A DISCUSSION FORUM ON LIFE CYCLE ASSESSMENT

JLU
NEUE WEGE. SEIT 1607.

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

Faculty 09 - Agricultural Sciences, Nutritional Sciences, and Environmental Management

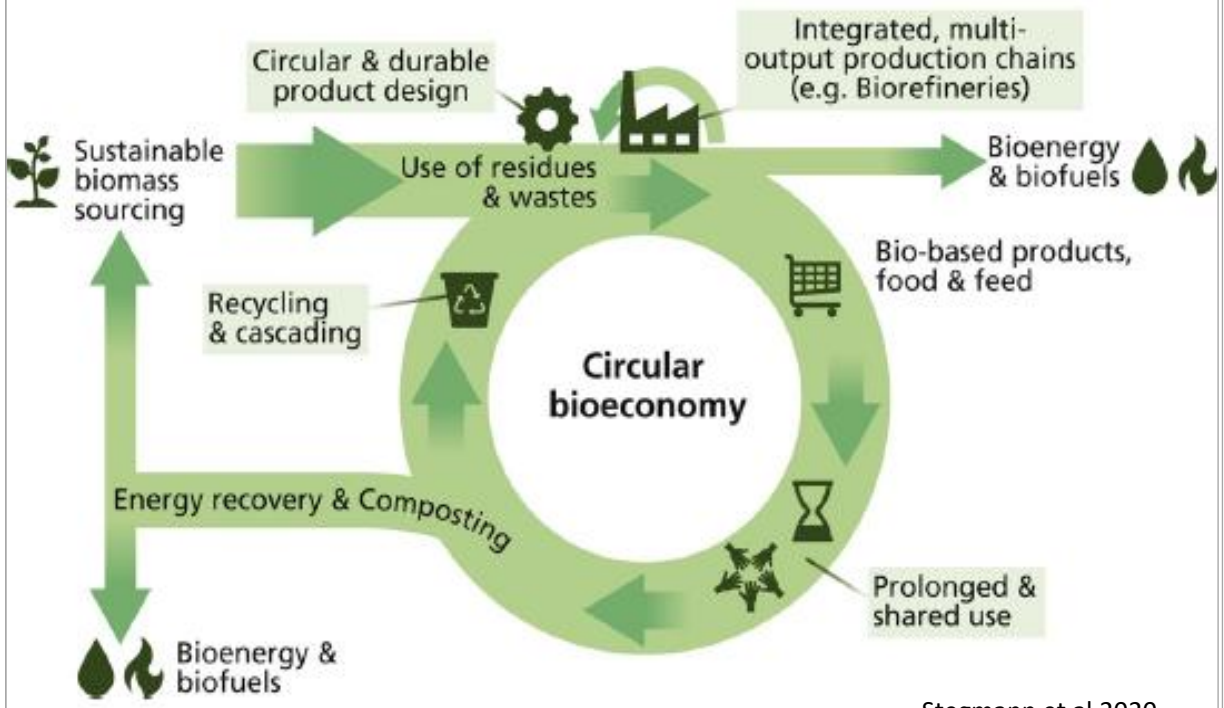
Methodological and data challenges in the assessment of by-product valorisation – and approaches to address them

Introduction- circular bioeconomy (CBE)

Feedstock

- Use of **biobased residues** as feedstock
- potentially offering more sustainable alternatives compared to the use of cultivated biomass

Circular bioeconomy



Stegmann et al.2020

Valorisation

- Use as feedstock in (new) **valorisation processes** to produce (high-value) food, feed, biochemicals, biomaterials
- **High-quality biowaste treatment**

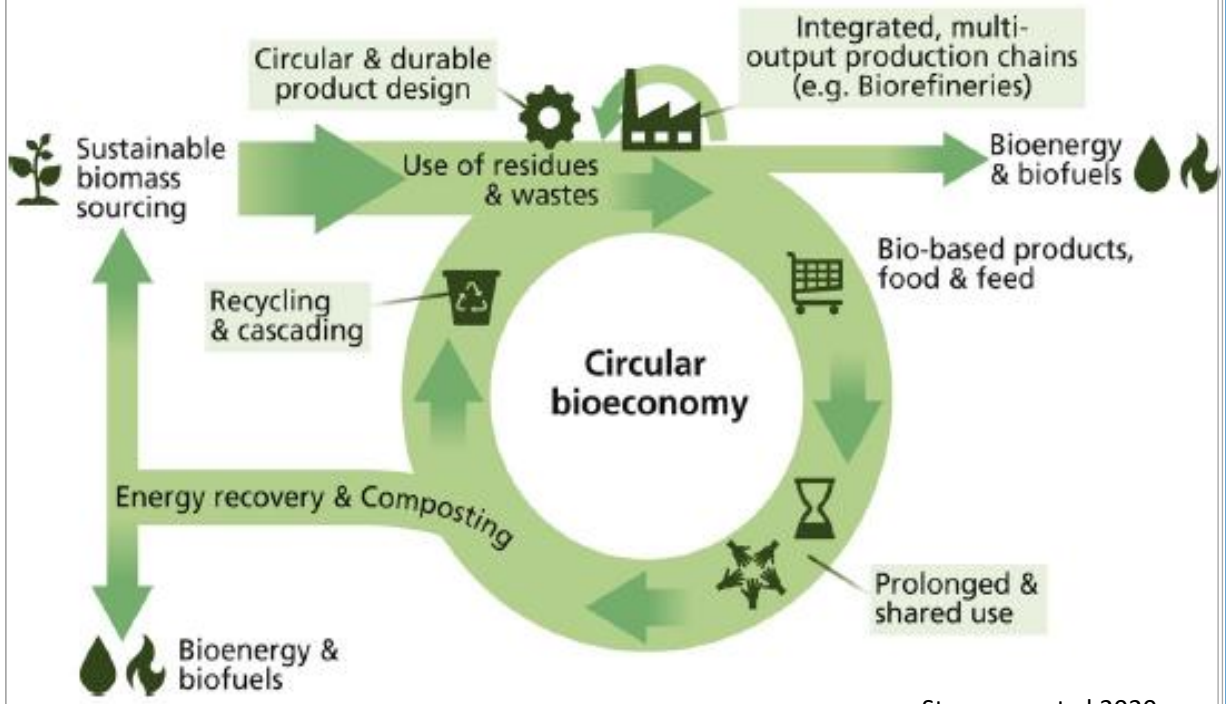
*"…CBE research is not yet significantly mirrored by the market, showing that its full potential is still **far from being realized**"*
*"need to develop further evidence that CBE-inspired products are indeed preferable to their fossil-based counterparts.. including **environmental sustainability**" (Brandao 2021)*

