https://circular-biomass-valorisation.com/

How to look at biomass availability data

Circularity of biomass utilization

- 25 August 2026| Wolter Elbersen (Wageningen Food & Biobased Research)

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Platform Hernieuwbare Brandstoffen.

BioMob #4 design workshop

Agenda

How much biomass can we mobilize?

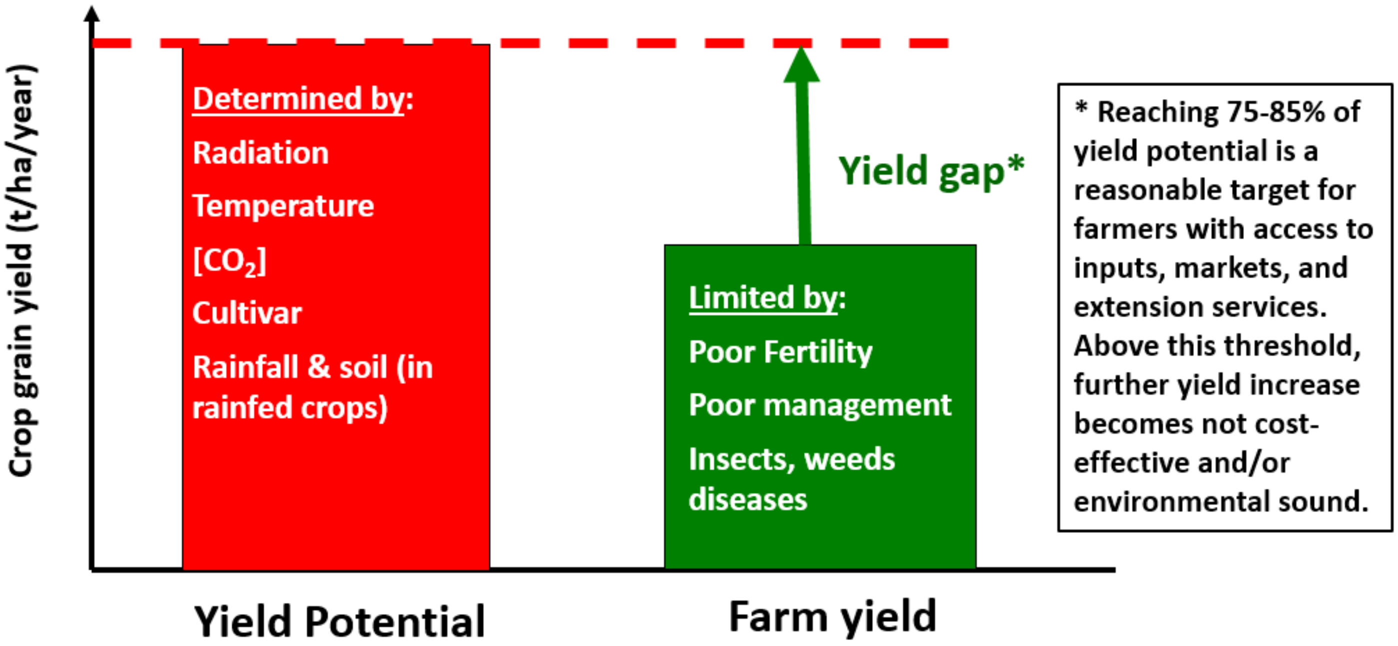
- Crops
  - Use more land? Marginal land crops or intermediate crops
  - Shift in crop use → feed to biobased?
- Higher yields?
- Use residues?
  - Shift in applications → BioShift project
  - What can we achieve with more circular biomass use?

Theoretical (residue) biomass availability?

= Total biomass – must be left behind for the soil, biodiversity, etc. – Current uses - Techno/econ constraint

- "Must be left behind for the soil"?
    - confuses goal and method → soil quality maintenance <u>does not mean leaving behind biomass</u>
- Current uses are fixed?
- Total biomass production varies in short and long term → how to deal with that?
- Result biomass availability = worst quality waste biomass
- We need a new approach!

More biomass?
Closing yield Gap = More yield



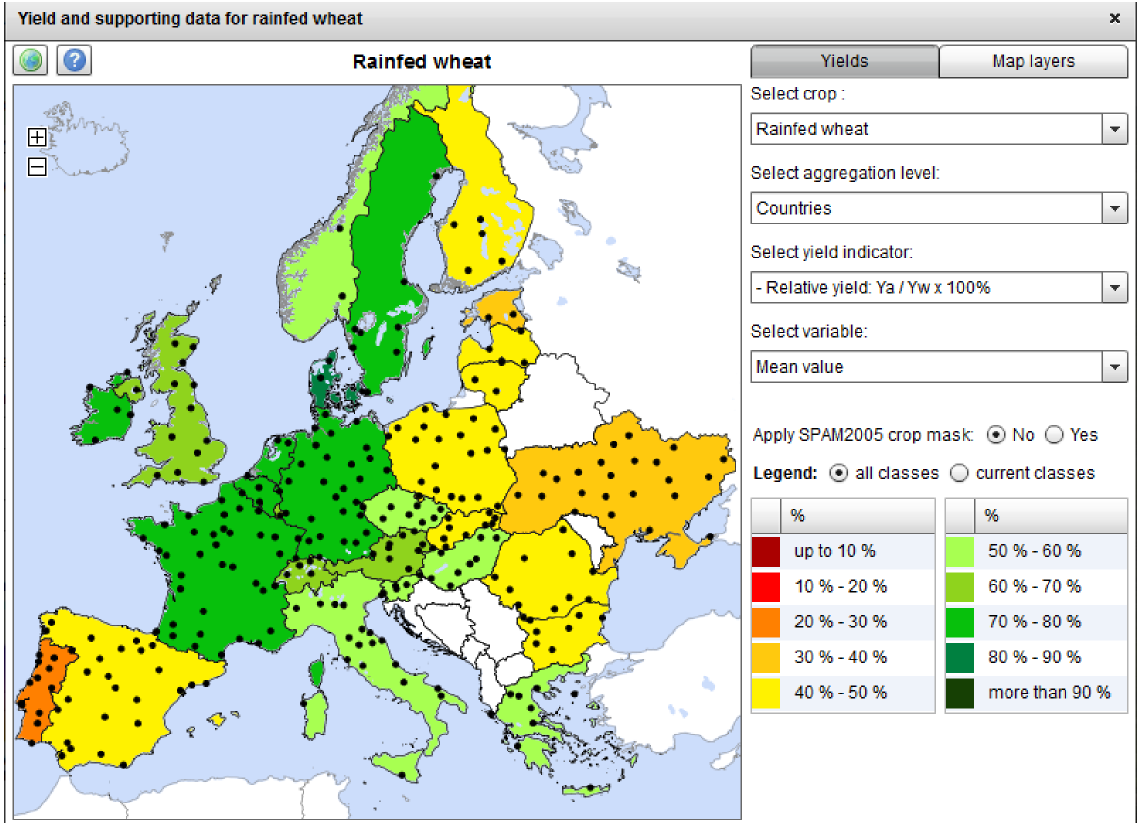
Modified from: van Ittersum and Rabbinge, *Field Crops Research* (1997)

Yield of rainfed wheat as % of potential yield

- Yield of rainfed wheat as % of potential yield
- Attainable by farmers = 80 % of potential

→High opportunity to increase yields on currently used land (Eastern Europe and many other regions)

→In NL little potential?



Ref. www.yieldgap.org/

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World: A lot of biomass is underutilized – Often causing pollution problems – how much can be used for biobased applications?

Top 10 crops in the world		Total field	Total mill
	Million hectares	Million ton DM crop residue per year	
Maize	185	1,038	
Rice, paddy	163	816	
Wheat	220	729	
Sugar cane	27	264	264
Oil Palm	19	192	52
Barley	49	173	
Sorghum	45	103	
Sunflower seed	25	66	8
Millet	31	43	
Seed cotton	35	35	
Sum:	**800**	**3,459**	**316**
All crops worldwide:	1,414		

What part can we mobilize?

Can we recycle the nutrients?

How do we maintain soil quality?

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Europe: Agri-residues are underutilized

EU biomass potential	Current potential	Used potential
	Million tons dry matter per year	
Wood from forests	325	350
Other forest biomass (forest industries)	185	140
Agricultural residues (field and agro-industries)	**342**	**15**
Waste	89	60
Cropped biomass	152	2

Manure: largest potential in NL → next workshop?

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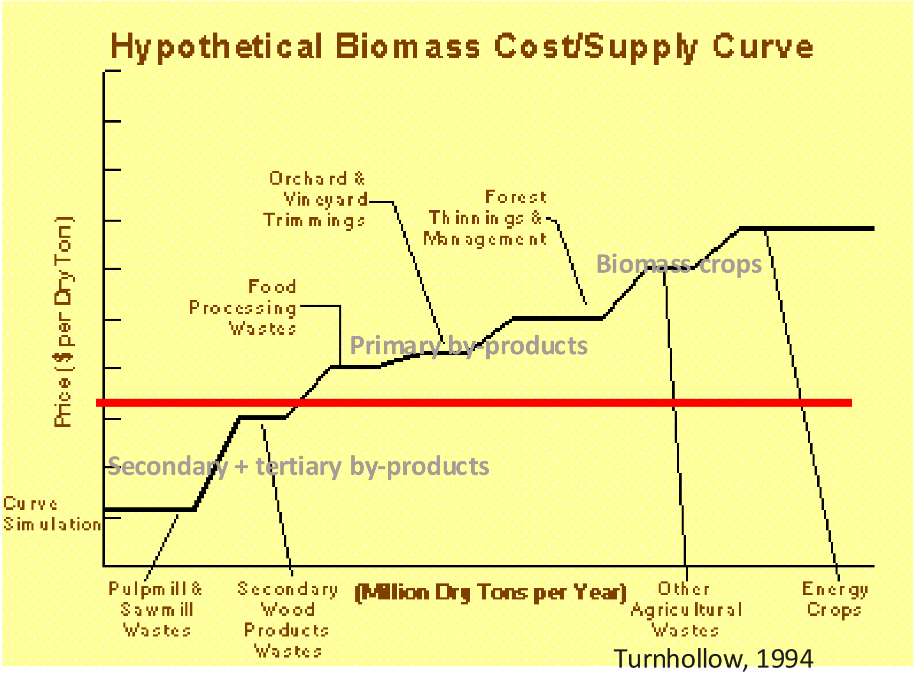
Panoutsou et al., 2016

Which biomass categories?

- Primary by-products: At the source, in the field = sugar beet tops, straw, verge grass, prunings, greenhouse residues, etc.
- Secondary by-products, later in the production chain, is a point source = potato peels, sugar beet pulp, sawdust, bagasse, palm mill residues, etc.
- Tertiary by-products, has had a use “waste” is collected = used frying oil, slaughterhouse waste, household organic wastes, used paper, demolition wood, *manure.*
- Specific crops, maize, wheat, sugar beet, sugar cane, sorghum, Miscanthus, switchgrass, wood crops, palm oil, soy, rape see, etc.

