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high-value products from agricultural residues through sustainable chains

Comprehensive decision support for valorisation of agricultural residues

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Webinar contents

- Introduction: motives for an residues valorisation support tool
- BREVIA: Biomass Residues Valorisation Impact Analysis decision support tool: what is in it?
- Examples of early impact estimates of residues applications
- Question to audience

Q&A: live via chat + Q&A session at the end

The essentials of this webinar are described in:

Broeze, J.; L. van der Hauwaert (2024) Second estimates of biomass residue volumes, composition, bio-based yields and environmental performances, EU-Agriloop project, Deliverable D1.5, available (later in 2025) via https://www.agriloop-project.eu/resources/documents/

Introduction
Motives & framework behind the decision support tool for agricultural residues

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Motives for a decision support tool for valorisation

Climate change impacts and rising geopolitical tensions highlight (among other solutions) the necessity for improving resource use efficiency (Talebian et al. 2024).

What do we have?

- Large amount of untapped residues with high value potential

- Data
- Models
- In-depth and multidisciplinary expertise

- Knowledge on valorisation pathways
- Stakeholder & consumer needs

- Droughts
- Floods
- Crop diseases, etc.

Talebian, S., Lager, F., & Harris, K. (2024). Solutions for managing food security risks in a rapidly changing geopolitical landscape. SEI Report. Stockholm Environment Institute. https://doi.org/10.51414/sei2024.044

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Motives for a decision support tool for valorisation

Climate change impacts and rising geopolitical tensions highlight (among other solutions) the necessity for improving resource use efficiency (Talebian et al. 2024).

What do we need?

New and adaptable **circular & sustainable process concepts**

Have a structured, rapid and flexible design approach to reuse blueprints

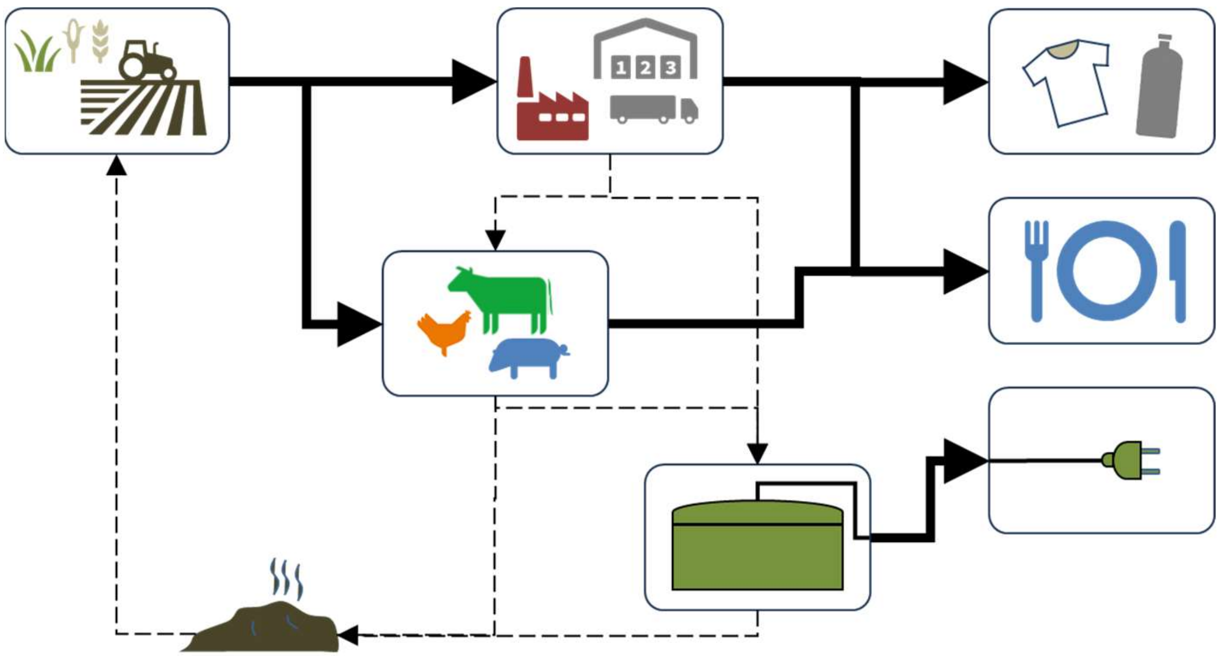
Include moving targets (e.g. from stakeholders, consumers) at an early stage

Include seasonal and fluctuating production volumes

Talebian, S., Lager, F., & Harris, K. (2024). Solutions for managing food security risks in a rapidly changing geopolitical landscape. SEI Report. Stockholm Environment Institute. https://doi.org/10.51414/sei2024.044

Motives for a decision support tool for valorisation

Current: Linear economy:
focus on final products, straightforward uses of by-products

