

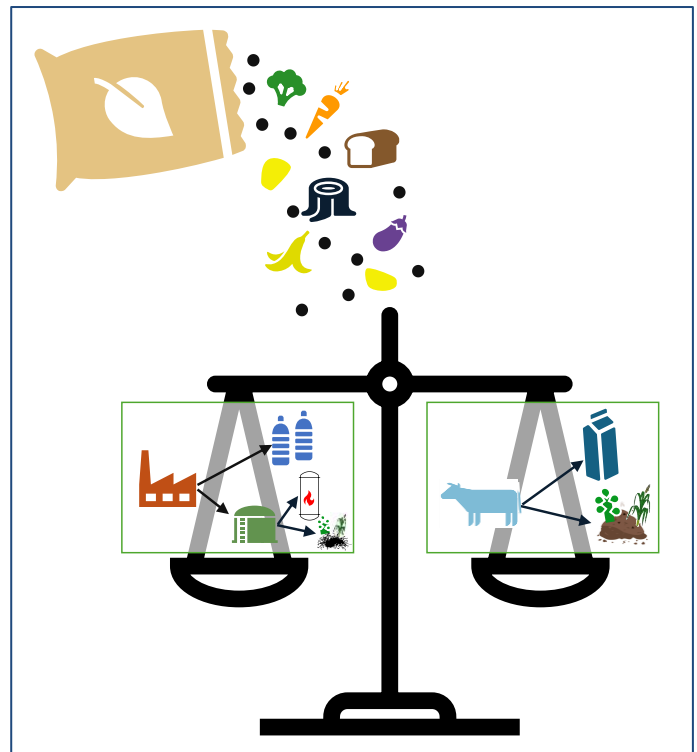
Comparative assessment of the environmental benefits of valorising agricultural residue streams for PHA production versus anaerobic digestion

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Introduction

It is broadly recognized that substituting primary inputs and fossil-derived fuels and materials by (renewable) biomass feedstocks – specifically residue streams – is environmentally beneficial. However, even in the scientific domain the question remains which destination is most beneficial. Rigid hierarchies (like the EU Food Waste Hierarchy) overlook specific functionalities of a material for a destination. For applications in similar domains (e.g. comparison of bioenergy and PHA) comparisons of (environmental) performance for different biobased applications are rarely addressed. Identified references that do actually make such comparisons focus on a single feedstock. Results presented in this leaflet show that the ranking of most beneficial destinations (in terms of environmental benefit) depends on characteristics of the residue stream



The results presented here are generated on the basis of funding by the Dutch Ministry of Agriculture, Fisheries and Food Security and Nature* the EU**.

* In diverse BO projects the foundational method for indicator 'degree of circularity' was developed, including quantitative elaboration of diverse common destination pathways (feed for diverse livestock and other agricultural uses including organic waste management options. In the KomCirc project the method was applied for diverse specific pathways (including parameterisation of dedicated alternative destination pathways and other biomass streams).

The KomCirc project 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.

** The Agriloop project has received funding from the European Union's Horizon Europe research and innovation programme under the grant agreement No. 101081776, the UK Research and Innovation (UKRI) fund under the UK government's Horizon Europe funding guarantee, the Swiss State Secretariat for Education, Research and Innovation (SERI) and from the National Key Research and Development Program of China (NKRDPC).

CAT-BREVIA: Circularity Analysis Tool - Biomass Resource Valorisation Impact Analysis

The CAT-BREVIA tool was developed for estimating and comparing 'degree of circularity' and 'consequential GHG emission effects' associated with allocating a biomass residual flow to various destination pathways.

Degree of circularity, an indicator for resource-use-efficiency

The CAT-BREVIA tool estimates and compares the yield of the application of bio-materials in 'destination pathways' to final products (food, energy carriers and biobased materials). The calculations are based on mass balance equations*, describing conversion efficiency per macronutrient (proteins, lipids, carbohydrates, etc.).

The analysis of a destination pathway includes all significant effects, including those arising from residual streams generated within the pathway. For example, for feed applications, the assessment considers not only the production of animal-derived food products but also the contribution of the resulting manure to feed and food production through its use as a fertilizer.