Cost supply curve is starting



Turnhollow, 1994

- Tertiary by-products
- Secondary by-products
- Primary by-products
- Dedicated crops

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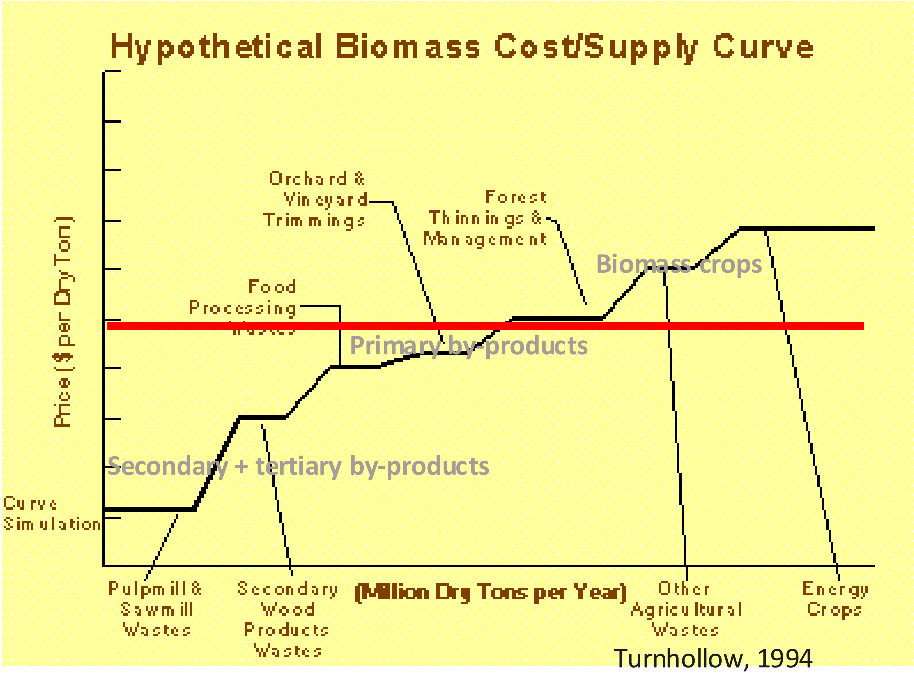

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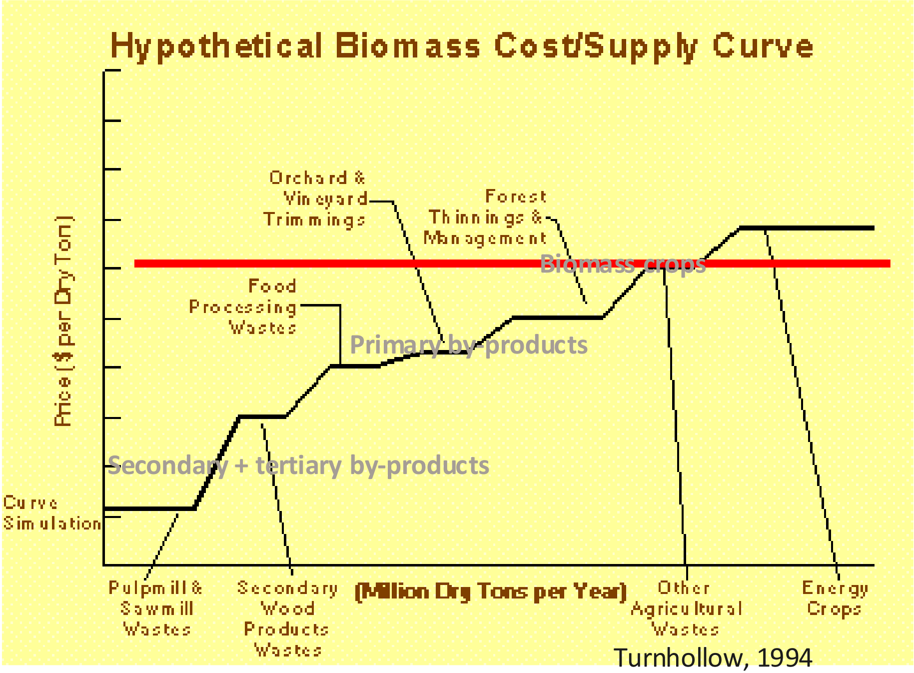

Turnhollow, 1994

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Circular use of biomass

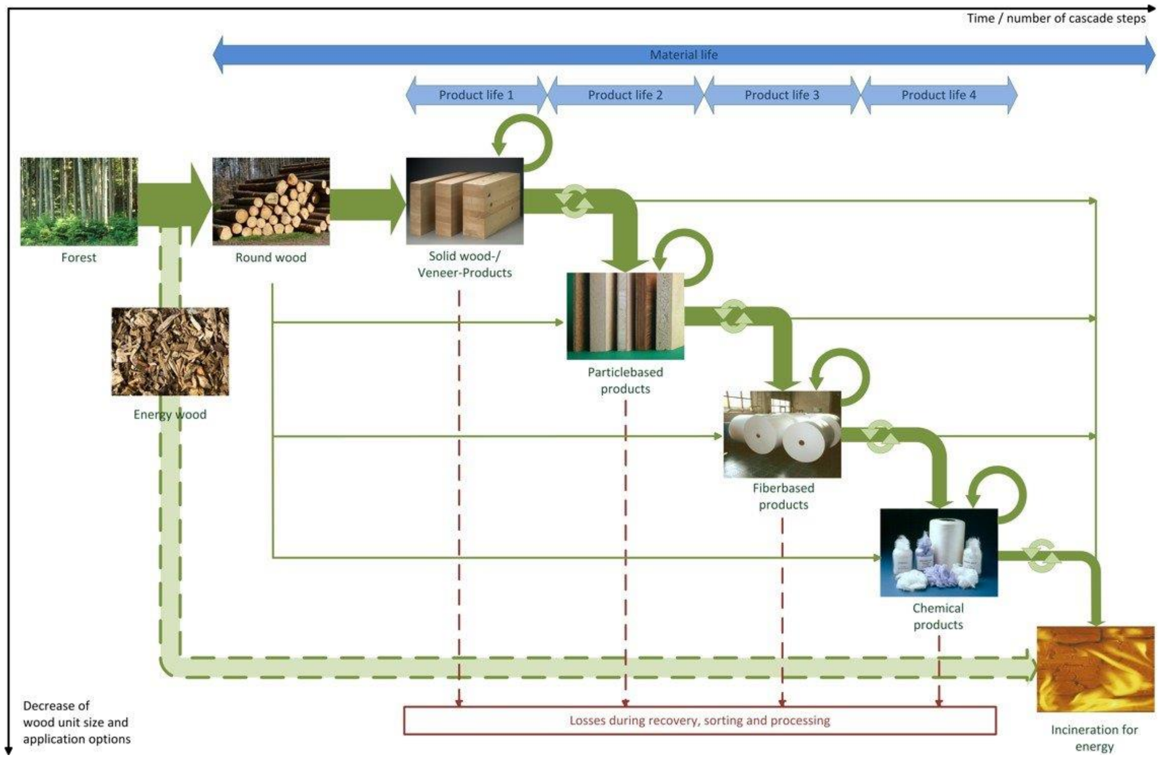
The rationale of cascading – example wood in Bavaria

- Cascading led to 14% savings in wood needed
- 7% less GHG emission for cascading scenario

Circular biomass use saves biomass, land, water, labour and energy!

Rule:

- **Food over feed and materials**
- **Maintain functionality of biomass**
- **Postpone final uses = soil and energy uses**
- **Maintain soil quality**



Ref: Höglmeier 2015; https://phys.org/news/2017-12-cascading-wood-sustainability.html

What application of wood is best from circularity viewpoint?

4 is the most circular applications of wood
0 is the least circular application of wood

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What application of wood is best from circularity viewpoint?

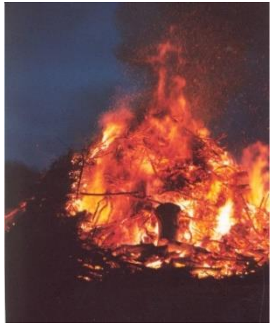
4 is the most circular applications of wood
0 is the least circular application of wood

3

1

1

4



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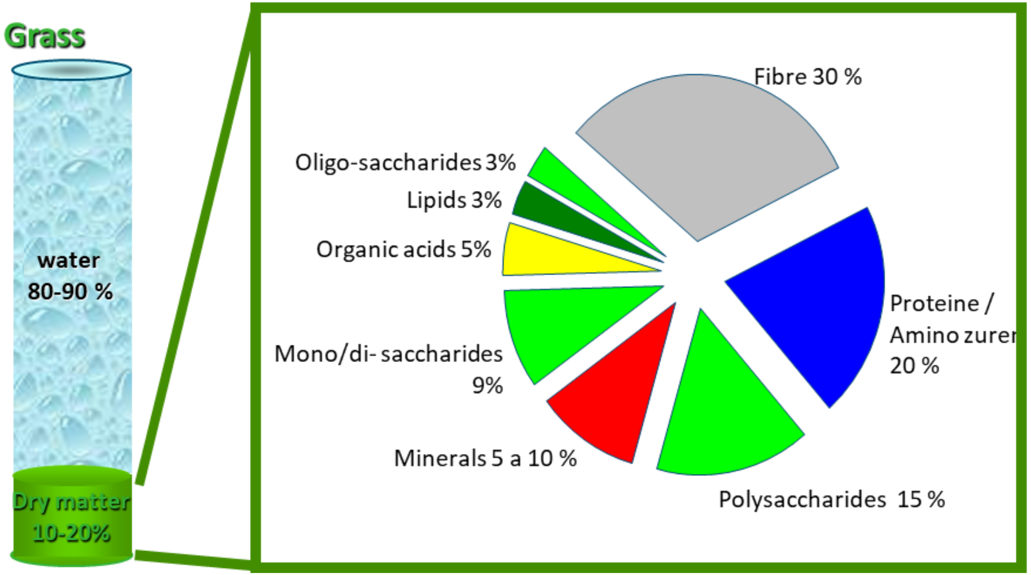
Measuring circularity of biomass applications; extending the cascade – maintaining functionality

Most biomass residues are mixed:

- Some components are scarcer or have more value / appreciation
- Applications have a different hierarchy



Component	Protein	Fat /oil	Fibre	starch, sugar	Nitrogen N	Phosphate P	Potassium K
Appreciation	4	2.2	1	1	6.3	9.4	3.1

Hierarchy in applications: Different for biomass components

Functionality /priority level	Fibre	Protein (Nitrogen)	Fat and oil	Carbohydrates (starch and sugars)	N, P,	Other
4	Materials	Food	Food	Food	Food	Food
3	Pulp, Feed, etc.	Feed / Materials	Feed / Materials (paint, chemicals) /	Feed / Materials	Feed	Feed
2	Monomers (chemicals and fuels[1])	Fertilizer	Transport fuels[1]	Monomers (chemicals and transport fuels[1])	Fertilizer and high value chemicals	Material
1	Energy[2], Soil	Energy[2]	Energy[2]	Energy[2], Soil	Materials	Fuels[1], Soil
0	Loss, Pollution	Loss, Pollution	Loss, Pollution	Loss, Pollution	Loss, Pollution	Loss, Pollution

Formula to calculate circularity score

$$Circularity_{Appl.\,j} = \sum_{Comp.\,i} \begin{matrix} Content_i \\ \times\, Efficiency_{i,j} \\ \times\, Appreciation_{i,j} \\ \times\, Funtionality_{i,j} \end{matrix} \Big/ Ref.value$$