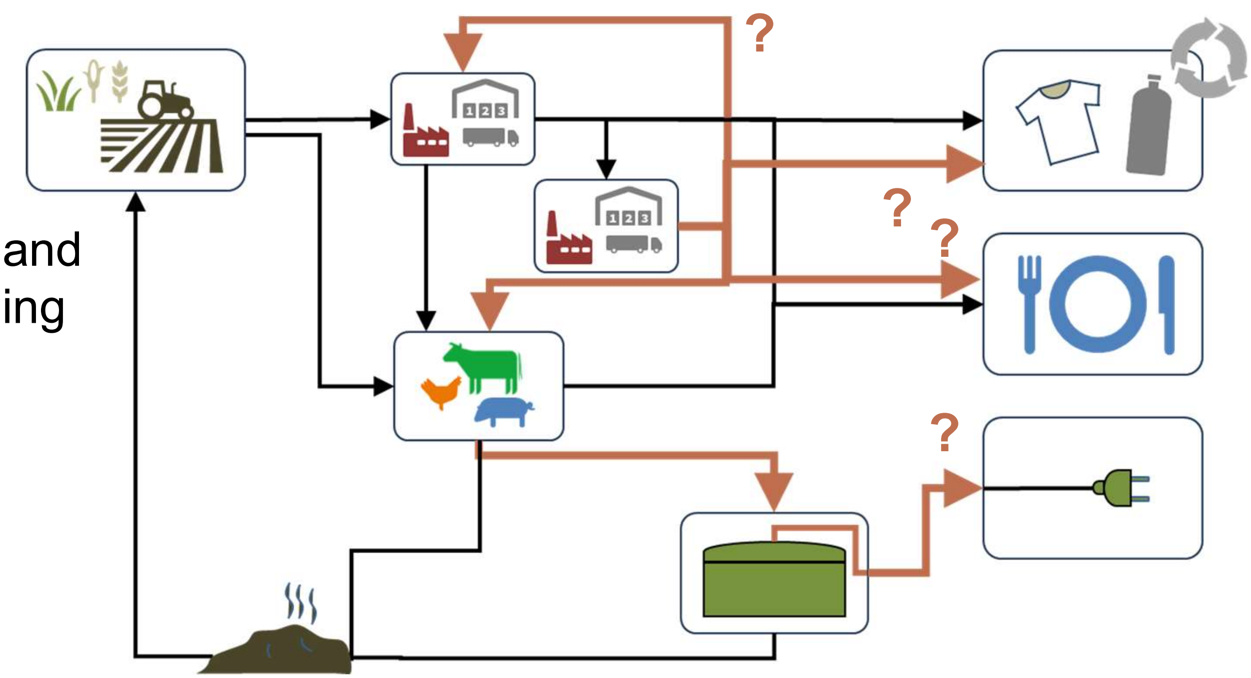


Motives for a decision support tool for valorisation

Towards more circular adaptable (bio-)economy:

all streams (including 'residues') become relevant resources

Fixed and changing



Challenge: how to effectively* fulfil the total demand for food, materials and energy/fuels *effective = resource-efficient & sustainable

Motives for a decision support tool for valorisation

Research question:

What changes in terms of agricultural residue valorisation have the highest sustainability (economic, social and environmental) benefits

today?
and tomorrow?

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Potential users and applications

Users: farmers, traders, cooperatives and representative organisations

Applications:

- Which by-products have the **highest potential**?
- What applications are the **most beneficial/sustainable** with the available by-products?
- What **challenges** and how to address them in terms of quality and sustainability?

Scoping within Agriloop

Scope: valorisation of agri-residues

from:

- Primary production: crops and livestock
- Secondary residues (processing residues)

Identify processing pathways and destinations

Applications on scope:

New pathways for biopolymers and (feed/food) proteins vs current applications (e.g. biofuels, feed)

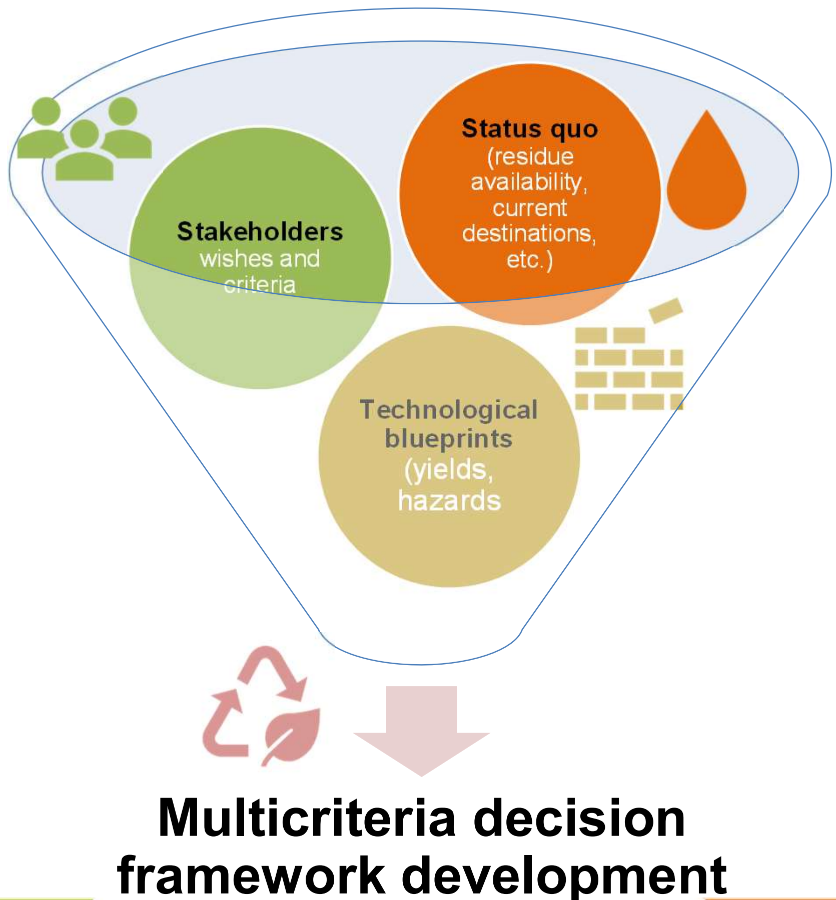
https://www.epa.gov/sustainable-management-food/wasted-food-scale

Method development

- How to address the different **sustainability aspects simultaneously** and with **up-to-date** information (e.g. annual crop and residue yield)?