Introduction- LCA applied to CBE

Feedstock

- Biomass input allocation issues
- Regional and case-specific variability

Environmental assessment



Stegmann et al.2020

Valorisation

- Complex valorisation pathways
- Low TRLs and scale-up uncertainty

Assessment of the **valorisation process**

Residue….

Homogenous residues





Heterogenous, mixed waste





New valorisation process

Pre-treatment	Main Conversion	Downstream
Physical: milling, grinding, chipping	**Thermochemical:** pyrolysis, gasification, combustion, hydrothermal liquefaction	**Separation & purification:** solid–liquid separation, extraction, chromatography
Chemical: acid, alkaline, organosolv, ionic liquids, oxidation	**Chemical:** transesterification, chemical hydrolysis	**Product upgrading:** bio-oil refining, syngas conditioning, biogas upgrading
Physicochemical: steam explosion, AFEX, liquid hot water	**Biochemical:** hydrolysis, fermentation, anaerobic digestion, solid-state fermentation, composting, insect farming	**Product synthesis:** polymerization, chemical synthesis, composite production
Biological: fungal, microbial, enzyme-assisted	**Extraction-based:** solvent extraction, ultrasound-assisted extraction, steam distillation	**By-product treatment:** digestate processing, effluent neutralization, lignin and silica recovery
Combined: sequential and hybrid methods		

Based on Polipalli et al. 2025

…to high value

- Pharmaceuticals & Fine Chemicals
- Food and feed
- Bioplastics & Polymers
- Bulk chemicals and materials
- Energy and heat

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Residue-to-product yield !

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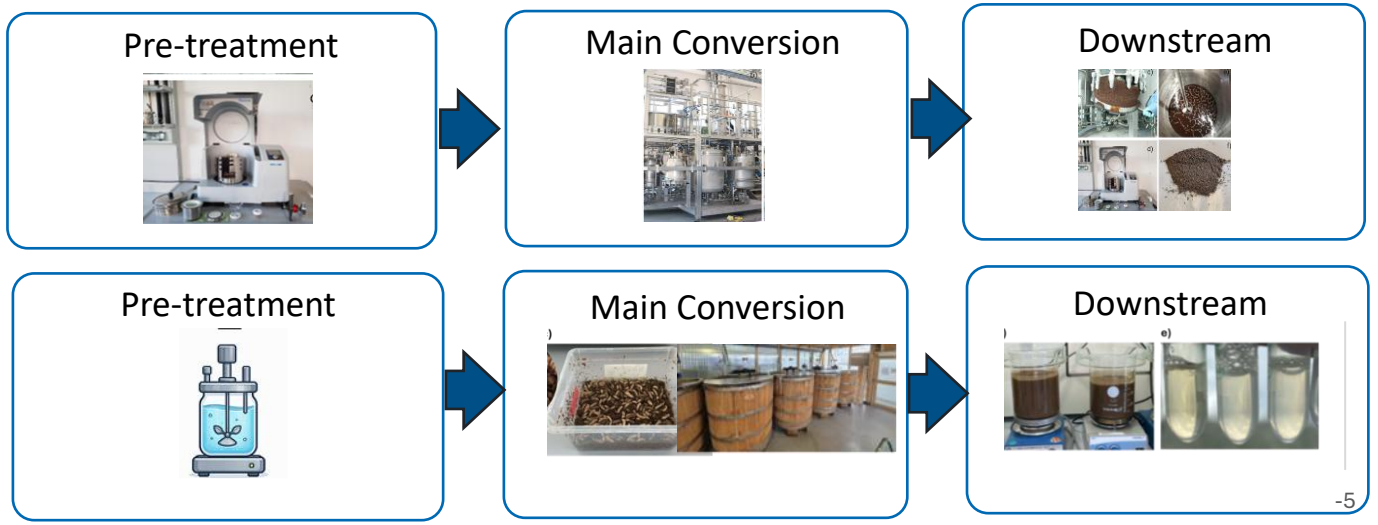
Assessment of the **valorisation process**