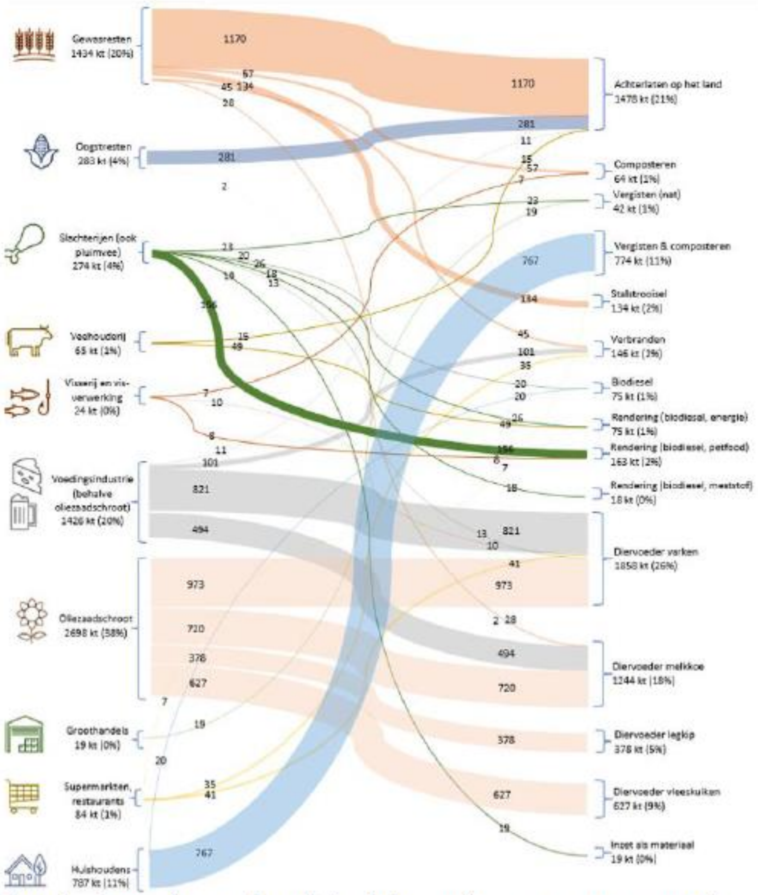
Ref value =

Efficiency is 100%

Appreciation = weight per type of component

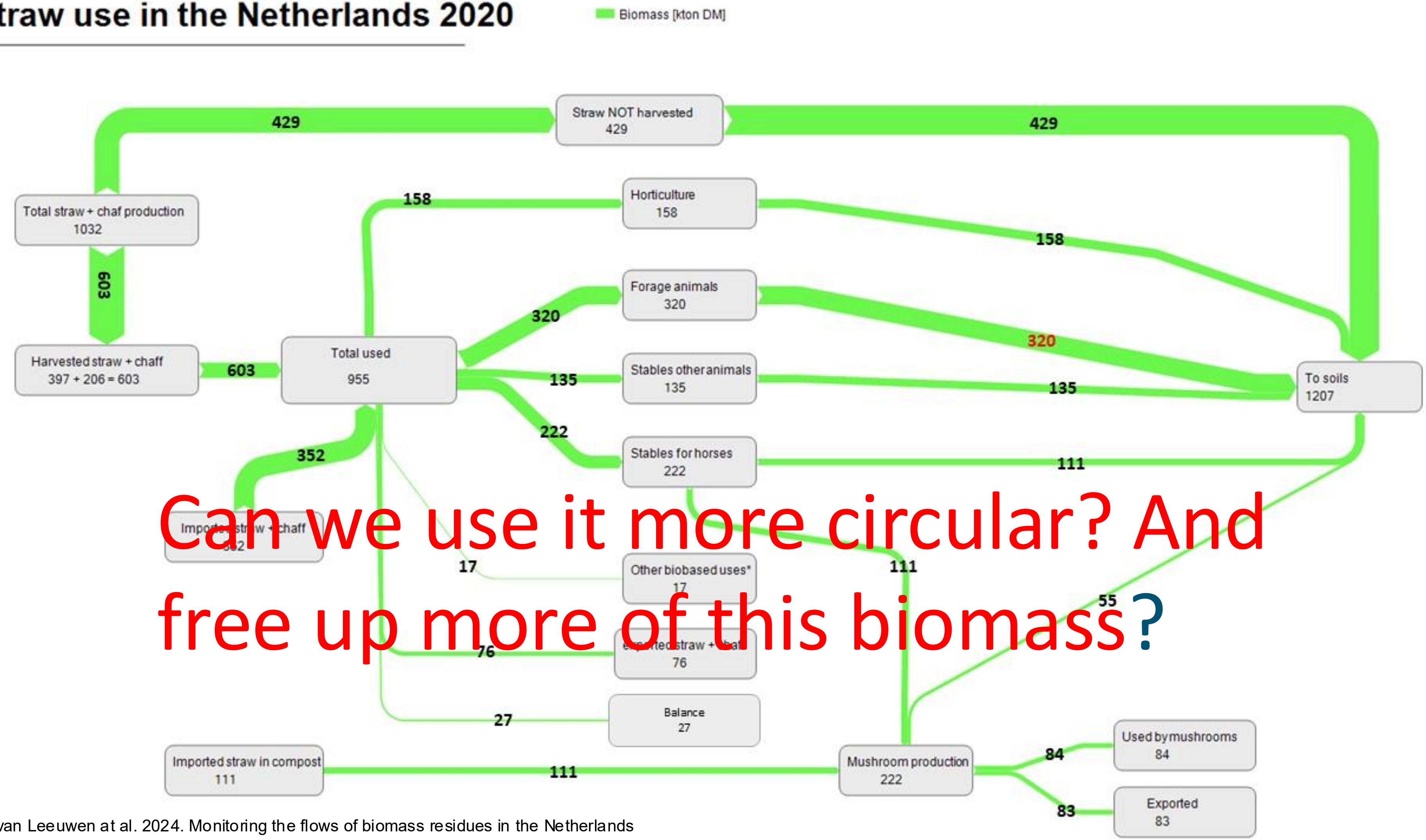
Functionality = 4

Agri-residues in the Netherlands will it shift?



Figuur 1 ***Stroomschema met hoeveelheden (kt droge stof) agro-reststromen per categorie (links) en toepassingen in Nederland in 2021 (rechts)1.***

Straw use in the Netherlands 2020



Can we use it more circular? And free up more of this biomass?

Ref: van Leeuwen at al. 2024. Monitoring the flows of biomass residues in the Netherlands

Thank you!

wolter.elbersen@wur.nl

KomCirc project

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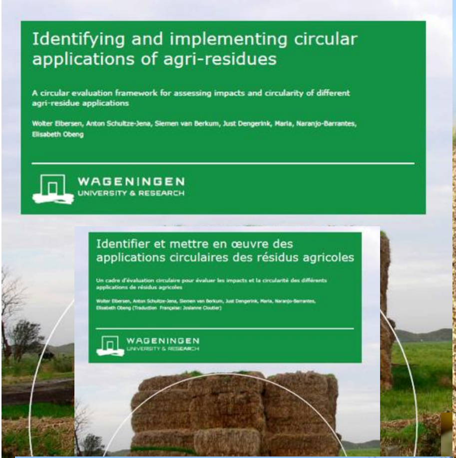
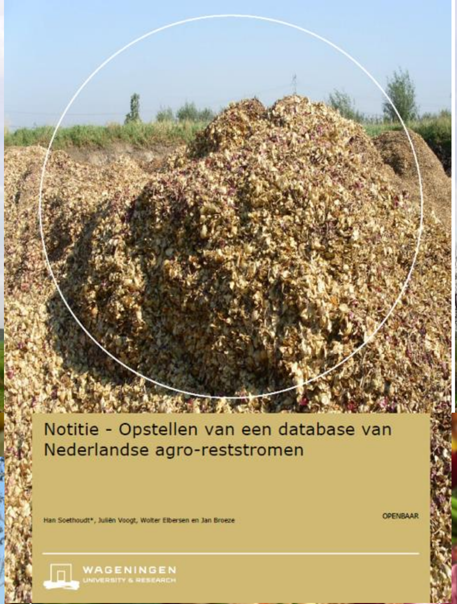
Hoogwaardig: definitie Annevelink et al (2025)

- De mate van ‘hoogwaardigheid’ van het gebruik van biogrondstoffen is een combinatie van **verschillende criteria**
- Voor ieder van die criteria zijn **meerdere indicatoren** denkbaar
- **Relatieve score** van een indicator voor een nieuwe toepassing t.o.v. de huidige toepassing: **hoogwaardiger**
- Hoogte van scores en onderlinge weging daarvan kan **verschillen per stakeholder** (waardering is subjectief proces)
- Het is **onmogelijk** om één enkel absoluut **totaalgetal** vast te stellen
- Geadviseerd wordt om een **multicriteria analyse** uit te voeren (liefst met verschillende typen stakeholders)





WP 1: Curriculum

1.1: Curriculum materialen ontwikkelen voor en met MBO, HAS

1.2: Workshops en masterclasses voor docenten en experts

WP 2: Online tools en modellen

2.1: Bestaande tools bruikbaar maken voor onderwijs en praktijk – online

2.2: Website circulair verwaarden. Link met Groen Kennisnet

WP 5: Projectmanagement

WP 3: Cases

3.1: Cases uitwerken voor en met bedrijven en studenten

3.2: In-/aanvullen van databases n.a.v. de cases

WP 4: Webinars en Workshops

4.1: Webinars en workshop met bedrijven, beleid, NGO's, anderen

4.2 Ontwikkelen communicatie-materialen: filmpjes, handleidingen, infographics,

KomCirc project

https://circular-biomass-valorisation.com/

≈

Towards resource-use-efficient and low-emission biomass exploitation

25 August 2026| Jan Broeze & Wolter Elbersen (Wageningen Food & Biobased Research)

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Platform Hernieuwbare Brandstoffen.

BioMob #4 design workshop

Overview

(Wolter) Intro – circular residues/biomass valorisation

(Jan) Quantitative analysis: degree of circularity & consequential GHGe effects

Examples:

- Surplus bell peppers → energy | feed | food
- Sugar beet leaves → left in the field | biogas | food (proteins)
- Wheat → food | feed | ethanol + feed

(Jan) Effectively fulfilling demand for energy, fuels, feed & food

- Benefit of functional use of biomass components

Intro – circular residues/biomass valorisation

(Wolter)

o.a. Wat is circulair?