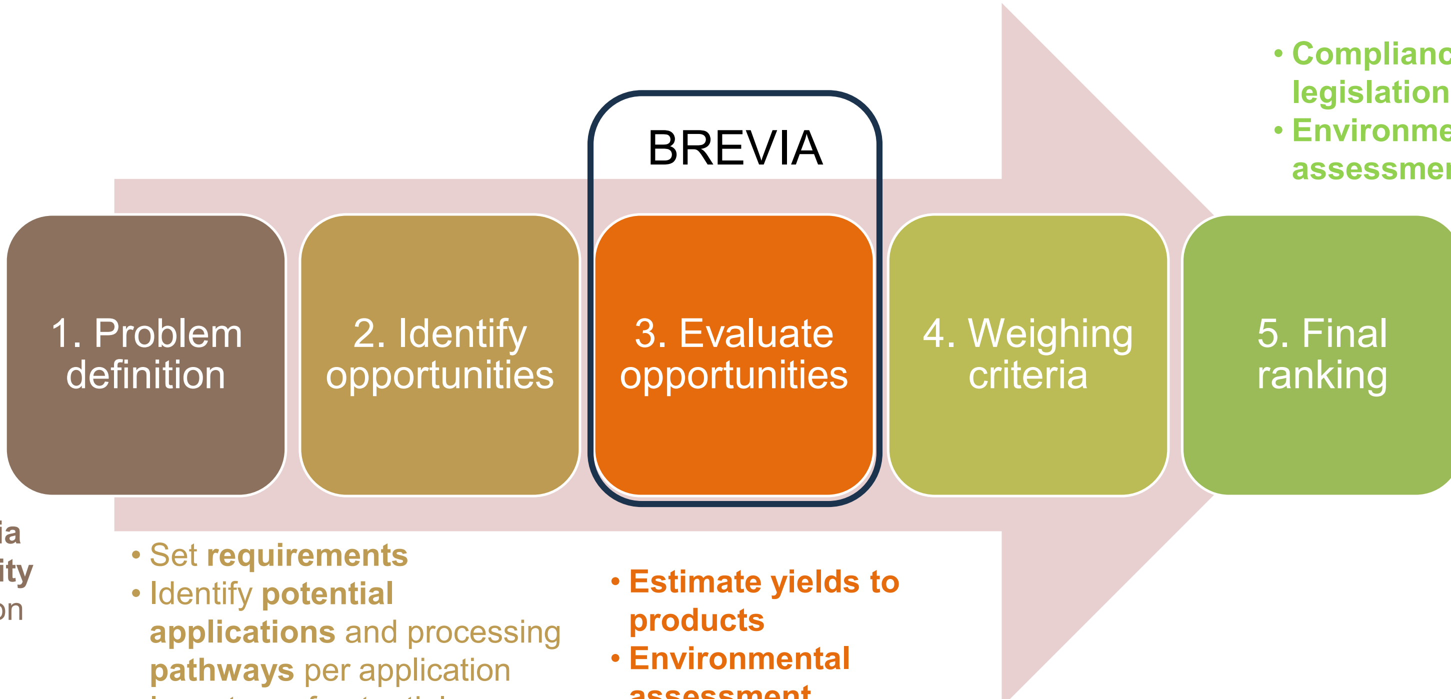
- How to identify an **effective*** supply of food, materials and energy/fuels?

*effective = resource-efficient & sustainable



Model and multicriteria decision-support framework:

From problem definition to final decision



- Defining **actors** (stakeholder, experts)
- Identification of **criteria**
- Side stream **availability** and volumes per region (country)

- Set **requirements**
- Identify **potential applications** and processing **pathways** per application
- Inventory of potential **hazards**

- **Estimate yields to products**
- **Environmental assessment**
- **Evaluate hazards**

- **Include preferences from stakeholders**

- **Compliance with legislation**
- **Environmental assessment**

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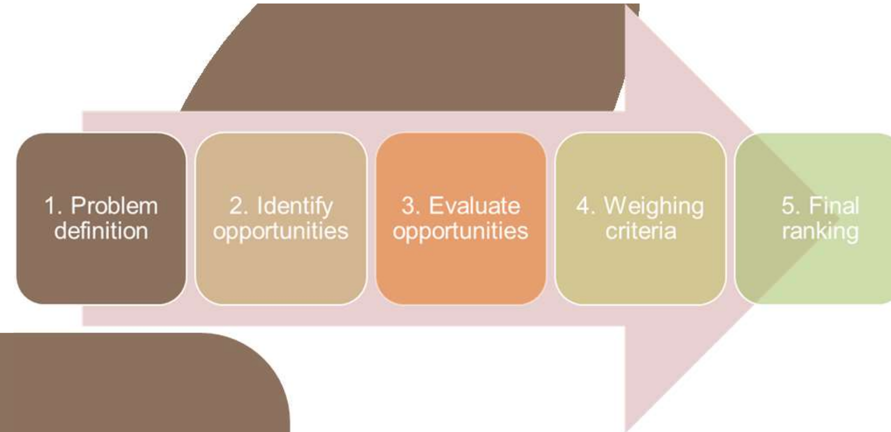
Problem definition



Volumes of available agri-residues

Per country/ Per year (or per year average):

- **crop residue volumes**: estimated from crop production statistics & residue-to-crop ratios
- **secondary residues volumes**: estimated from national production statistics & residue-to-product ratios

Current destinations of residues

Availability (incl. soil quality)