The degree of circularity is calculated as the ratio of the energy content of the end products relative to that of the input material (as – often hypothetically – food), with two adjustments:

- Considering the specific nutritional importance of proteins in food, beyond their energetic value, and the generally lower agricultural yields of protein crops compared to energy crops (expressed in MJ ha⁻¹), higher additional weighting factor is assigned to proteins in food: whereas in the tool other components are appreciated at their specific heat of combustion, proteins in food are appreciated at 3 times their specific heat of combustion.
- Distinct appreciation factors for final product categories: food, energy carriers and biobased materials:
 - Food is – based on societal preferences – considered here as the reference.
 - Generally, application of biomaterials for production of energy carriers is considered lower-value than for food production. This (societal) preference is reflected by lower or comparable prices for feedstocks for anaerobic digestion or biofuels production (compared to food and feed for livestock). Furthermore, energy carriers (like biomethane and biofuels) are commonly generated with substantially higher (energetic) efficiency from feedstocks than the conversion of livestock feed into food products. Based on these considerations energy carriers are assigned a lower appreciation factor (25%) compared to food products in the tool.
 - Biomaterials can be utilized multiple times throughout their life cycle, e.g. through recycling and incineration (with potential of energy recovery) at the 'end-of-life'. Therefore, a higher appreciation factor is assigned to biomaterials compared to energy carriers. Based on typical recycling rates for bioplastics found in literature (between 60 and 90%), here biomaterials are appreciated at 3x the value for energy carriers.

Appreciation factors for final product categories may be adapted with changing (societal) preferences.

The net increase of the *degree of circularity* resulting from the reallocation of a material from a reference destination pathway to an alternative destination pathway is defined as the difference between the *degrees of circularity* associated with the two pathways.

Consequential GHG emission effects

The CAT-BREVIA tool estimates consequential GHG emission effects, in accordance with common consequential greenhouse gas emission quantification recommendations. The following effects are taken into account:

- the use of energy and other processing inputs;
- the substitution of primary materials (such as commonly used animal feed or fossil fuels);
- for products (including produced residuals) that do not substitute a material:
 - carbon sequestration (in material or in the soil),

- emissions of other greenhouse gases induced in the 'final' destination:
 - CH₄, with a Global Warming Potential (GWP) of 27 kg CO₂ equivalents (CO₂e) per kg,
 - N₂O, with a GWP of 273 kg CO₂e per kg.

For comparing different destination pathways, it is recommended to use marginal GHG emission factors. For substituted materials, generally using average/typical GHG emission intensities of primary materials is considered adequate. For electricity the tool provides proxies for 'marginal' emission factors (next to average emission factors) for many countries.

The net *consequential GHG emission effect* of reallocating a material from a reference to an alternative destination pathway is defined as the difference between the *consequential GHG emission effects* of the two pathways.

Note: The consideration of all consequential effects in this method fundamentally differs from attributional greenhouse gas emission accounting ('carbon foot printing').

To facilitate rapid assessments, the tool contains a database with information about average/typical compositions of diverse biomass materials, residual flows and products.

**Disclaimer: The method relies on parameters derived from reference studies that are often limited in scope and/or based on average values. Consequently, its application to individual case studies may involve some inaccuracy and uncertainty due to the inherent generalizations and averaging assumptions.*

The CAT-BREVIA tool is subject to ongoing development and refinement. New insights can lead to adjustments of pathway parameter values. Likewise, greenhouse gas emission factors, for example for energy carriers and crops, will be regularly updated. This will inevitably result in (generally small) differences generated with different versions of the tool. Results for scenarios calculated with different versions of the CAT-BREVIA tool should not be mutually compared.

More information – including a downloadable version of the tool – can be found on <https://circular-biomass-valorisation.com/quantification>.

The CAT-BREVIA tool was developed based on public funded research projects, supported by the Dutch Ministry of Agriculture, Fisheries Food security and Nature* and from EU**.

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*** In EU Agriloop project, the method was extended with the indicator 'consequential GHG emission effects' and some alternative destinations, including bioplastics and microbial proteins. The Agriloop project has received funding from the European Union's Horizon Europe research and innovation programme under the grant agreement No. 101081776, the UK Research and Innovation (UKRI) fund under the UK government's Horizon Europe funding guarantee, the Swiss State Secretariat for Education, Research and Innovation (SERI) and from the National Key Research and Development Program of China (NKRDPC).*

Described effects in both destination pathways

For the destination *anaerobic digestion* it is assumed that generated biomethane substitutes natural gas, whereas the digestate is assumed to be used as fertilizer. Other GHG emission effects are shown in Figure 1.

For the destination *PHA production* it is assumed that produced PHA substitutes fossil-derived plastics. The processing residues are assumed to be anaerobically digested, with the effects as described above.

Further details of the assumed heuristics and processing parameter values can be found in the factsheets for *Destination Anaerobic (co-)digestion with application of digestate as fertilizer* and *Destination PHA production*.