- functionaliteit in toepassing
- "waardebehoud" (cascadering Hogelmeier, eiwit in voeding)
- total use: vee produceert naast voeding ook meststoffen

2	*Case study:*	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*
3	Material	Wheat grain	Wheat grain	Wheat grain	Wheat grain	Wheat grain
4	Valorisation pathway	Food (substitute SoyProte	Feed (pigs)	Ethanol + pig feed	Feed (dairy cattle)	Ethanol + cattle feed
6	*TOTAL degree of circularity (%)*	*100.0%*	*19.3%*	*24.4%*	*28.0%*	*26.*
7	*TOTAL GHGe effect (kg CO2e/kg DM)*	*-1.508*	*-0.923*	*-1.802*	*-0.920*	*-1.7*
8	*TOTAL GHGe effect (kg CO2e/kg as-is)*	*-1.336*	*-0.818*	*-1.597*	*-0.815*	*-1.5*
9	*Land occupation effect (m2 x y / kg DM)*	*-3.838*	*-2.587*	*-1.264*	*-2.572*	*-1.1*
10	*Land occupation effect (m2 x y / kg as-is)*	*-3.402*	*-2.293*	*-1.120*	*-2.279*	*-0.9*
11	Upstream effect (re-allocate from reference c					
12	*NET GHGe effect (kg CO2e/kg DM)*	*-0.876*	*-0.291*	*-1.170*	*-0.288*	*-1.1*
13	*NET GHGe effect (kg CO2e/kg as-is)*	*-0.776*	*-0.258*	*-1.037*	*-0.255*	*-1.0*
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18	+ Substituted products (GHGe & Land sp. acco					
43	Substitution GHGe effect (kg CO2e/kgDM)	-1.508	-0.923	-2.006	-0.920	-1.5
45	+ Optional: Transport					
67	+ Optional: Generic unit operations					
81	+ Optional: Add. inputs processing and packaging					
106	+ Emission factors: consumed and gener. ener					
116	Detailed results					
117	+ P					
135						
136	Pr					
137						, simple
138	Yie					0.:
139	*Ci*					*9.*
145	Cli					-1.:
146	Cli					
147	*Ne*					*-1.3*
148	***Ne***					***-1.1***
149						
150	Product/Effect 2	Food energy	Food energy, animal-base	Energy use in process	Food energy, animal-base	Energy use in process
151	Comment			may be 2x higher (DDGS d		may be 2x higher (DDG

Method for quantitative circularity analysis

CAT – Circularity impact Assessment Method

BREVIA – Biomass Resource Efficiency Value Impact Assessment

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Quantitative analysis of circular biomass use

Fundamentals:

- resource-use-efficiency indicator

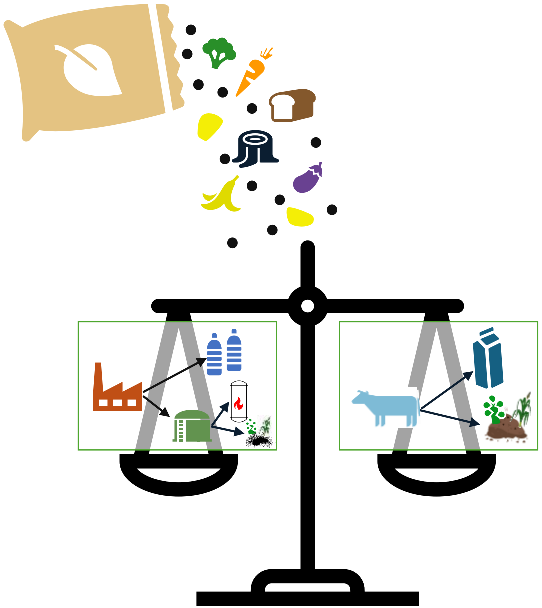
  biomass composition

  ×

  yield factors (per macro-nutrient) to products

- environmental impact indicator

  consequential GHG emissions effect



Quantitative analysis of circular biomass use

CAT - Circularity Analysis Tool

- *Degree of circularity* (indicator for resource-use-efficiency)

    Ratio of the energy content of all products generated in a destination pathway (relative to the energy content of the biomass stream)

    Appreciation correction for proteins in food and energy carriers (based on economic factors)

$$\boldsymbol{Degree\ of\ circularity}\,(\%) = \frac{\sum_{\boldsymbol{products}\ \boldsymbol{k}} \boldsymbol{A_k} \times \sum_{\boldsymbol{components}\ \boldsymbol{j}}\left(\sum_{\boldsymbol{components}\ \boldsymbol{i}}\left(\boldsymbol{y_{i,j,k}} \times \boldsymbol{K_{j,k}} \times \Delta \boldsymbol{H^0_{c,j}} \times \boldsymbol{m_i}\right)\right)}{\sum_{\boldsymbol{components}\ \boldsymbol{i}}\left(\boldsymbol{K_{i,food}} \times \Delta \boldsymbol{H^0_{c,i}} \times \boldsymbol{m_i}\right)}$$

- Consequential *GHG emissions effect*
    - substitution of reference materials (such as common primary feed raw materials or fossil fuels)
    - up to the point of substitution and for non-substitution effects:
        - use of energy and other inputs
        - carbon sequestration (in material or in the soil)
        - emissions of other greenhouse gases: methane and nitrous oxide.

Each material has a specific chemical composition
Each destination has specific mass balance parameter values

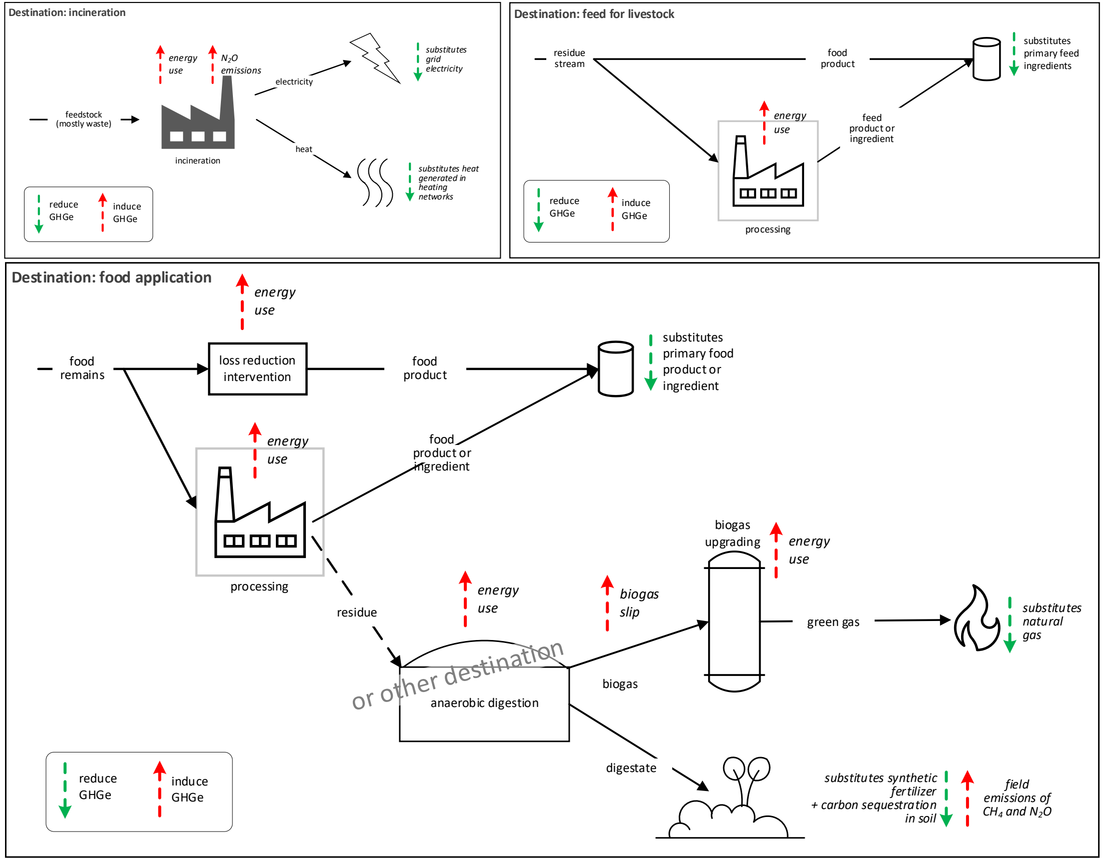
→ results will be specific per material and application

neglected:
- digestibility variations (e.g. inhibition by lignin)
- differences of protein nutrional quality

All effects are estimated based on mass-balances
(e.g. nitrous oxide emissions in composting are estimated from protein content of the material)

Destinations

- Landfill
- Not harvested / Land application
- Incineration, without or with energy recovery
- Combustion
- Thermal conversion pathways (like torrefaction)
- Composting, extensive and intensive
- Composting, combined with anaerobic digestion
- Anaerobic (co-)digestion
- Anaerobic digestion, combined with incineration
- Animal feed, without or with manure digestion
- Conversion to food ingredients
- Extraction of e.g. protein fraction
- Insect animal feed
- Pet food
- Biodiesel (+ animal feed)
- Bioethanol (+ animal feed)
- Microbial proteins
- A few pathways to bioplastics
- …



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Case study results

Common and 'alternative' uses of resources

Food, feed and biobased applications

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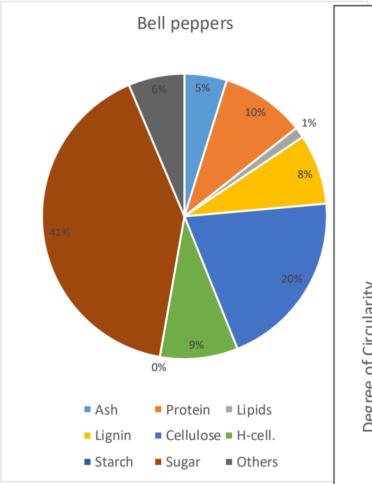
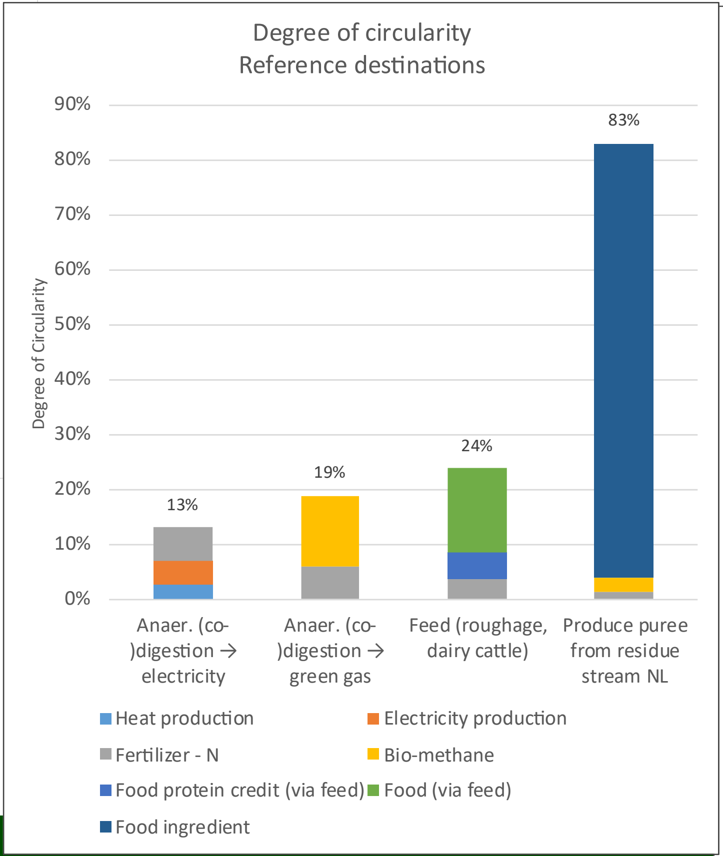
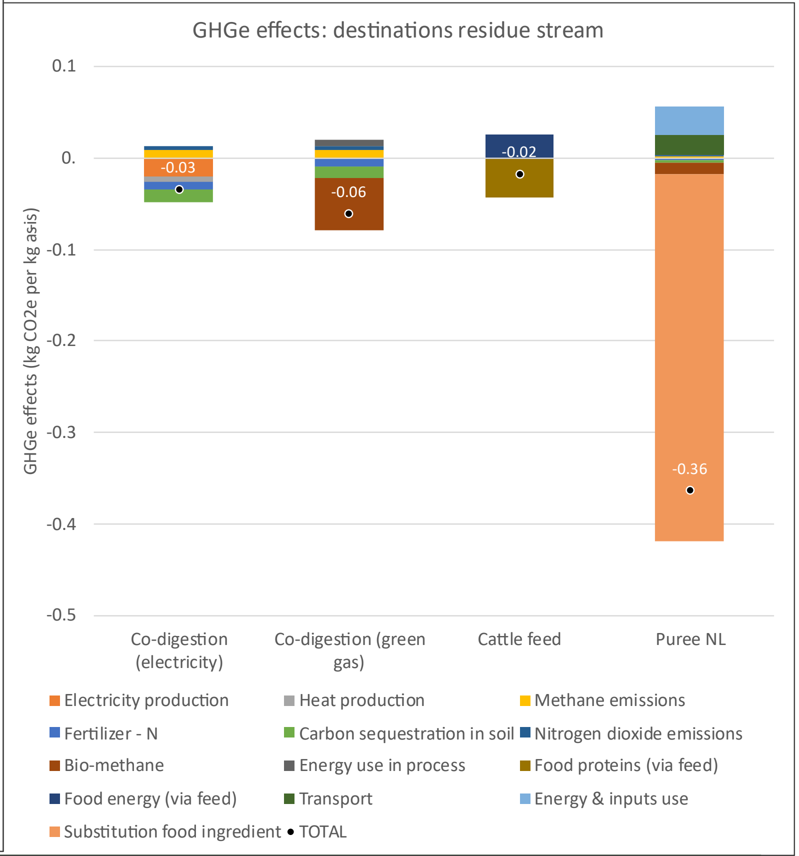
Results surplus bell peppers