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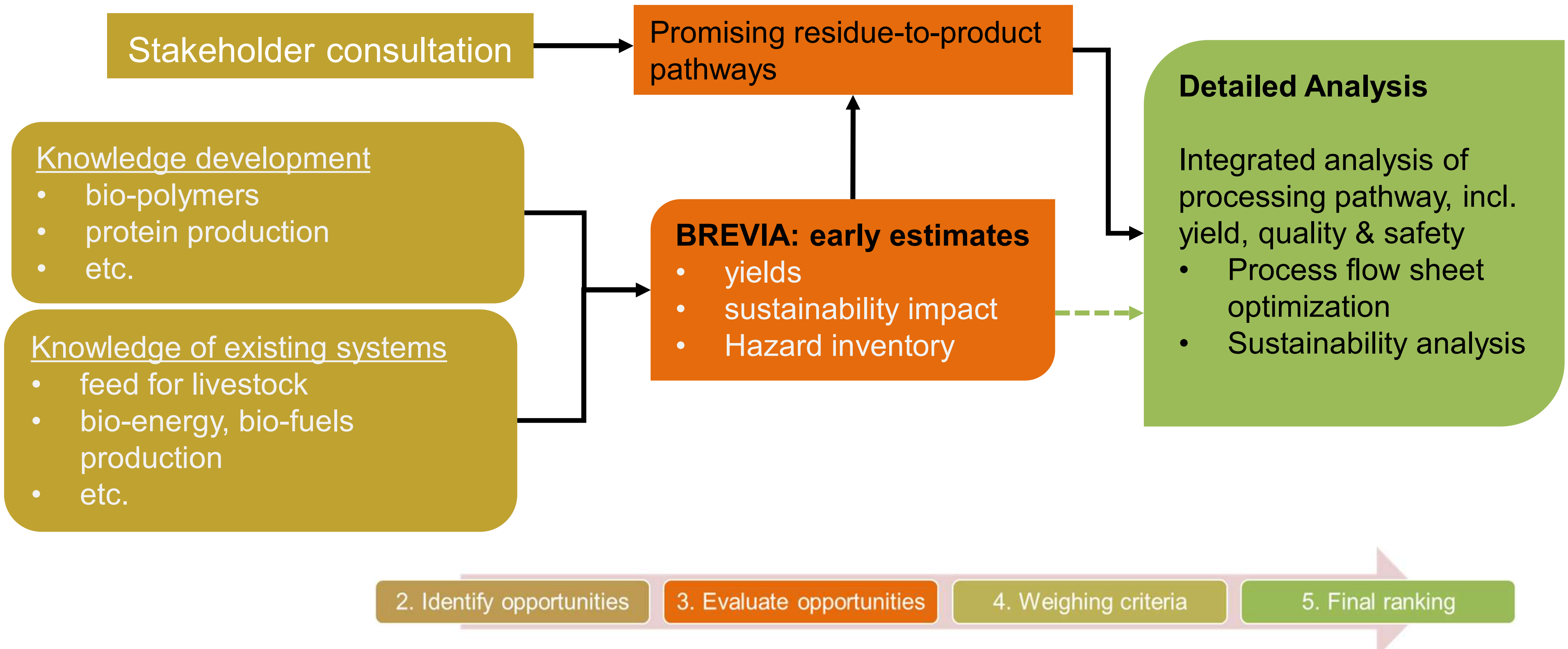
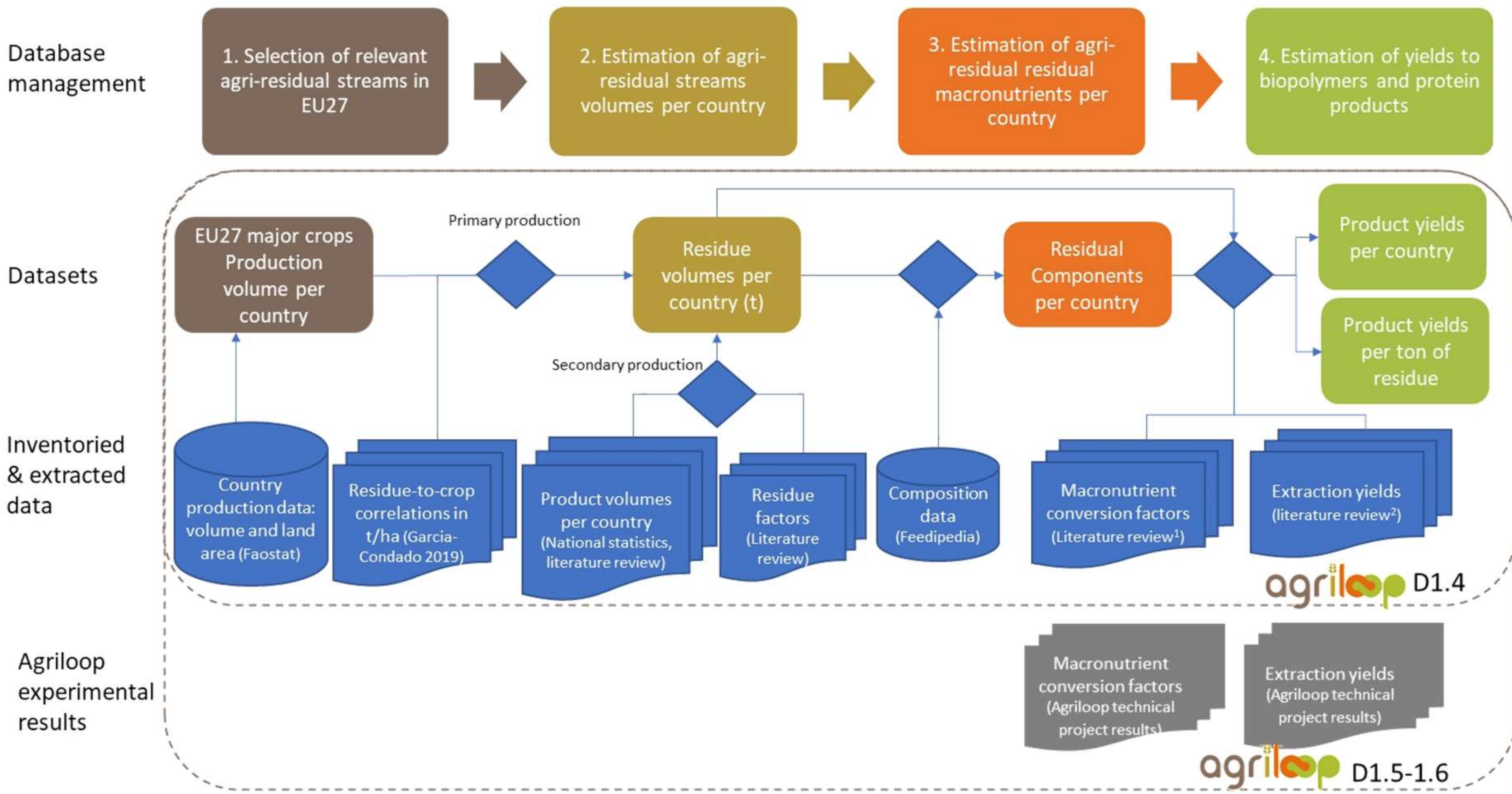
Model Framework



Data framework behind BREVIA

Country specific production data available **per year**

(variability)



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Decision support modules BREVIA: *what’s in it?*

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BREVIA
Biomass REsidues Valorisation Impact Analysis tool

Modules

Compositions
- Primary residues
- Secondary residues

Conversions & Fractionations
- Pathways
- Yields

Sustainability impacts
- Climate impact
- Circularity

Warning: Heuristics and parameters used in this method are based on (averages from) reference studies with mostly limited scope; the averaging and generalisation may lead to some inaccuracy for case analyses.
The method will be further developed; new underpinnings may lead to adjustments of heuristics and parameters, which will inevitably result in (mostly small) effects on results from case studies. Therefore, results obtained with different versions of the tool should not be compared.

