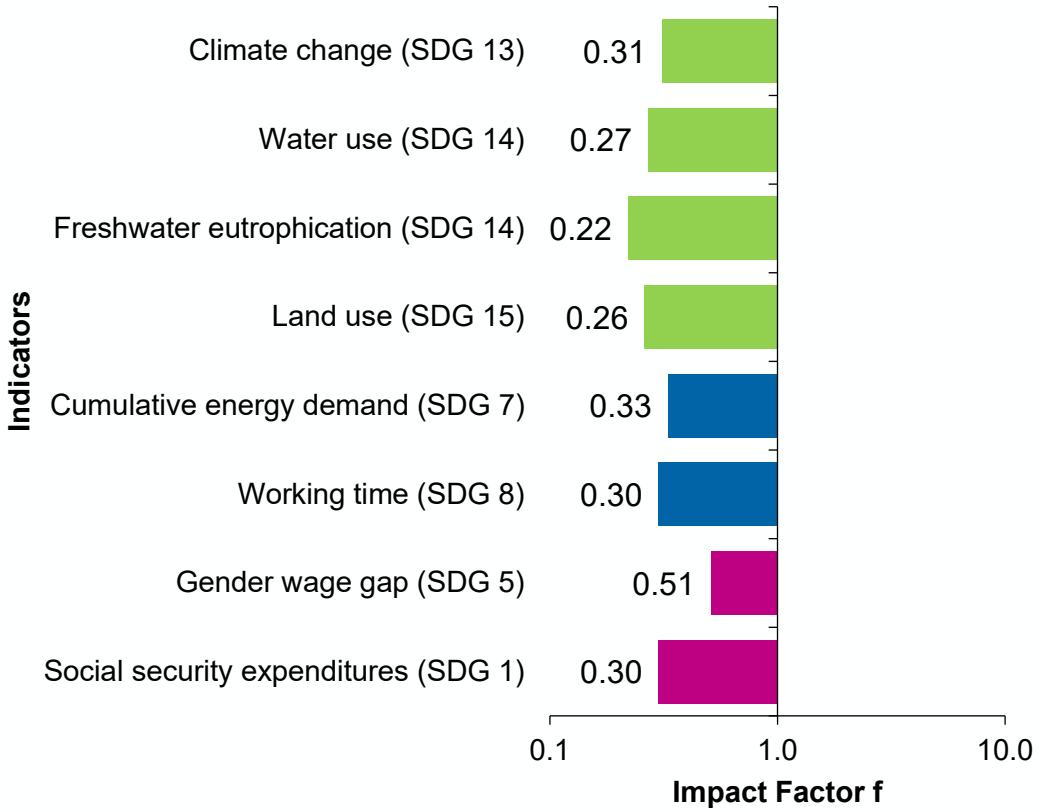






f per SDG = A / B, equal FU; f < 1: A more sustainable. Colour scale 0.1–4 (log), shared by the three comparisons.