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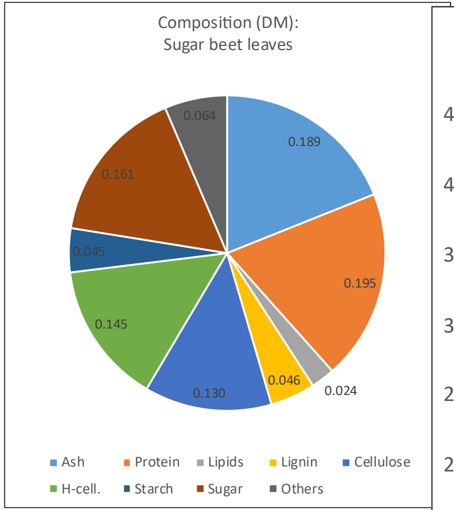
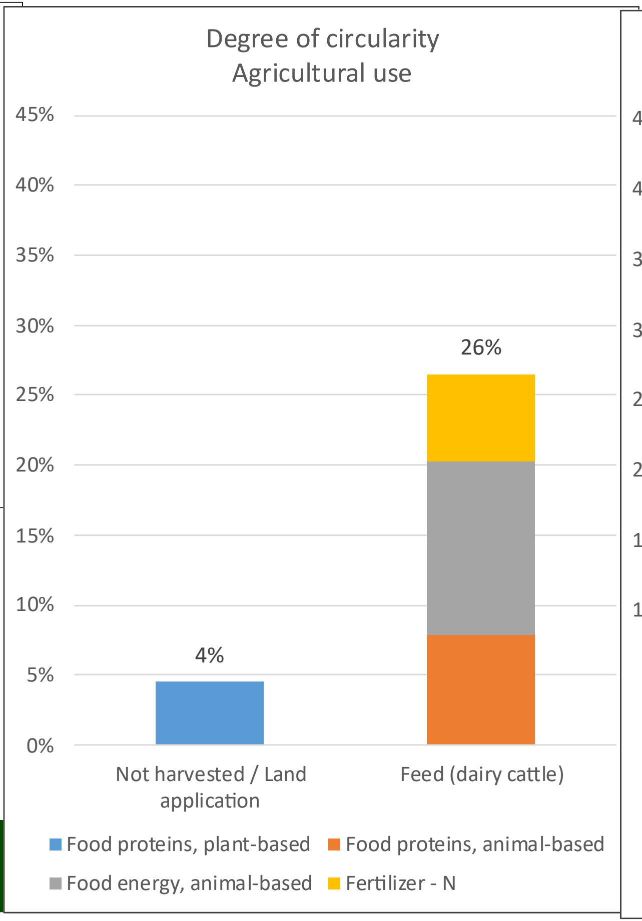
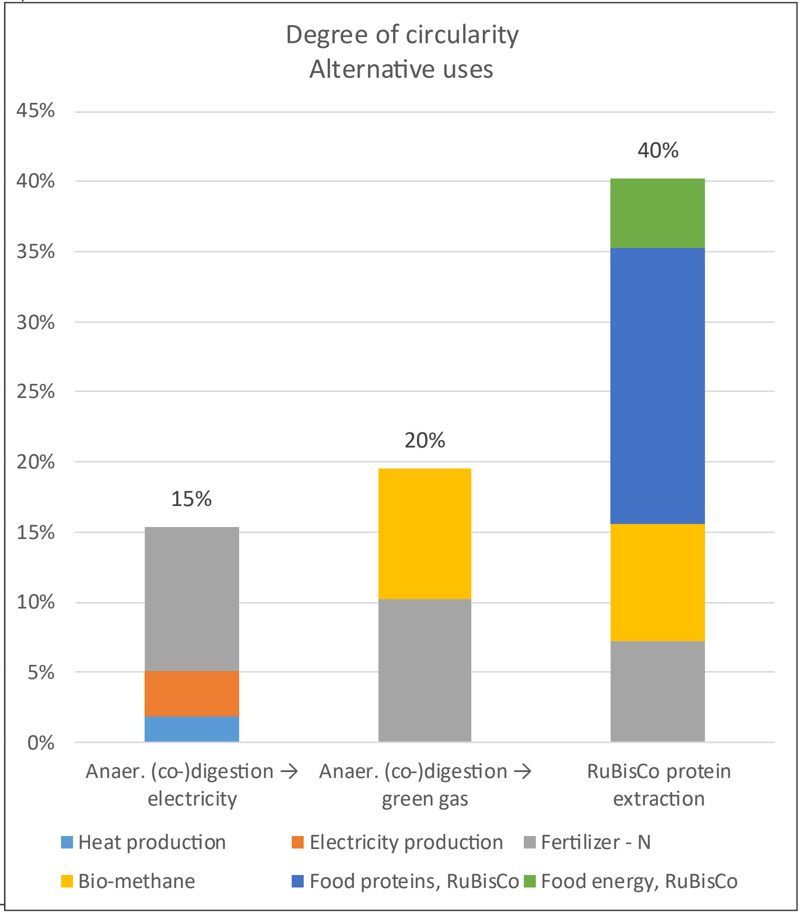
Results sugar beet leaves: degree of circularity







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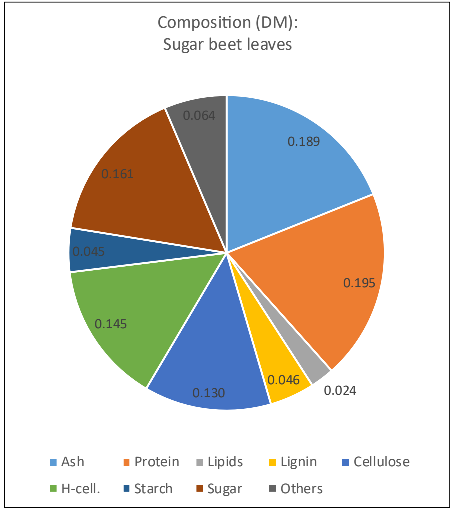
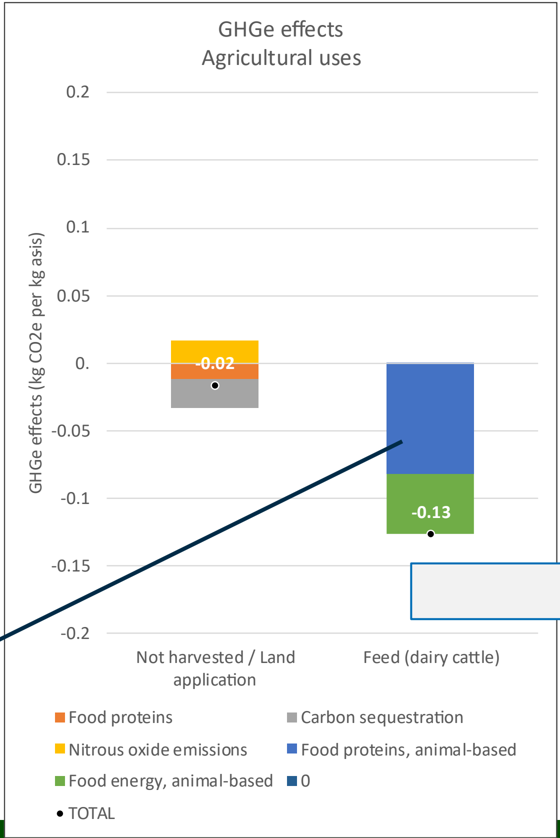
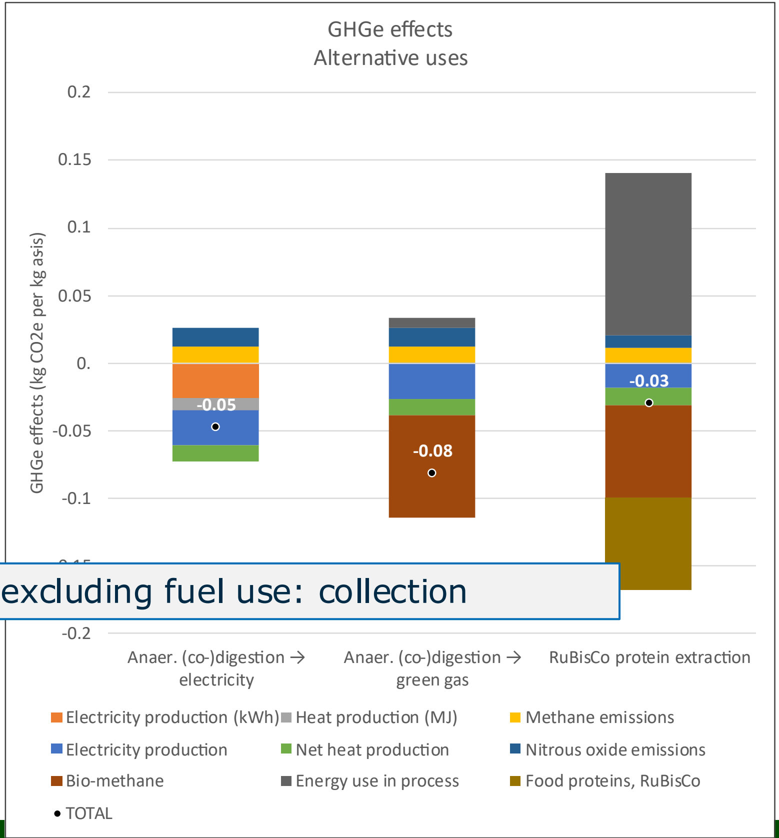
Results sugar beet leaves: consequential GHGe