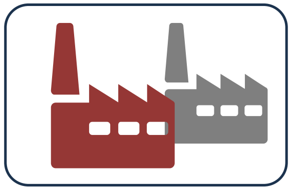
Agriloop deliverable D1.5
https://www.agriloop-project.eu/resources/documents/

Compositions

- Primary residues
- Secondary residues

Estimates of chemical composition (macro-nutrients)

- wheat straw
- maize (or corn) stover
- barley straw
- rye straw
- oat straw
- triticale straw
- rice straw
- tomato crop residues
- grape branches and leaves
- rapeseed straw
- sunflower stalks (straw)
- olive tree pruning branches
- olive leaves
- potato crop residues
- sugar beet leaves



- apple pomace,
- brewer's spent grain, brewer’s yeast
- distillers' grains from maize
- distillers' grains from wheat
- grape pomace, grape seeds
- olive pomace, olive stones
- peanut meal, peanut skins
- potato peels, potato pulp, grey starch
- rice (broken, discoloured, unripe rice)
- rice bran, defatted rice bran
- rice husk
- sugar beet molasses,
- sugar beet pulp
- tomato pomace,
- tomato skins

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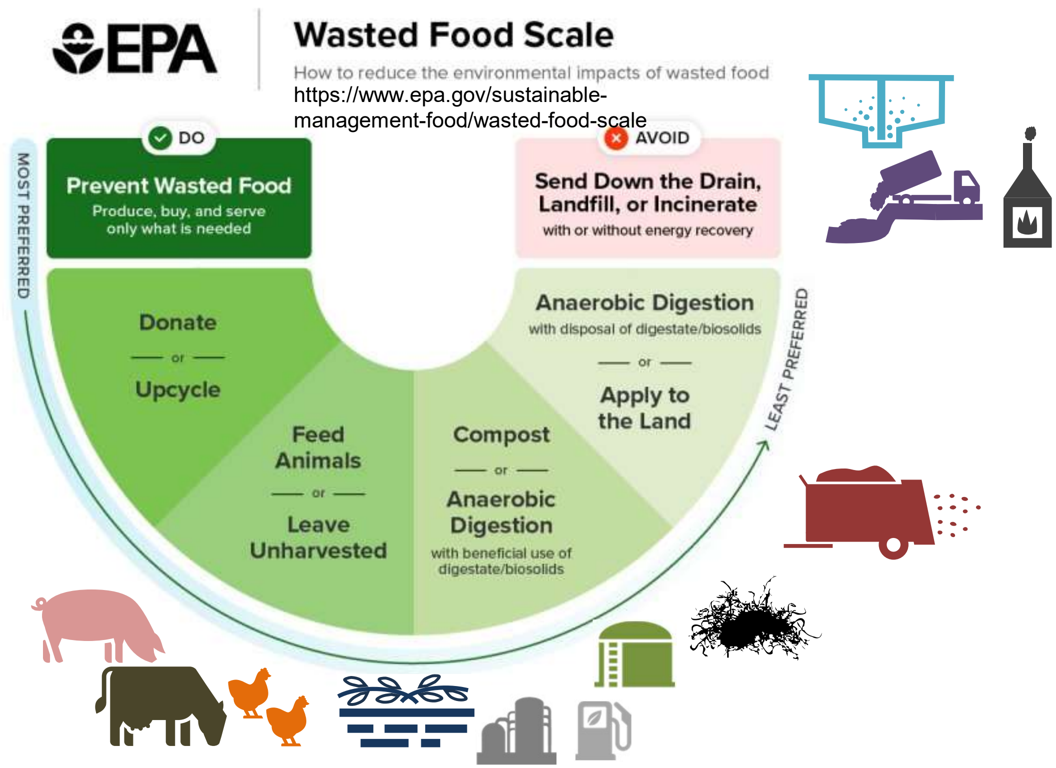
Valorisation pathways

Conversions & Fractionations

- Pathways

Common application/valorisation pathways



Upcycling: 'novel' valorisation pathways in scope of Agriloop

- microbial protein production → animal feed
- protein extraction → food ingredient
- bioplastics (PHA)

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Conversions & Fractionations

- Pathways
- Yields

Estimates of yields to products:

Residue streams	DM content (g/kg) (default value)	(optional user-specified)	Yield to products (kg product per ton residue-with-provided-DM-content): Bio-methane	Bio-ethanol (incl. hydrolysis)	Bio-ethanol (first generation)	Bio-ethanol (BTL)	Bio-diesel	PHA/PHB (Formula: dry_matter_content X sum_comp)
Apple pomace	208	1000	192.0	279.7	130.0	116.4	37.8	39.5
Barley straw	909	1000	168.0	284.8	23.9	66.2	12.6	13.2
Brewer's spent grain	240	1000	234.6	212.0	39.1	45.2	82.8	46.3
Brewer's yeast	907	1000	267.8	176.6	95.3	76.6	75.6	74.3
Broken rice	885	1000	255.6	436.1	403.6	229.0	7.2	256.7
DDGS from maize	903	1000	262.4	213.1	87.4	72.9	112.5	60.7
DDGS from wheat	916	1000	242.1	196.0	85.4	70.2	61.2	47.3
Discolored rice	883	1000	226.1	370.2	299.7	173.2	18.0	208.6
Grape branches and leave	563	1000	168.8	277.2	117.5	112.0	15.3	14.3
Grape pomace	397	1000	148.6	192.6	94.6	72.4	0.0	63.1
Grape seeds	450	1000	163.0	134.1	7.7	29.1	102.6	43.2
Maize (corn) stover	296	1000	178.9	287.3	46.1	74.2	16.2	14.6
Molasses	787	1000	231.4	382.7	339.8	203.8	1.8	205.5

All are estimated from ‘yield factors’ per macro-nutrient

For example for PHA production:

$$M_{PHA} = 0.35 \times M_{lipids} + 0.40 \times M_{sugar} + 0.35 \times M_{starch}$$

estimated from Nova (2015), IfBB (2021), Burniol-Figols et al. (2018), Sohail et al. (2020)

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BREVIA
Biomass REsidues Valorisation Impact Analysis tool