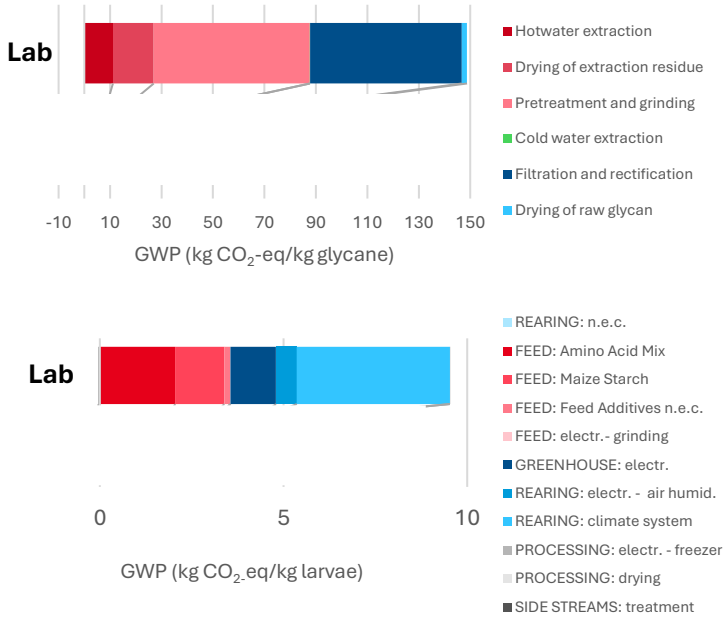


Residue….

New valorisation process



…to high value



Environmental hotspots & give recommendations for process improvements

Assessment of the **valorisation process**

Residue….



New valorisation process

Pre-treatment



Main Conversion



Downstream



…to high value

?



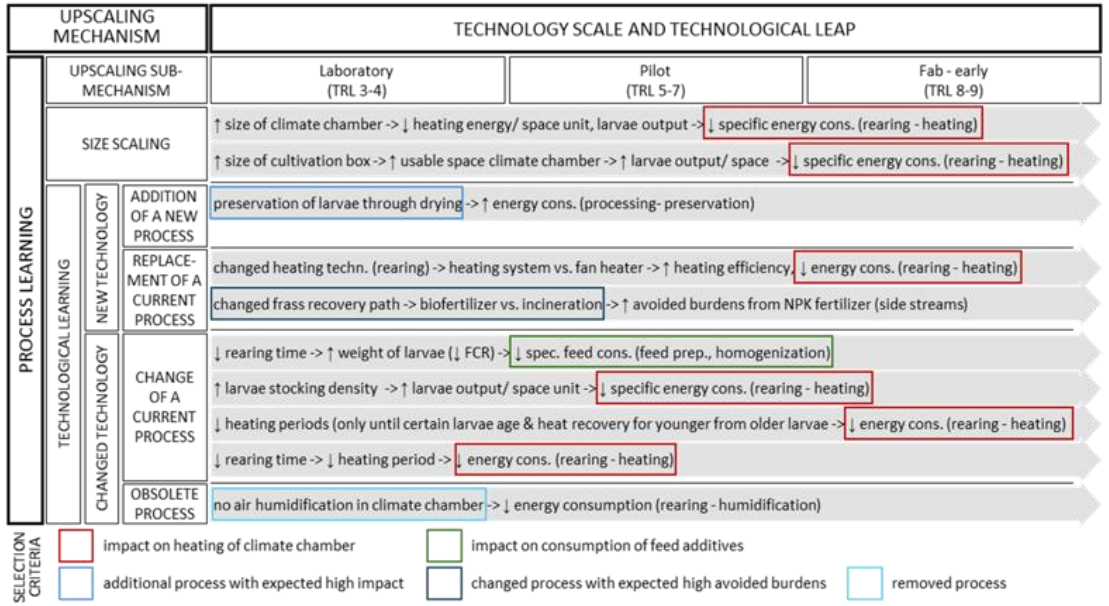
Prospective LCA frameworks

- Arvidsson et al., 2017; Cucurachi et al., 2018; van der Giesen et al., 2020; van der Hulst et al., 2020; Weyand et al. 2023

Key steps- upscaling

- Clear definition of **initial and target TRL**
- Identification of **upscaling mechanism** and selection of **upscaling method**
  - Decision tree to identify upscaling methods for Novel and Emerging Technologies for BIO-based products (JRC 2022)
  - Upscaling for chemical processes (Piccinno et al. 2016)