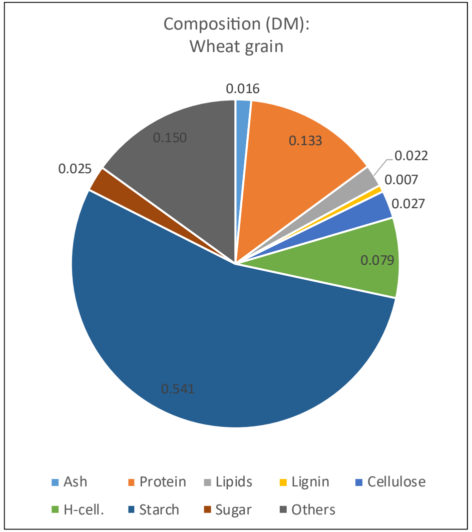


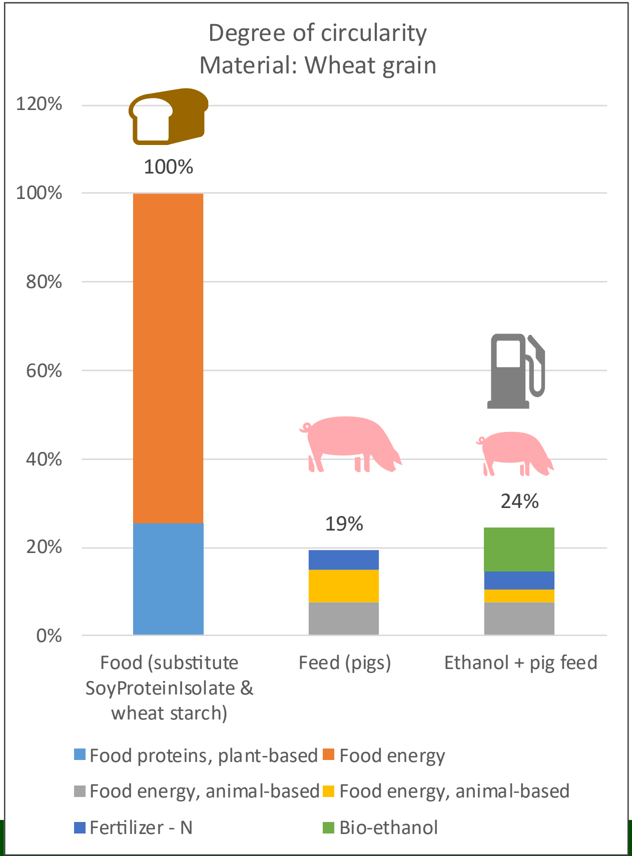


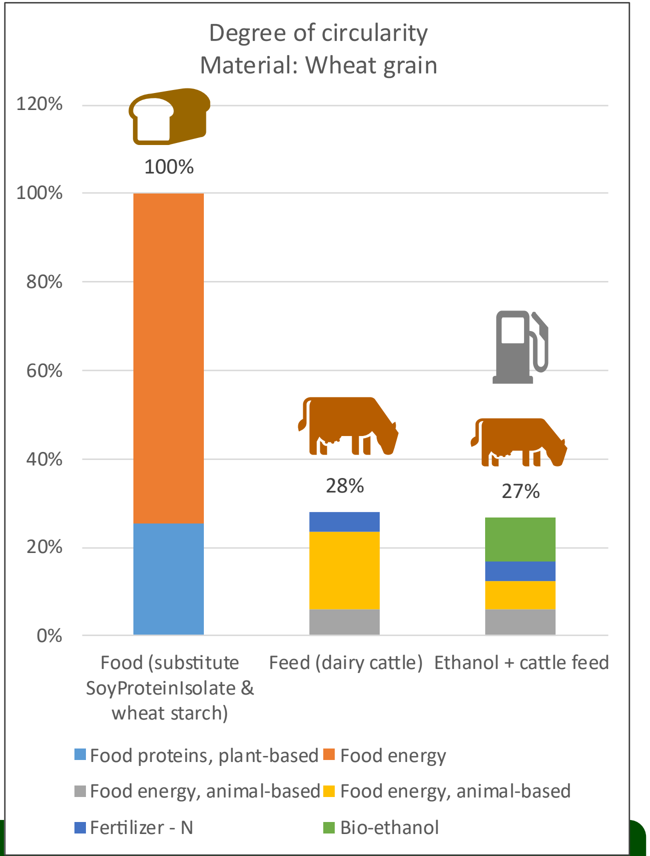
excluding fuel use: collection

CFP soybean meal is critical

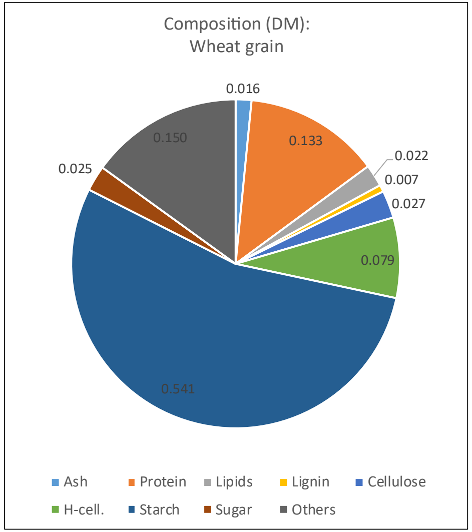
Results wheat: degree of circularity

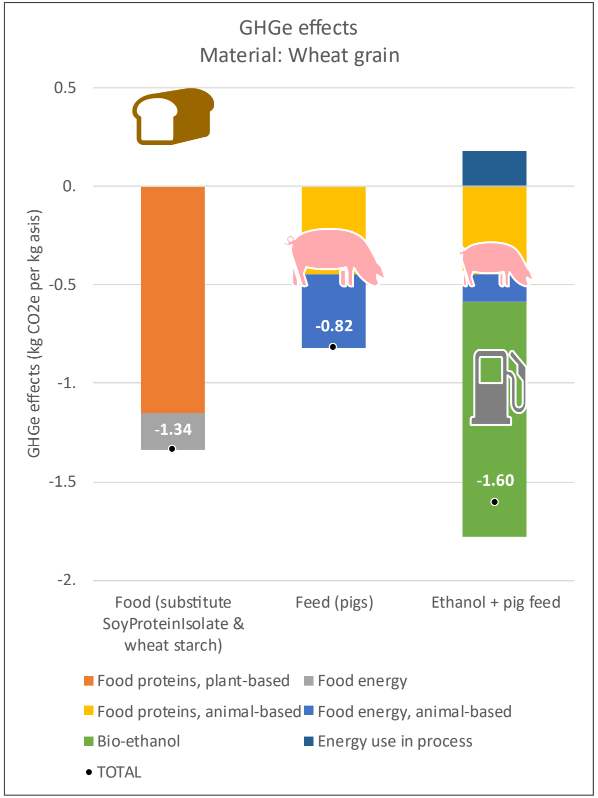


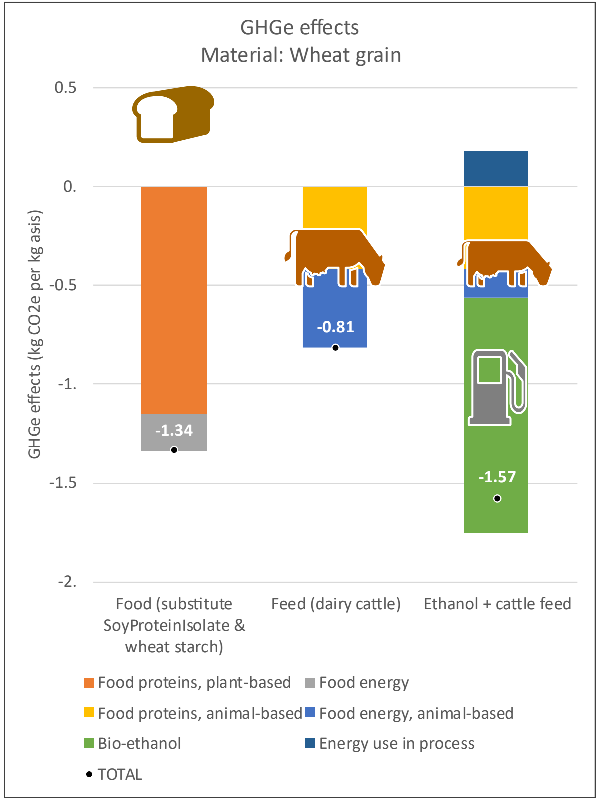




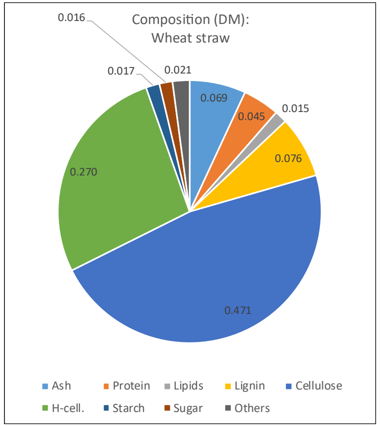
Results wheat: consequential GHGe effect