Insect protein powder vs. Mealworm protein



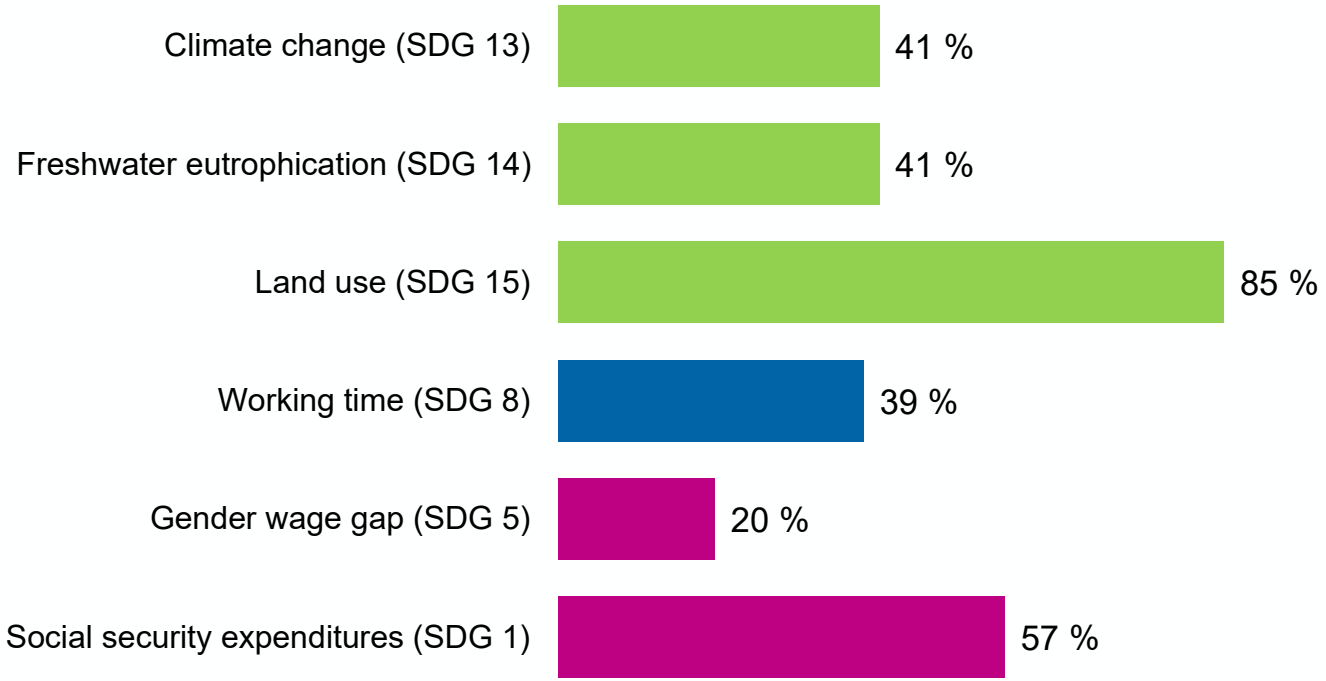
Planetary Boundaries Economy Society

f < 1: CHEERS powder more sustainable; scale 0.1–10

Indicator	A: CHEERS powder	B: Mealworm protein
Climate change	Wheat bran	Wheat bran, carrots, Austrian electricity
Water use	Wheat bran irrigation, barley for beer	Irrigation
Freshwater eutrophication	Wheat farming, coal mining spoil	Lignite mining spoil, Austrian electricity
Land use	Wheat bran	Wheat bran
Cumulative energy demand	Spanish electricity	Austrian electricity
Working time	Indian hard coal	Carrots, Indian hard coal
Gender wage gap	South African coal	South African coal
Social security expenditures	Indian hard coal	Indian hard coal

The co-feed, not the side stream, drives the impact

Share of wheat bran in the CHEERS powder



6 %

of climate change comes from BSG itself (10 % of land use)

Further drivers

Spanish electricity: 26 % of climate change

Natural gas heat for drying: 17 % of climate change

Background of all products: coal mining in India in the social indicators

Could we answer our question?

Is insect protein powder upcycled from BSG environmentally, economically and socially more sustainable as common reference products?

vs. Whey protein powder

Yes

Total f = **0.40**
in 67 of 80 indicators
more sustainable

0.28	0.43	0.47
Planetary Boundaries	Economy	Society

vs. Pea protein powder

Not yet

Total f = **1.95**
in 13 of 80 indicators
more sustainable

2.46	1.57	2.11
Planetary Boundaries	Economy	Society

vs. Mealworm protein (w/o side stream feed)

Yes

Total f = **0.30**
in 75 of 80 indicators
more sustainable

0.20	0.32	0.36
Planetary Boundaries	Economy	Society

Upcycled insect protein can compete with animal proteins, but not yet with plant protein

Limitations

Method: HILCSA and soca

- Results are relative: f depends on the chosen reference
- Geometric mean without weighting: strengths and weaknesses average out
- Social data are risk-based sector averages (PSILCA), less developed than environmental LCA data
- soca v3 is not the latest version; update to soca v5 expected with more regionalised processes

Data and model

- Pilot data from one producing module, projected to industrial scale
- Protein content of 80 % assumed for all products; lab analysis pending
- Reference datasets from different sources
- Economic dimension via SDG indicators

Conclusion

1

More sustainable than animal proteins

f = 0.40 vs. whey protein powder, 0.30 vs. mealworm protein (AT), in all three dimensions

2

Plant protein remains ahead

f = 1.95 vs. pea protein powder; the gap comes from the wheat bran co-feed and energy

3

The co-feed decides

Wheat bran drives most indicators, BSG only about 6 % of impacts: the feed is the main lever

Next steps

Model	Data	Scenarios	CHEERS
Update to HILCSA v3 with soca v5 (End of 2026) and further evaluate the method	Lab analysis of the protein content; final validation of the inventory with the partners	Feed conversion ratio (FCR) of the larvae; feed with spent yeast and less wheat bran; renewable energy	LCSA of the microbial platform value chains; synthesis at biorefinery level

Thank you for your attention

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