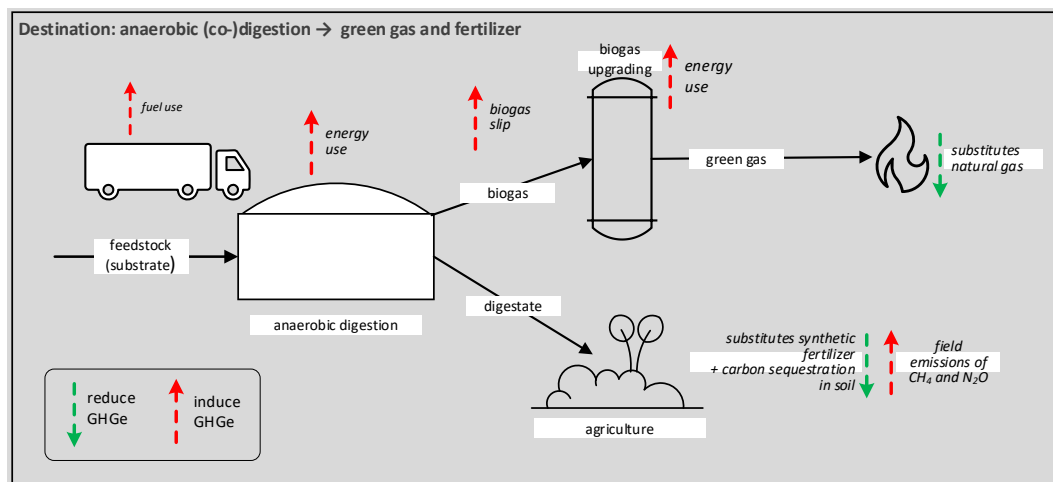


Figure 1. Described GHG emission effects for destination 'Anaerobic digestion'.

Remark: In this generic analysis, GHG emissions due to transport are neglected.

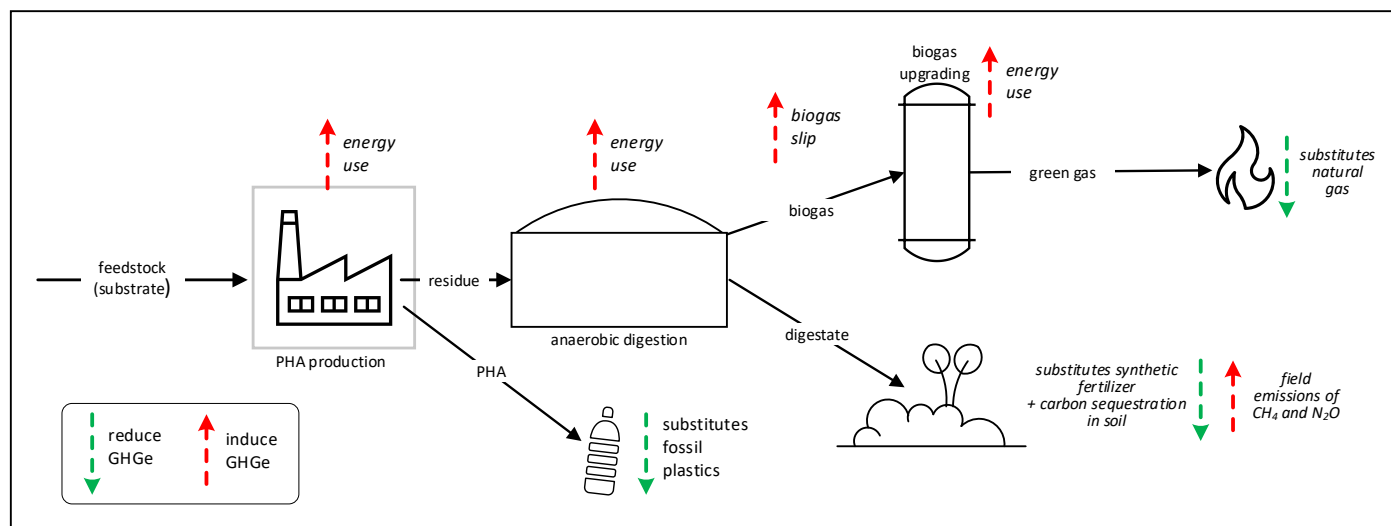


Figure 2. Flow chart of the PHA production pathway, showing the system's GHG emission effects.

Considered feedstocks

- cattle manure
- corn cobs
- mixture of corn cobs and cattle manure (50:50 on dry matter basis)
- grey starch
- tomato pomace

Results

Results for both indicators for the selected feedstocks are presented in Figure 3 and Figure 4 respectively. Apparently, feedstocks with high contents of simple carbohydrates (such as grey starch and potato peels) score significantly better in terms of both indicators in the PHA pathway than in the anaerobic digestion pathway. This can be explained by the high functionality of simple carbohydrates for PHA production; see details in Figure 5 - Figure 8.