Example: apple pulp to insect farming upscaling



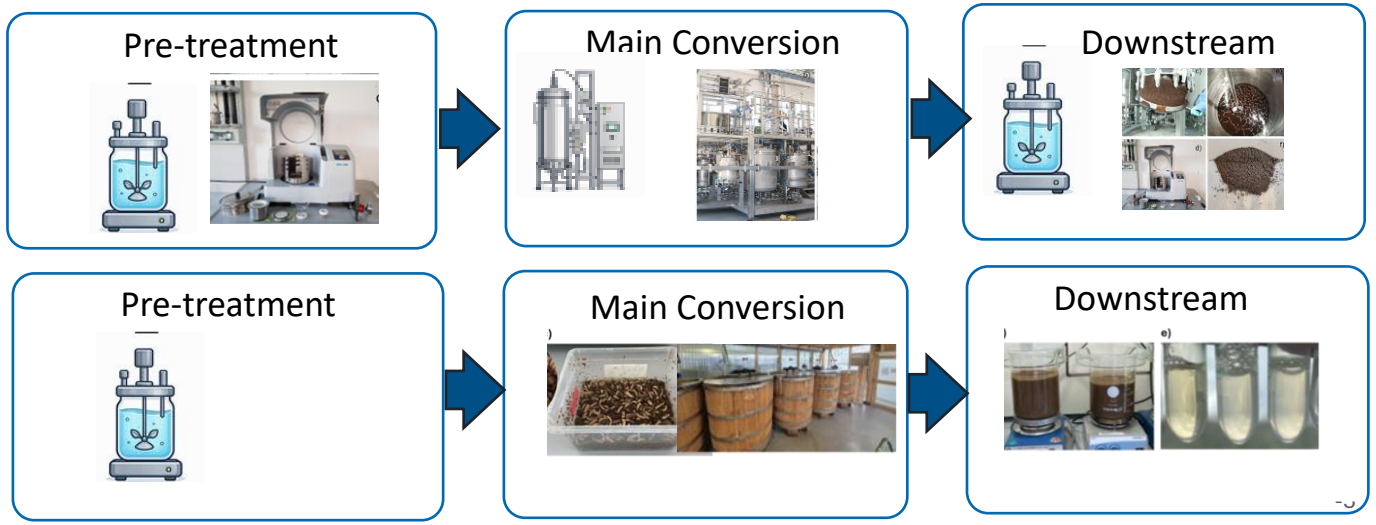
Güldemund et al. 2025b

Assessment of the **valorisation process**

Residue….



New valorisation process



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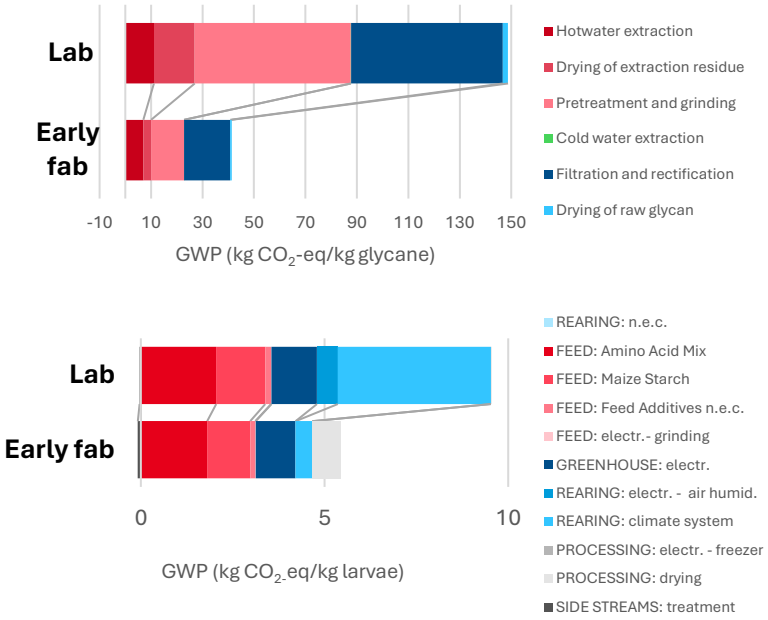