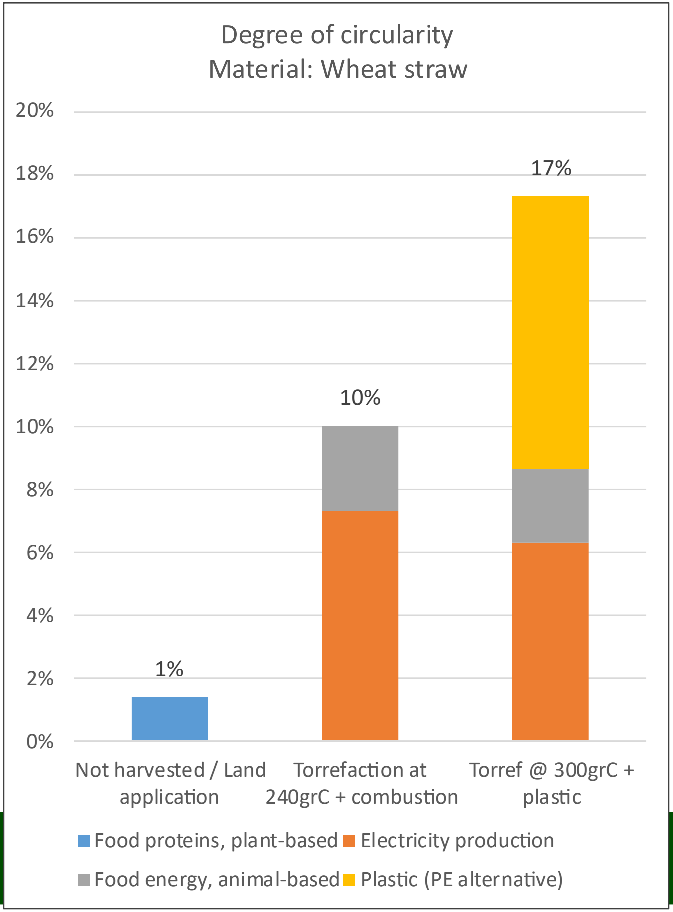


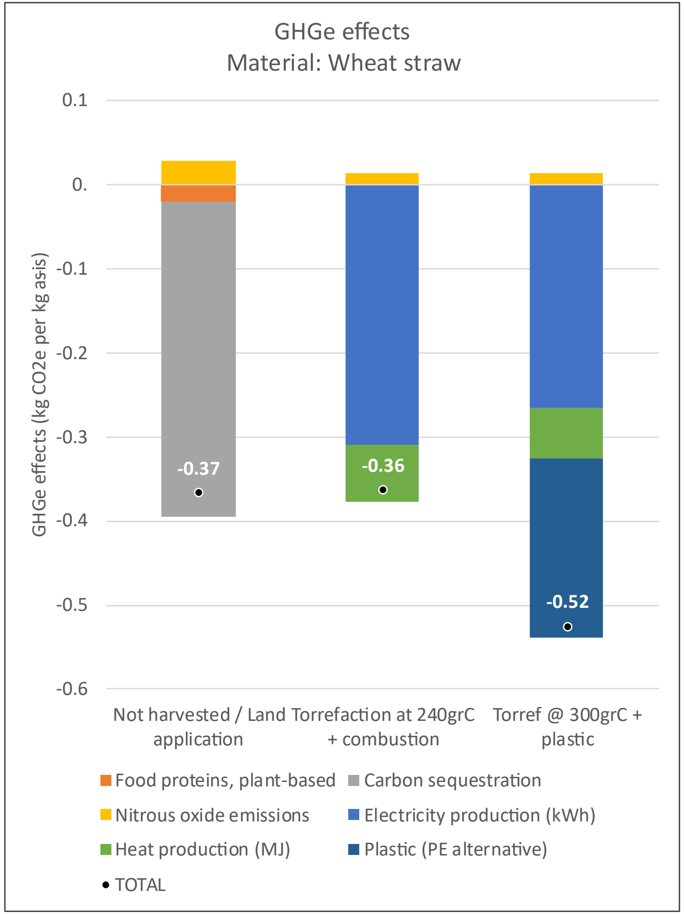




Results wheat straw







2	Case study:	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
3	Material	Wheat grain	Wheat grain	Wheat grain	Wheat grain	Wheat grain
4	Valorisation pathway	Food (substitute SoyProt	Feed (pigs)	Ethanol + pig feed	Feed (dairy cattle)	Ethanol + cattle feed
6	*TOTAL degree of circularity (%)*	*100.0%*	*19.3%*	*24.4%*	*28.0%*	*26.*
7	*TOTAL GHGe effect (kg CO2e/kg DM)*	*-1.508*	*-0.923*	*-1.802*	*-0.920*	*-1.*
8	*TOTAL GHGe effect (kg CO2e/kg as-is)*	*-1.336*	*-0.818*	*-1.597*	*-0.815*	*-1.*
9	*Land occupation effect (m2 x y / kg DM)*	*-3.838*	*-2.587*	*-1.264*	*-2.572*	*-1.*
10	*Land occupation effect (m2 x y / kg as-is)*	*-3.402*	*-2.293*	*-1.120*	*-2.279*	*-0.*
11	Upstream effect (re-allocate from reference c					
12	*NET GHGe effect (kg CO2e/kg DM)*	*-0.876*	*-0.291*	*-1.170*	*-0.288*	*-1.*
13	*NET GHGe effect (kg CO2e/kg as-is)*	*-0.776*	*-0.258*	*-1.037*	*-0.255*	*-1.*
14	*NET land occup. effect (m2 x y / kg DM)*	*-1.855*	*-0.604*	*0.719*	*-0.589*	*0.*
15	*NET land occup. effect (m2 x y / kg as-is)*	*-1.644*	*-0.535*	*0.637*	*-0.522*	*0.*
18	+ Substituted products (GHGe & Land sp. acco					
43	Substitution GHGe effect (kg CO2e/kgDM)	-1.508	-0.923	-2.006	-0.920	-1.
45	+ Optional: Transport					
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116	**Detailed results**					
150	Product/Effect 2	Food energy	Food energy, animal-base	Energy use in process	Food energy, animal-base	Energy use in process
151	Comment			may be 2x higher (DDGS d		may be 2x higher (DD

Analysis of co-production of food & biobased

Scenario's for optimised land use & processing pathways

(hypothetic analysis with limited scope)

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Scope

Essential assumption in quantitative estimates: fixed yield factors
- neglect different digestibility factors
- neglect differences of protein quality

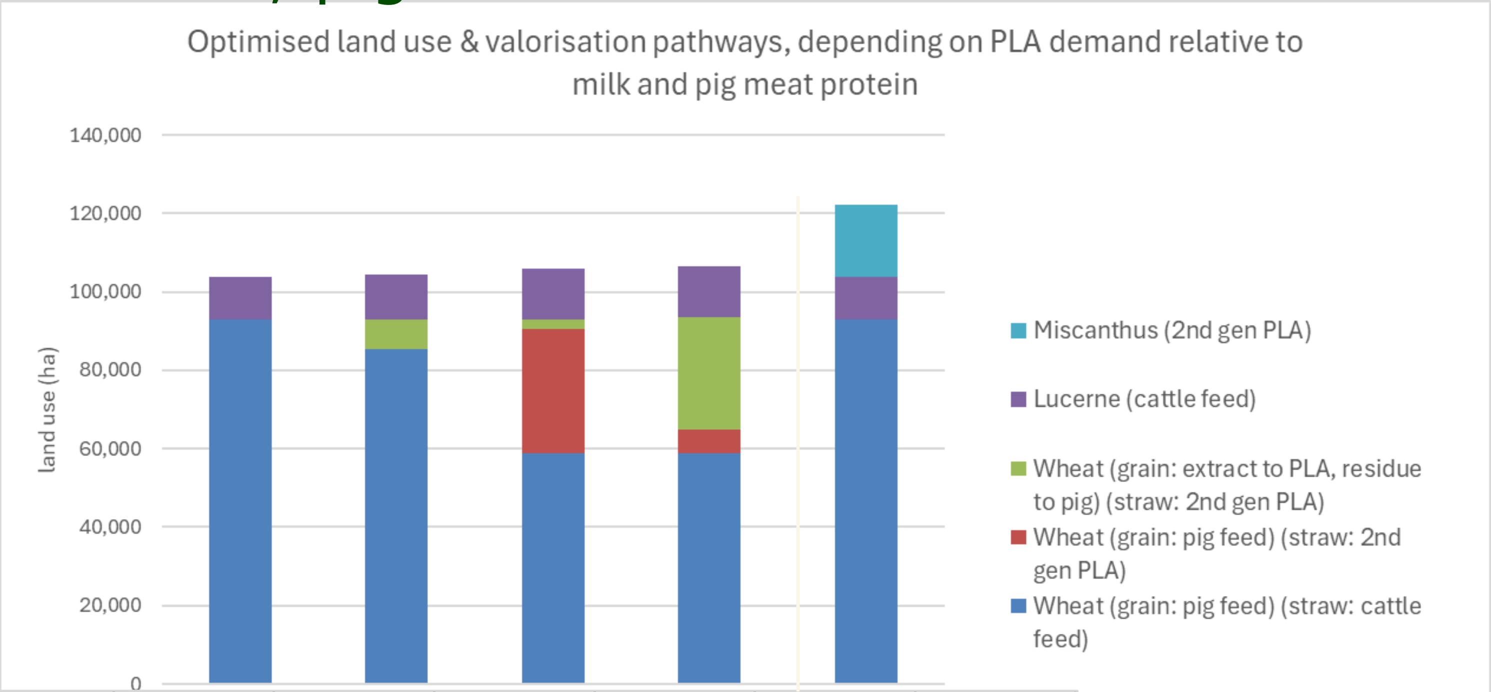
Considered crops:
- from production in NL:
  - wheat (+ straw)
  - maize grain (+ stover)
  - maize silage
  - lucerne
  - miscanthus
- from European production:
  - soyabean meal

Considered valorisation pathways:
- feed for cattle → milk
- feed for pigs → pig meat
- PLA from simple carbohydrates + cattle feed from residue
- PLA from simple carbohydrates + pig feed from residue
- via hydrolysis to PLA (2nd generation)

Scenario comparisons:
- fixed demand for food: milk protein and pig protein
- range of demands for PLA

Compare: Integrated production system for food & biobased
Separated production systems: PLA from miscanthus

Optimisation: milk, pig meat & PLA



Demand for milk protein	0.226	0.226	0.226	0.226	0.226
(with total energy to milk	1.192	1.149	1.000	1.000	1.192
Demand pig meat prote	0.400	0.400	0.400	0.400	0.400
(with total energy to pig r	2.097	2.018	2.071	1.807	2.097
PLA	0.000	0.500	1.000	2.000	2.000
(all in PJ)	integrated production of food & PLA				(PLA from Miscanthus)

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Conclusion: crops (not) in results

No soybean meal

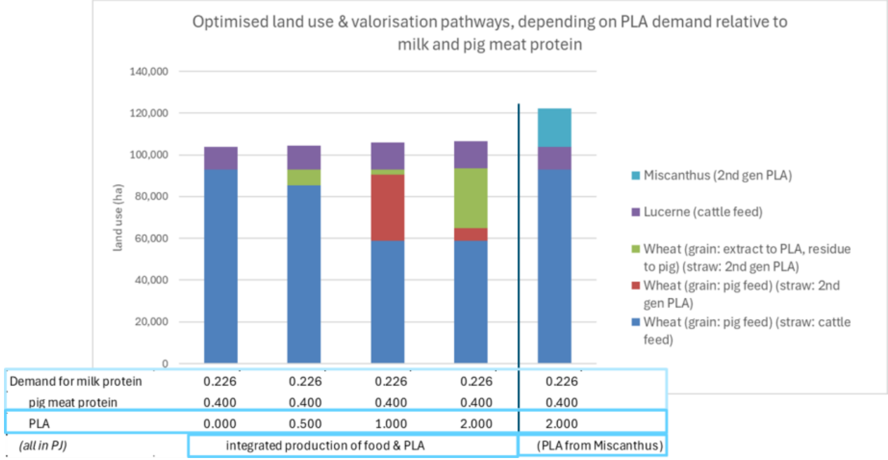
because agricultural yield is relatively low

No maize silage

- because protein content is relatively low (soybean is not used)
- protein yield from lucerne is higher than from maize silage

Wheat grain is preferred over maize grain

because of (slightly) higher protein yield per hectare



Dependency on optimised result with increasing demand for PLA

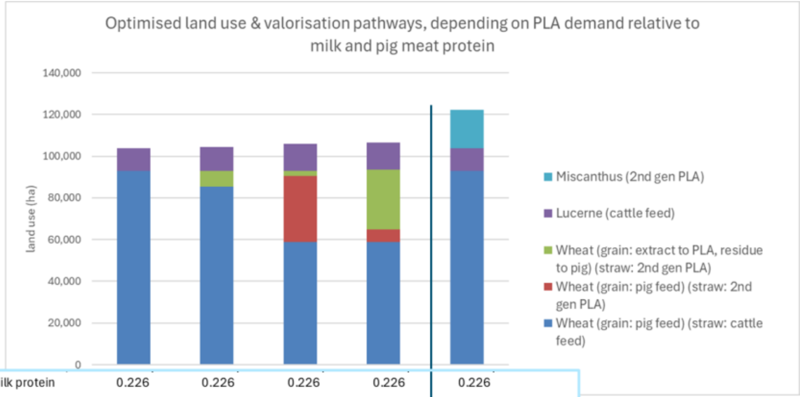
Scenario 1 (no demand for PLA)

- Pigs are fed with only wheat grains
- Cattle is fed with only straw (residue from wheat for pigs) & lucerne

Scenarios 2-4 (increasing demand for PLA)

- with limited demand for PLA, because of high demand for proteins for feed, fist we see that PLA is produced from wheat straw (2nd gen) & from extracted starch from wheat (protein fraction for pigs)
- with increasing demand for PLA, first only straw is increasingly used for PLA, and later again starch from wheat grains.