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Sustainability impacts

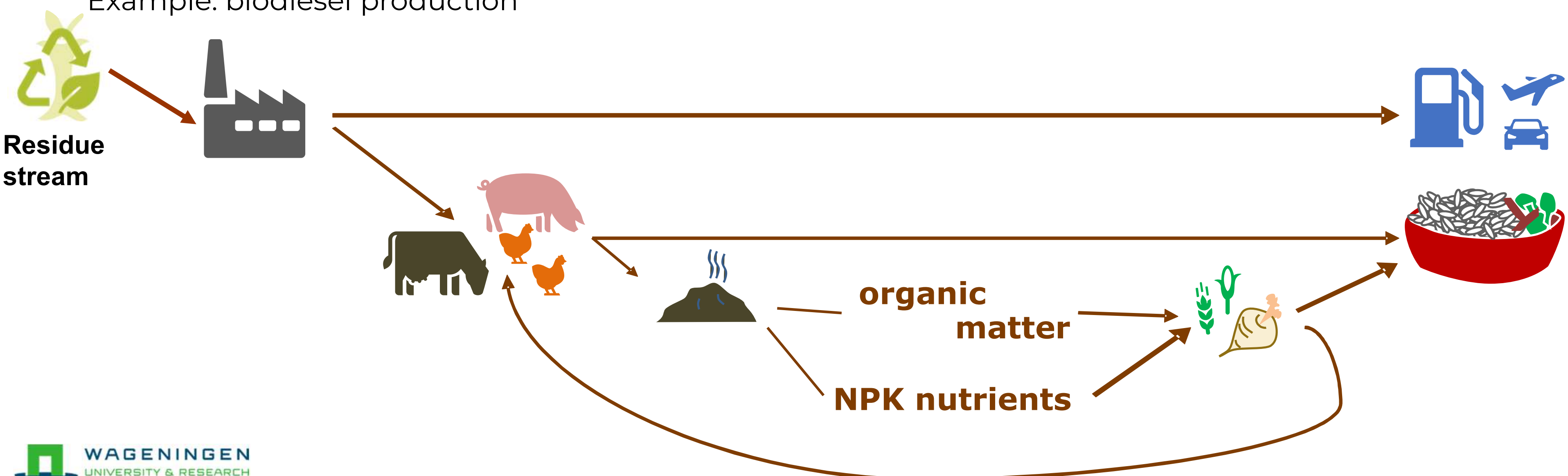
- Climate impact
- Circularity

Introduction of methodology for early estimates of sustainability impact

Principles:

- **<u>All outputs</u> : all products (incl. residues) that are generated in the valorisation process must be considered**
- **<u>Substitution</u> and <u>System expansion</u> (LCA-based approach)**

Example: biodiesel production

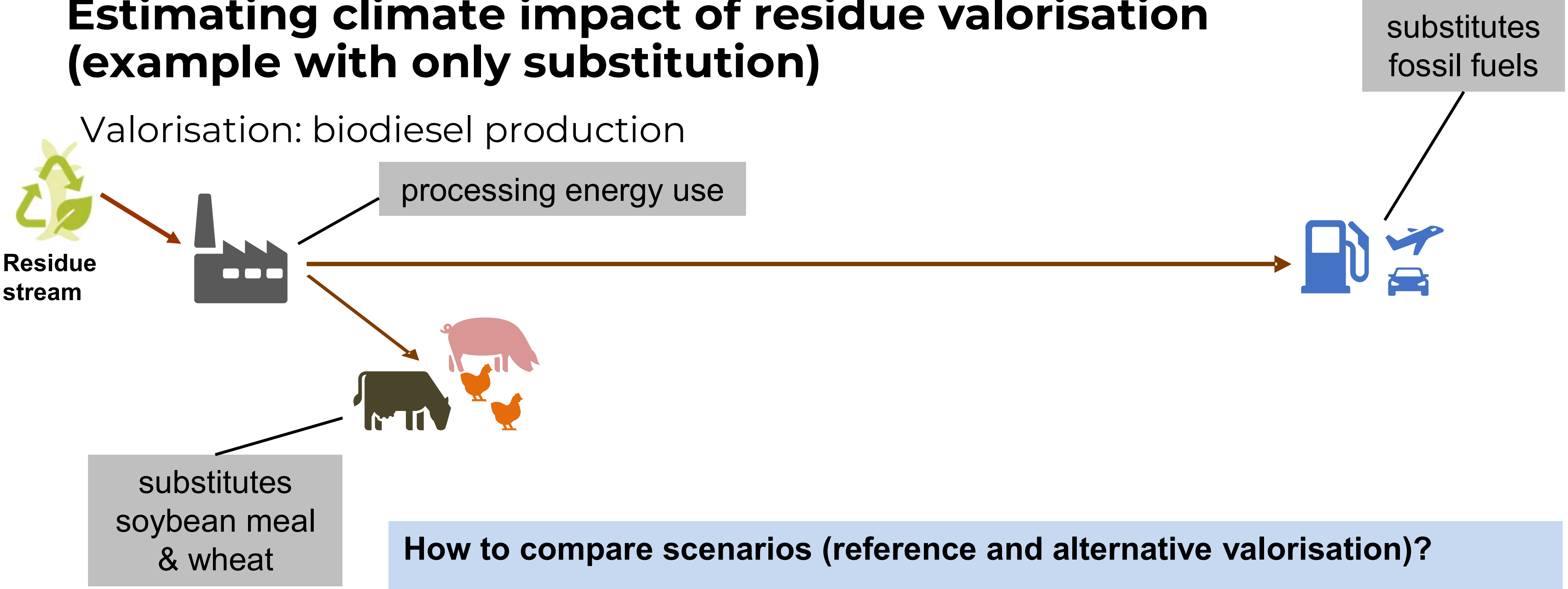


Sustainability impacts

- Climate impact
- Circularity

Estimating climate impact of residue valorisation (example with only substitution)

Valorisation: biodiesel production



How to compare scenarios (reference and alternative valorisation)?

Net effect of an alternative valorisation:

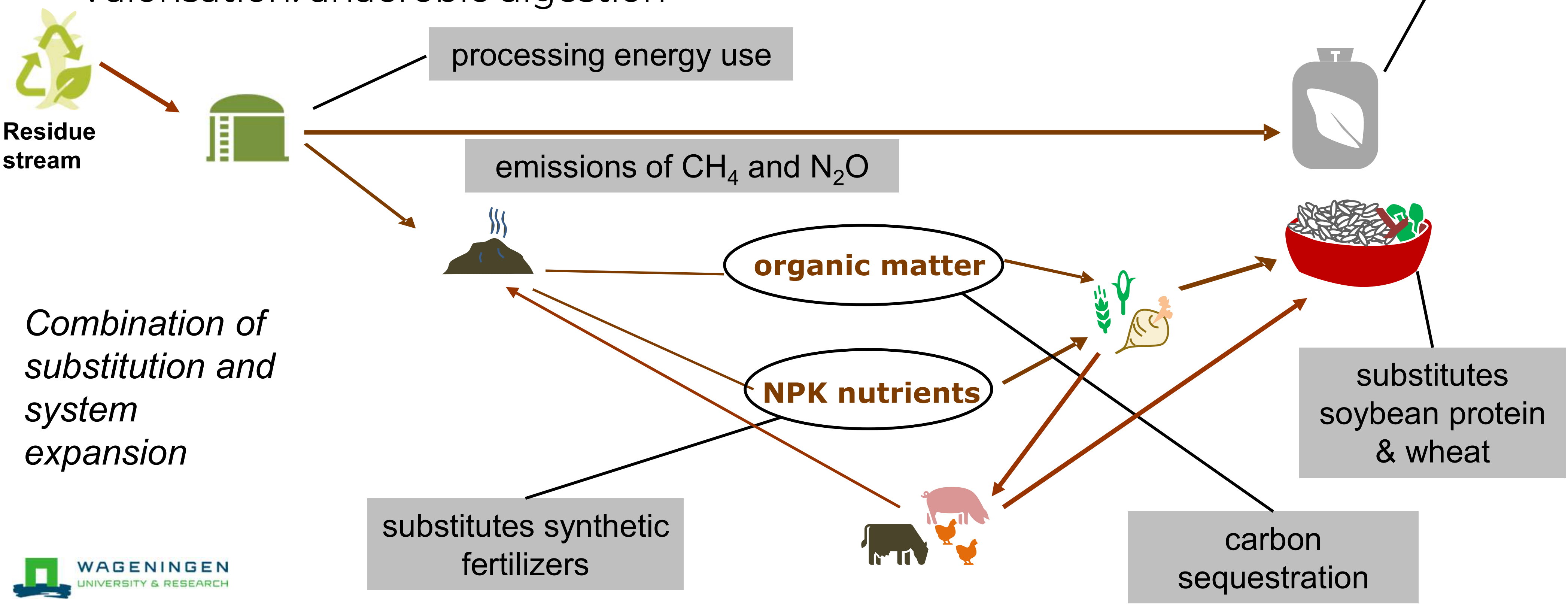
$GHG\_emiss\_savings_{alternative\_valorisation} - GHG\_emiss\_savings_{reference\_valorisation}$

Estimating climate impact of residue valorisation (example including system expansion)

Valorisation: anaerobic digestion

Sustainability impacts

- Climate impact
- Circularity



Combination of substitution and system expansion

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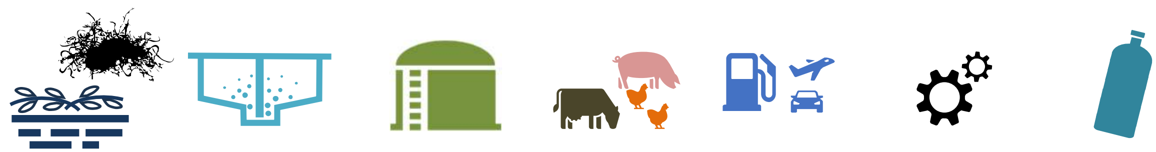
Sustainability impacts

- Climate impact
- Circularity

Factors taken in consideration in climate impacts estimations



Processing energy use		■	■				■
Carbon sequestration in soil	■		■				■
N_2O emissions	■	■	■				■
Methane emissions & leakage	■	■	■				■
Substitute synthetic fertilizer N	■		■				■
Substitute natural gas		■	■				■
Substitute fossil fuels					■	■	
Substitute soybean meal & wheat in feed				■	■	■	
Substitute soybean protein in food						■	
Substitute fossil derived plastic							■

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Sustainability impacts

- Climate impact
- Circularity

Estimating circularity (resource-use efficiency)

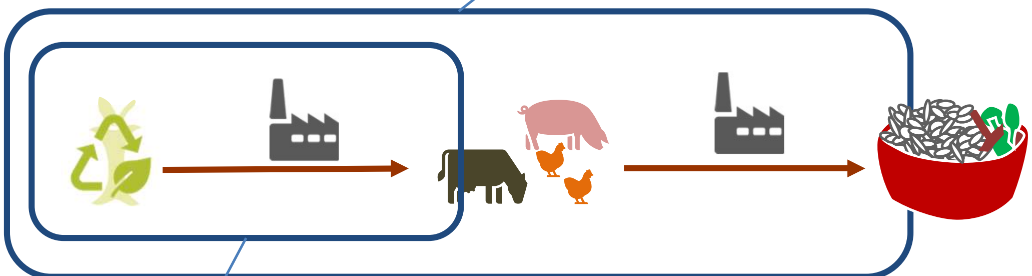
Yield – via a valorisation pathway – to production of (all) final products:

food, biobased materials, fuels, energy

$$Circularity = \frac{Energy\ \ of\ final\,products\ (MJ)}{Energy\ of\ residue\ (MJ)}$$

accounts for the functionality of the material for the application (like feeding value)

(MJ: in heat of combustion)



EU's 'circular material use rate'

Refinements:

- protein components are appreciated higher (in food/feed) than their energic value (reasons: land productivity & price)
- energy carrier products are appreciated lower than food and biobased products (reason: prices of substrates for co-digestion are mostly below feed price)