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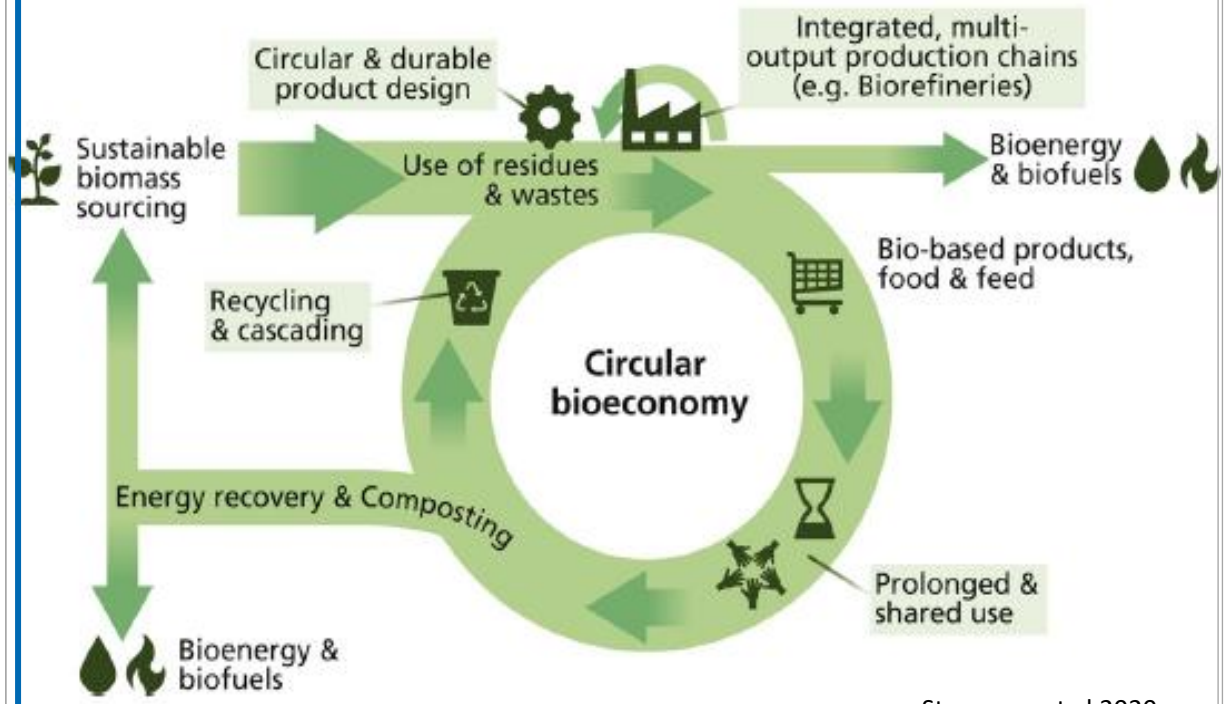

Stegmann et al.2020

Valorisation

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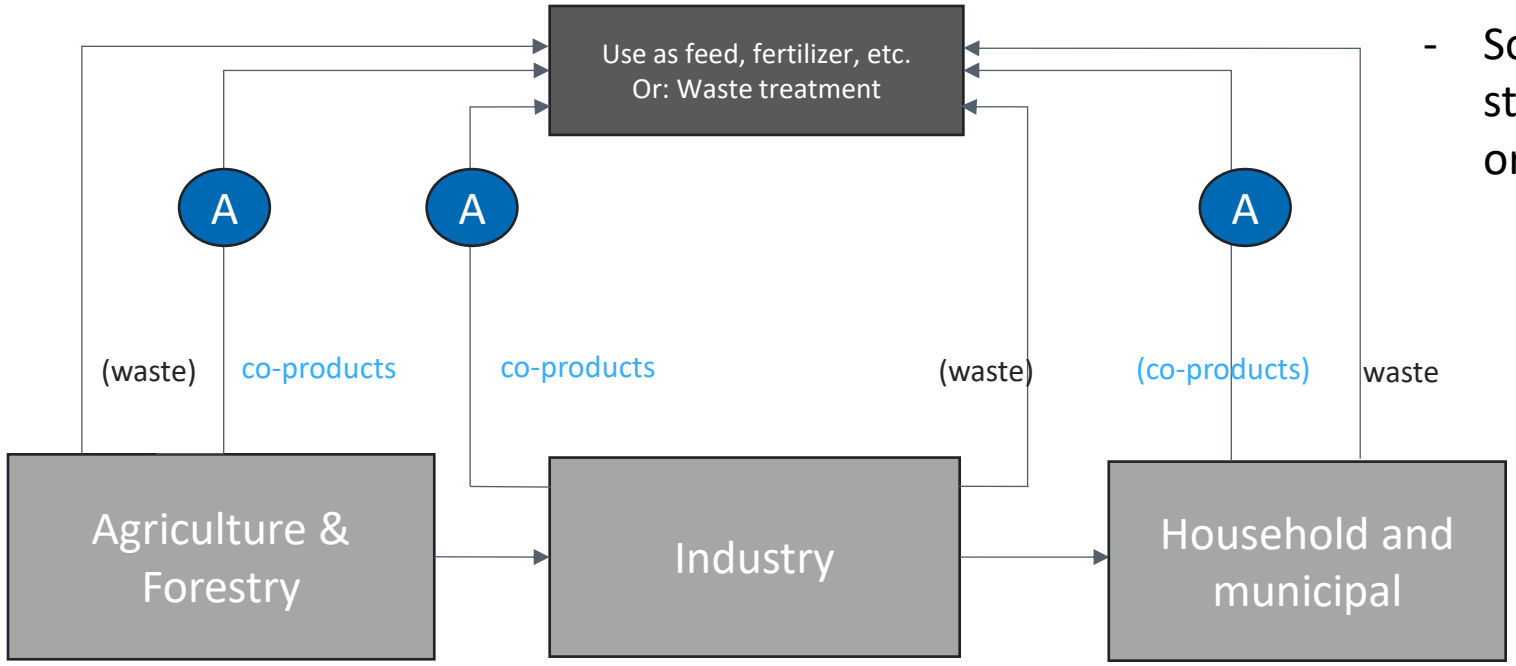
Assessment of the **feedstock use**

Attributional LCA

-> allocation factors

- upstream impact is allocated to the co-product (35% economic, 13% physical relation in food waste valorisation studies)
- AF of zero: use of co-product considered burden- free („waste“) (40% food waste valorisation studies)