Because protein supply is most limiting factor, in the ‘integrated system’ the total land use is hardly affected by the increasing demand for PLA (because proteins are most critical in this considered system)



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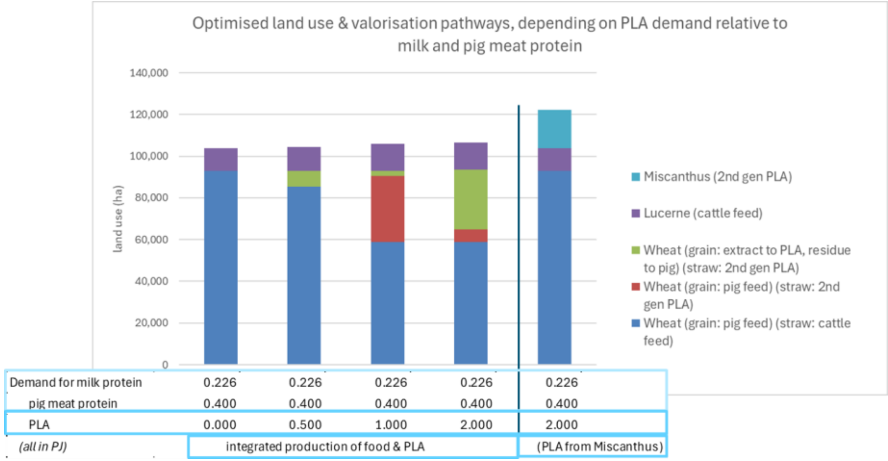
Comparison of results: integrated system (biorefinery) vs. separated

scenario 4 (integrated)

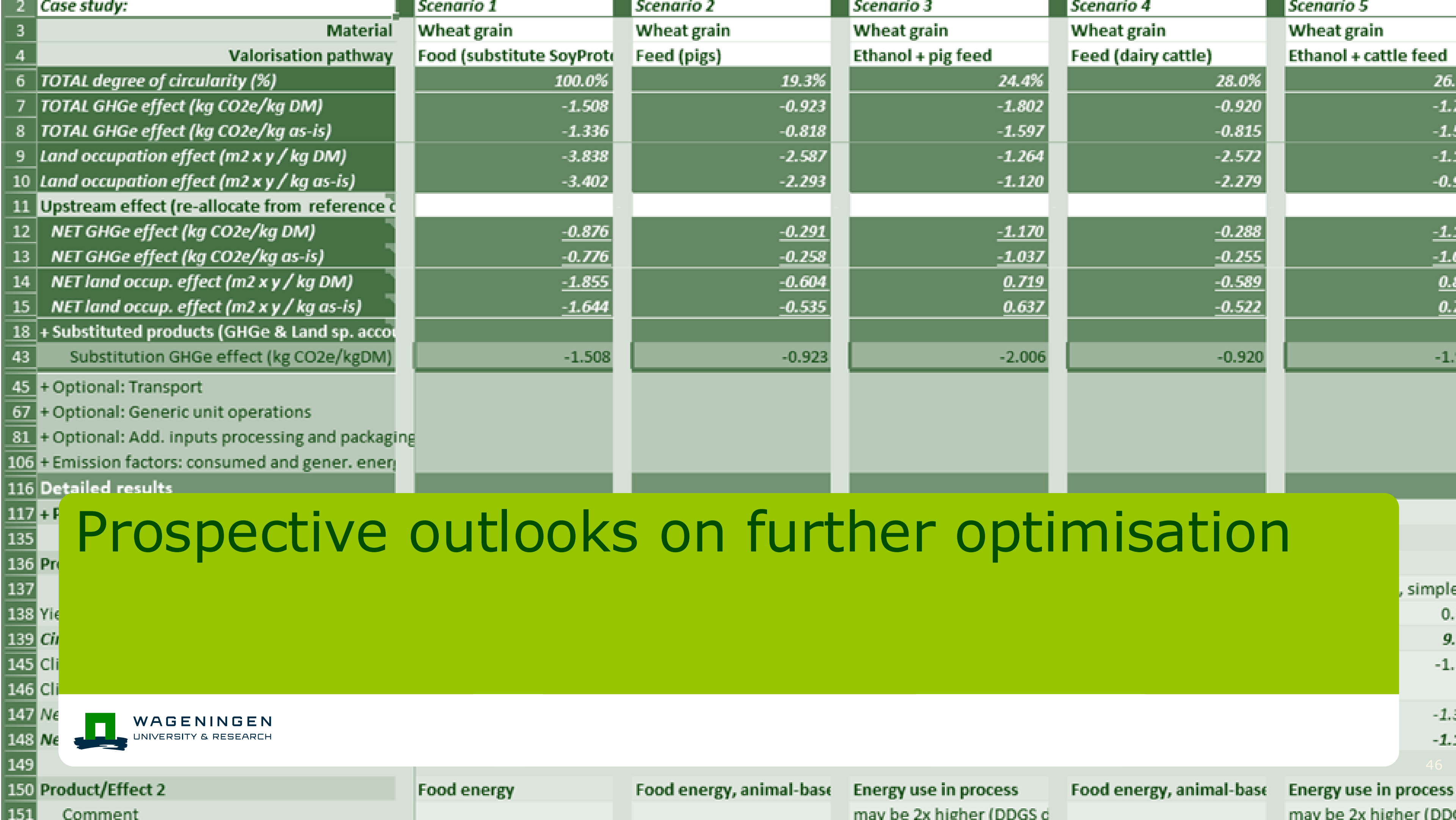
scenario 5 (separated systems for food & biobased)

- the integrated system has higher land-use efficiency
- in the separated system substantial extra land is required for PLA (via miscanthus or maize silage)



Conclusions
(note: scenario study has limited scope and strong assumptions)

- in each scenario protein supply is the critical factor
- carbohydrates are somewhat abundant; carbohydrate-rich fractions can be redirected to bio-PLA production
- this redirection of carbohydrates can be realized with hardly any effects on total land demand
- new value can be created (e.g. biobased products) with limited extra demand for land, through changes in especially valorisation pathways
- a methodology is available that can support such analyses



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Prospective outlooks on further optimisation

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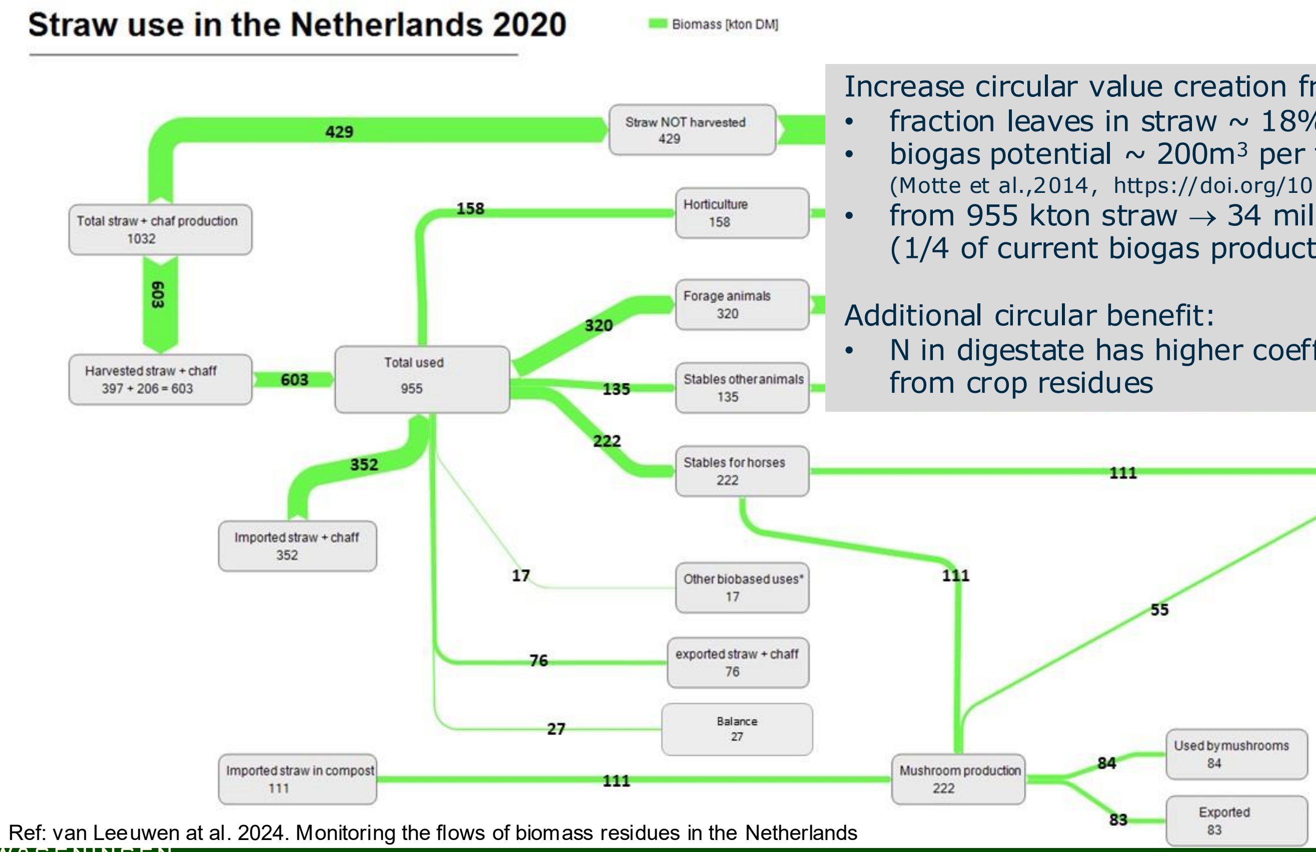
Increase circular value creation: straw biorefinery



Increase circular value creation from leaves in straw:

- fraction leaves in straw ~ 18%
- biogas potential ~ 200m^3 per ton leaves
  (Motte et al.,2014, https://doi.org/10.1016/j.indcrop.2013.11.038)
- from 955 kton straw → 34 million m3 biogas
  (1/4 of current biogas production volume in NL)

Additional circular benefit:

- N in digestate has higher coefficient of action in soil than from crop residues

Ref: van Leeuwen at al. 2024. Monitoring the flows of biomass residues in the Netherlands

Increase circular value creation: manure

Theoretical biogas potential of manures generated in NL: ~ 2000 million m^3/yr

(Scarlatt et al., 2018, JRC104329)

- this can be upgraded to ~ 1300 million m^3 green gas / yr
- which mitigates ~ 2800 million kg CO_2-eq./yr

(excl. energy use, methane slip and post-digestion emissions)

Additional benefit: reduce methane emissions from manure

- order-of-magnitude 20% of methane potential is emitted during storage

Groenestein et al. (2017, WLR

- total GHG emission reduction potential: up to 4000 million kg CO_2-eq./yr

(actual saving depends on fraction of methane emissions that can be prevented)

Thank you!

jan.broeze@wur.nl

wolter.Elbersen@wur.nl

This contribution is part of KomCirc project.
KomCirc received financial support from the Knowledge and Innovation Agenda agriculture, water, food. Within the KIA, the business community, knowledge institutions and government are working together on innovations for safe and healthy food (and a green living environment) for 9 billion people in a resilient world.

https://circular-biomass-valorisation.com/komcirc