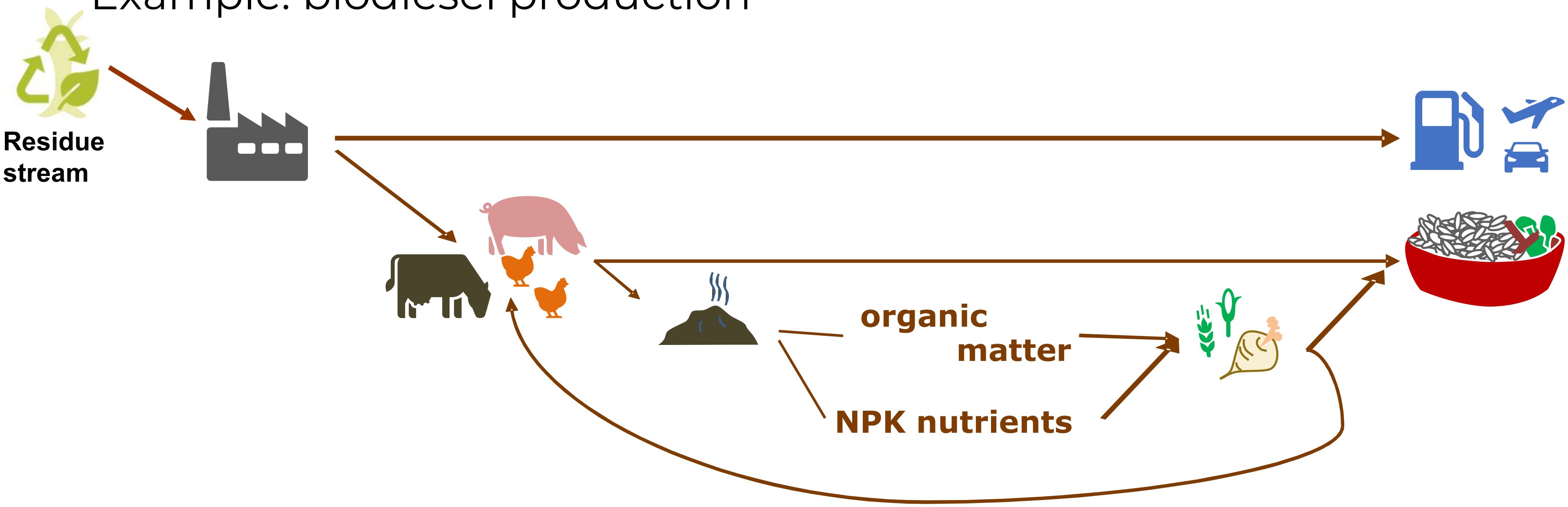
Broeze, J.; W. Elbersen; J. Voogt; H. Soethoudt (2024) Circulariteit van reststroombenutting. Wageningen Food & Biobased Research, Rapport 2584. DOI: 10.18174/672425. https://edepot.wur.nl/672425 (in Dutch). An English version of this report will be published later in 2025.

Sustainability impacts

- Climate impact
- Circularity

Early estimates of circularity
Always use principle of system expansion

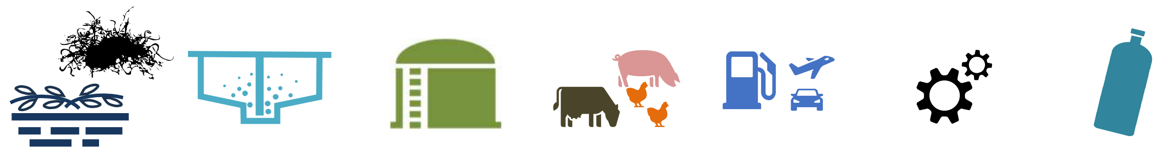
Example: biodiesel production



Sustainability impacts

- Climate impact
- Circularity

Factors taken in consideration in circularity assessment



~~Processing energy use~~							
~~Emissions~~							
Contribution to food production through fertilizer function							
Contribution to food through feed application of residue generated in the valorisation pathway							
Produce biomethane							
Produce biofuel							
Produce food							
Produce bioplastic							

Case study results

Example result: valorisation of brewer's spent grain

	Product & co-products	Associated net GHG emissions savings ($kg\ CO_2$-eq per kg DM)	Degree of circularity
Reference application: feed for cattle			
		1.14	28%

Example result: valorisation of brewer's spent grain

	Product & co-products	Associated net GHG emissions savings (kg CO_2-eq per kg DM)	Degree of circularity	GHG emissions savings	Degree of circularity
Reference application: feed for cattle				Benefit relative to Reference application	
		1.14	28%		
PHA/PHB production					
		0.79	26%	-0.35	-2%

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Example result: valorisation of brewer's spent grain

Product & co-products	Associated net GHG emissions savings (kg CO_2-eq per kg DM)	Degree of circularity	GHG emissions savings	Degree of circularity
			Benefit relative to Reference application	
Reference application: feed for cattle				
	1.14	**28%**		
PHA/PHB production				
	0.79	**26%**	**-0.35**	**-2%**
Enzymatic extraction of protein (food) & production of bioethanol (Voogt et al., 2023, doi.org/10.1016/j.fbp.2023.02.002)				
	2.4	**66%**	**1.3**	**38%**

Findings:

- Because of the low content of simple carbohydrates in BSG, yield to PHA is relatively low. These results confirm that it is not a very suitable valorisation pathway.
- The biorefinery pathway, with high-value use of proteins is more suited; that valorisation scores best for GHG emission reduction and circularity.

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Example result: valorisation of grey starch

Product & co-products	Associated net GHG emissions savings	Degree of circularity
Reference application: feed for cattle	(kg CO_2-eq per kg DM)	
	0.47	29 %

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Example result: valorisation of grey starch

Product & co-products	Associated net GHG emissions savings	Degree of circularity	GHG emissions savings	Degree of circularity
Reference application: feed for cattle	(kg CO_2-eq per kg DM)		Benefit relative to Reference application	
	0.47	29 %		
Anaerobic digestion				
	0.67	21 %	0.20	- 8 %

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Example result: valorisation of grey starch

Product & co-products	Associated net GHG emissions savings	Degree of circularity	GHG emissions savings	Degree of circularity
Reference application: feed for cattle	(kg CO_2-eq per kg DM)		Benefit relative to Reference application	
	0.47	29 %		
Anaerobic digestion				
	0.67	21 %	0.20	- 8 %
PHA/PHB production				
	0.52	37 %	0.05	8 %

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Example result: valorisation of grey starch

Product & co-products	Associated net GHG emissions savings	Degree of circularity	GHG emissions savings	Degree of circularity
Reference application: feed for cattle	(kg CO_2-eq per kg DM)		Benefit relative to Reference application	
	0.47	29 %		
Anaerobic digestion				
	0.67	21 %	0.20	- 8 %
PHA/PHB production				
	0.52	37 %	0.05	8 %
Single cell protein (SCP) production & use as fish feed (Spiller et al., 2020)				
	1.46	37 %	0.99	12 %

Findings:

- Anaerobic digestion scores good (GHGe) because of relatively high GHGeI of natural gas
- Single cell proteins score better than PHA because of high climate impact of soybean meal

Take home messages

- A method is available for rapid comparison of sustainability impacts of various valorisation options for residual streams/biomass: BREVIA
- The utilisation of by-products that are generated in an application can have a significant impact on the total sustainability impact of a valorisation route
- Results are sometimes inconsistent across sustainability criteria
- In the examples presented, the expected sustainability gains of alternative valorisation options are confirmed.

Question to audience: *brainstorm*

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Thank you for your attention!
Are there any questions?

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