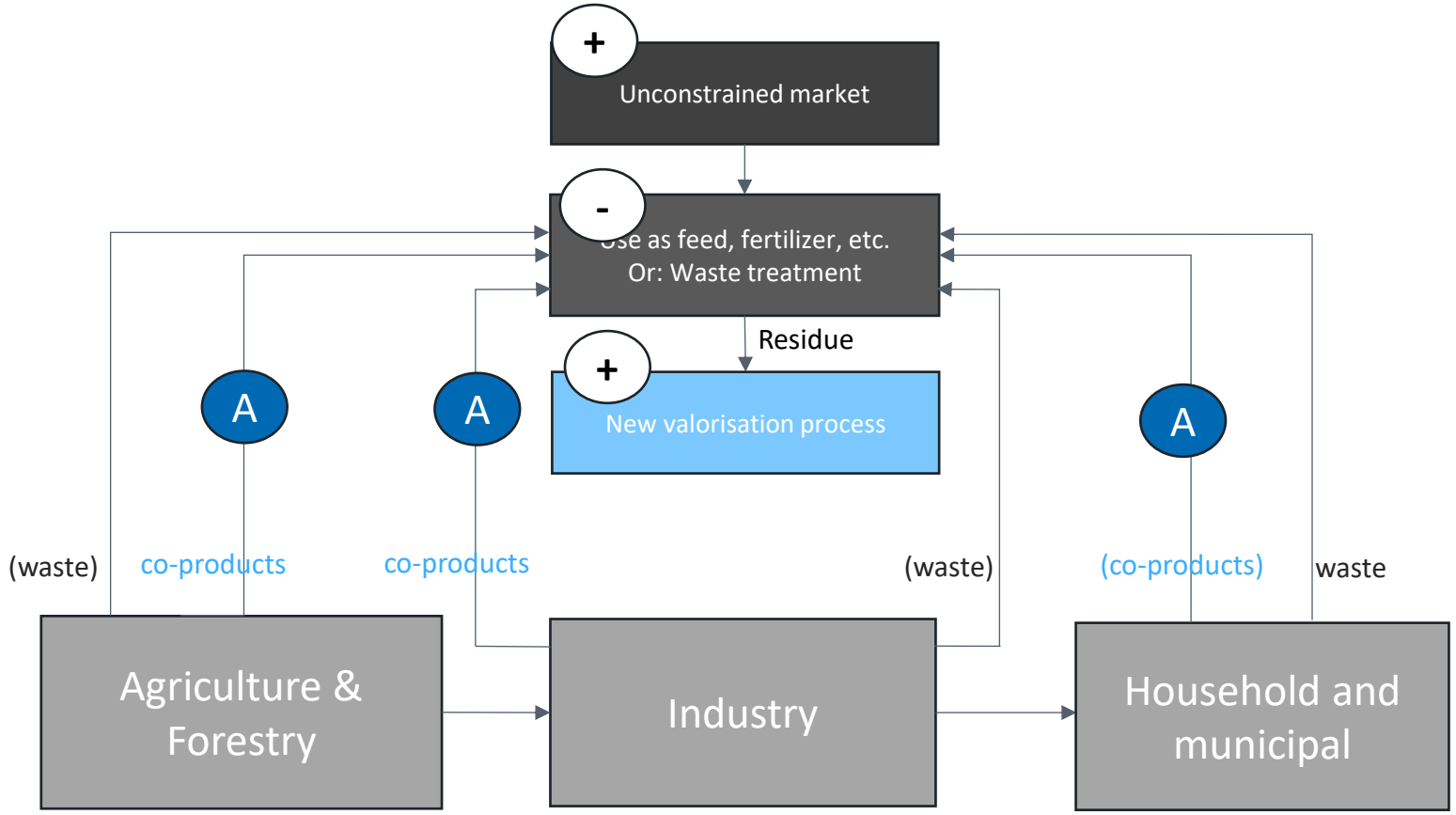
(*Dominguez Aldama et al. 2023*)



Consequential LCA

- Solution depends on study perspective: use or supply?

Assessment of the **feedstock use in cLCA**



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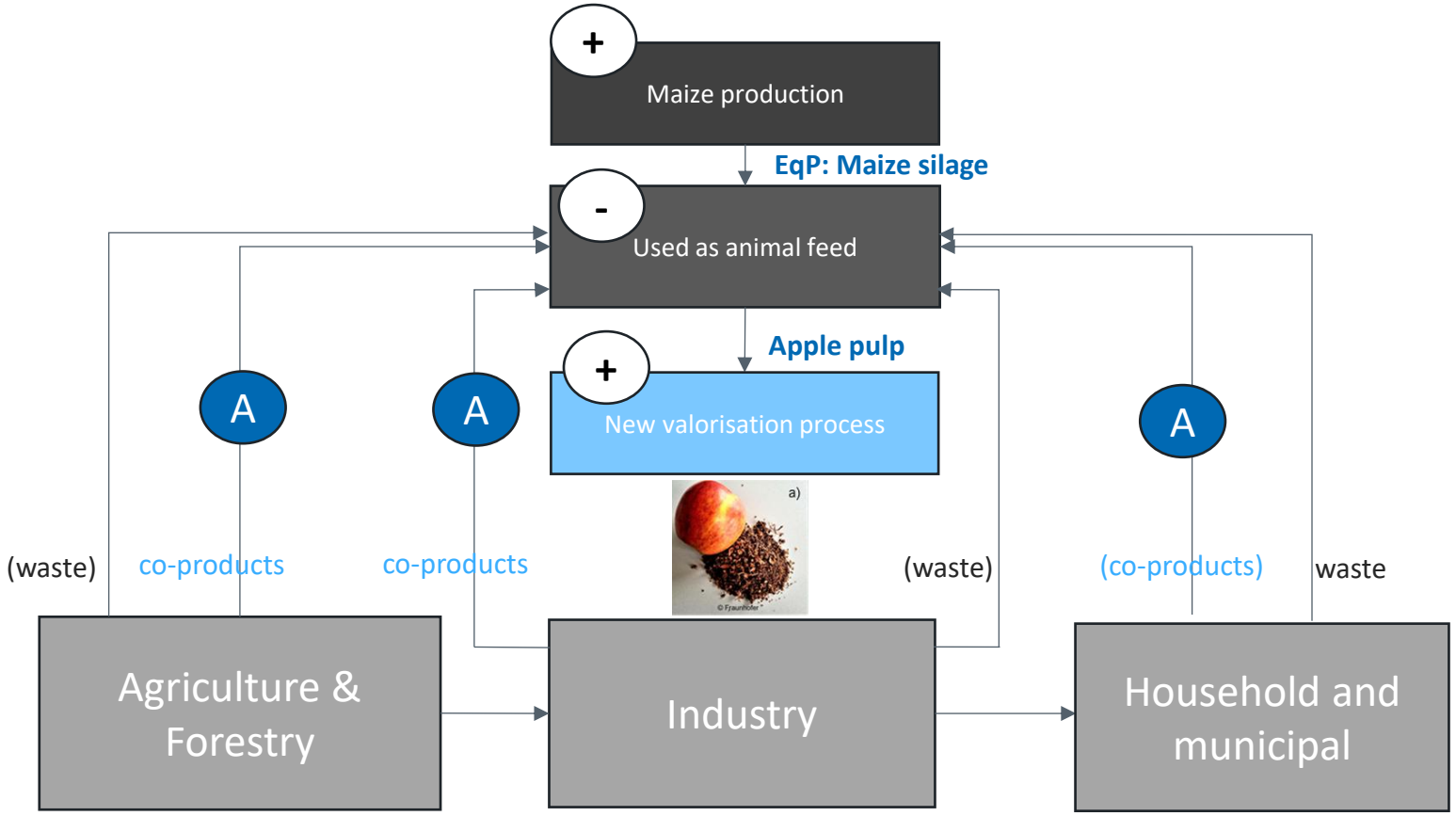
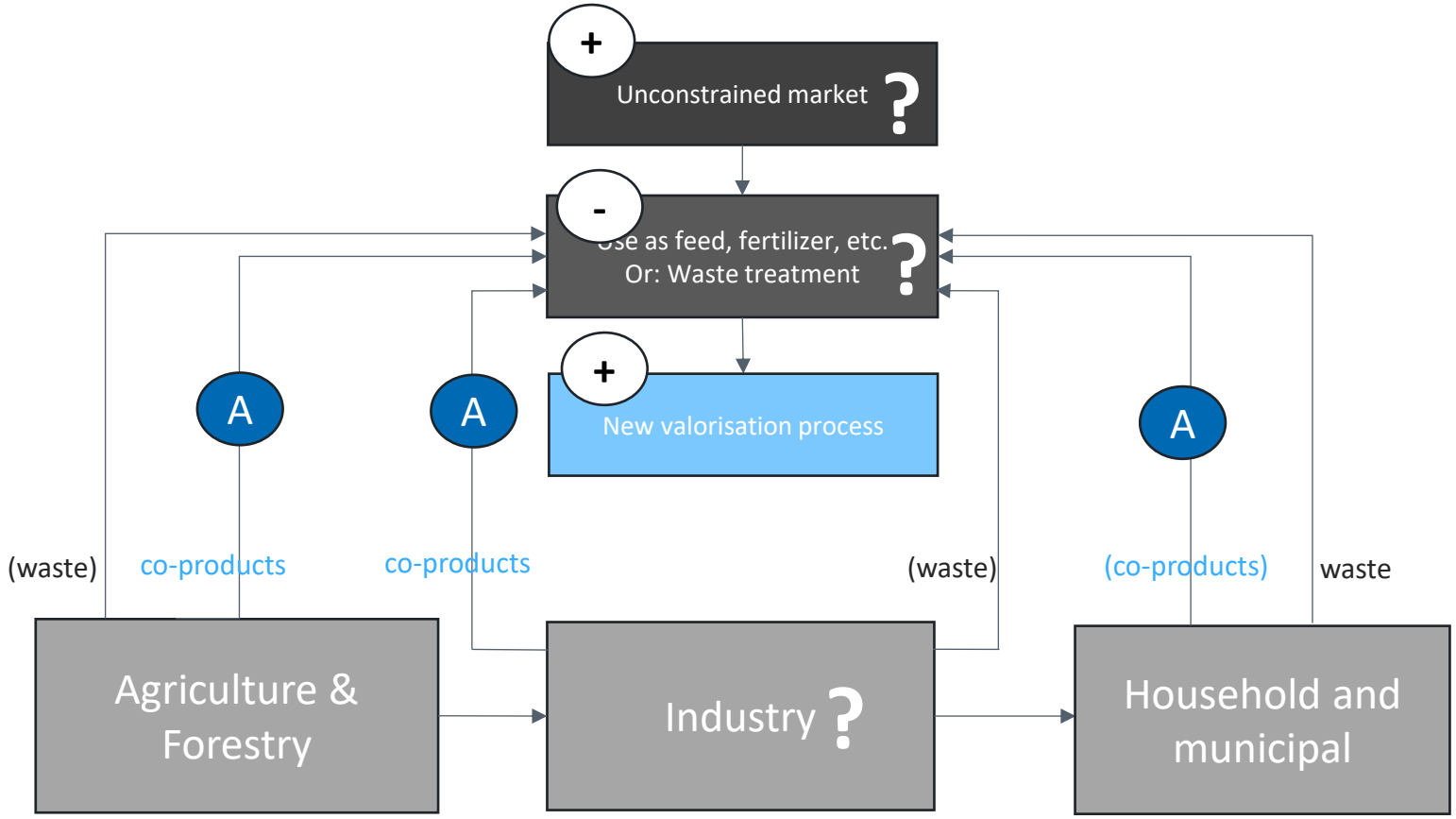


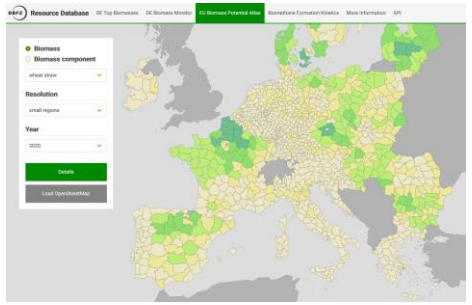
Examples: food waste diverting from waste treatment in *Albizatti et al. 2021*

Assessment of the **feedstock use in cLCA**



Residue databases, potential studies and waste statistics

- https://datalab.dbfz.de/resdb/maps?lang=en
- https://urban-bioeconomy.de/bioball/webcan.html



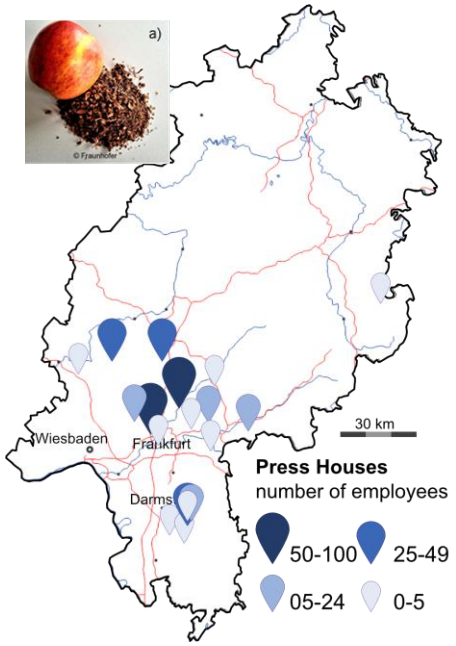
Industrial residues:

- Approaches to estimate residue generation based on monetary waste factors (Güldemund et al. 2025 a)
- Industry surveys

Assessment of the **feedstock use in cLCA**

Feedstock generation
- 18 active press houses, 5-6 press houses with >20 employees in Hesse
- 11300 tFM apple pomace per year in Hesse

Feedstock use
- Apple pomace is fully in use, provided free of charge to the recipient
- AP is primarily utilized as
  - feed for ruminant livestock (cattle and sheep), as feed for wildlife
  - biogas substrate



Feed scenario
- AP from feed-> (+ Maize silage; + additional transport; – avoided AP transport)
- ~1500tCO_2-eq./regional AP (~ 0.13kg CO_2-eq./kg AP)

Biogas scenario
- AP from biogas -> (+ heat, electricity and fertilizer; - avoided biogas process and transport)
- ~ 350tonCO_2-eq./ regional AP (0.03 kg CO_2-eq./kg AP)

Güldemund et al. 2025b

➔ use of AP not impact-free
➔ not a precise picture, but covering scenarios based on real use situation

Conclusions

- Residue-to-product valorisation is not a sustainable solution *per se*; more evidence is needed regarding its environmental performance.
- **Data Focus:** Due to the complexity of valorisation processes and low TRL, there are many data-related challenges for environmental assessments. Addressing this complexity and low TRL requires a focus on residue-to-product yields, process completeness, and transparent upscaling.
- **Feedstock impact** for co-products: Impact varies between upstream (attributional) and market-driven (consequential) effects, reflecting different research questions; both point towards the fact that the use of co-products is not impact-free.

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Thank you for your attention!

Contact:
vanessa.zeller@uni-giessen.de