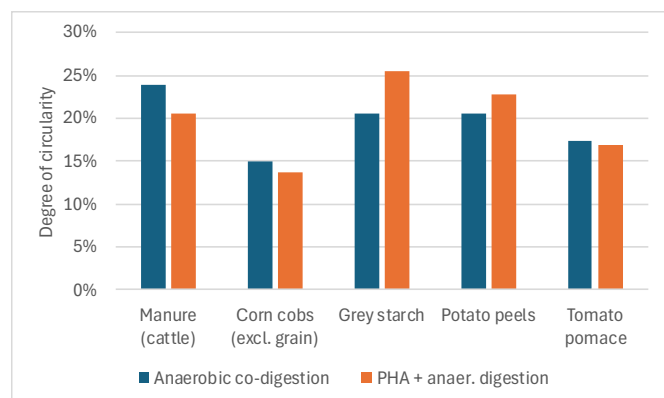


Figure 3. Calculated Degree of circularity for both destination pathways for the selected feedstocks.

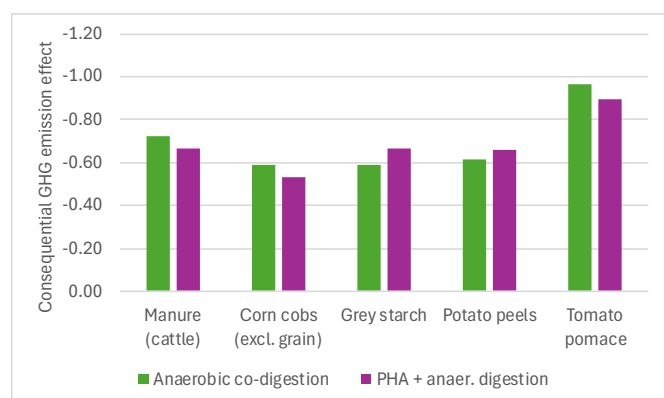


Figure 4. Calculated Consequential GHG emission effect (kg CO₂e per kg dry matter feedstock) for both destination pathways for the selected feedstocks.

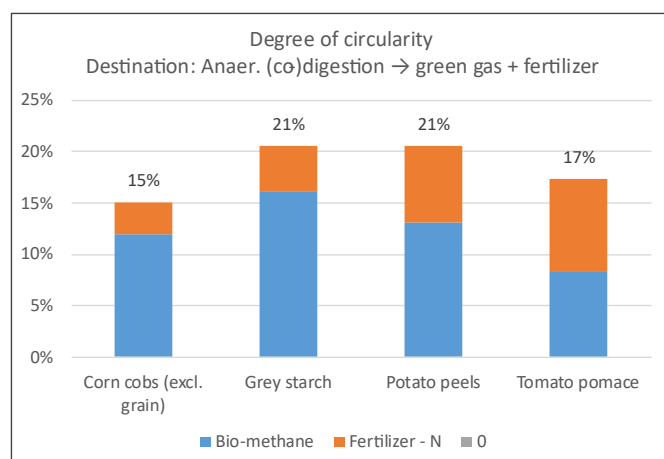


Figure 5. Breakdown of contributions to Degree of circularity by products generated in destination pathway Anaerobic digestion for a selection of materials.

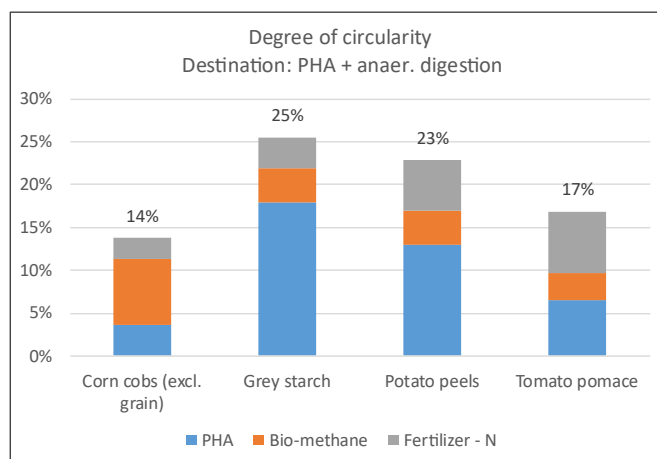


Figure 6. Breakdown of contributions to Degree of circularity by products generated in destination pathway PHA production.

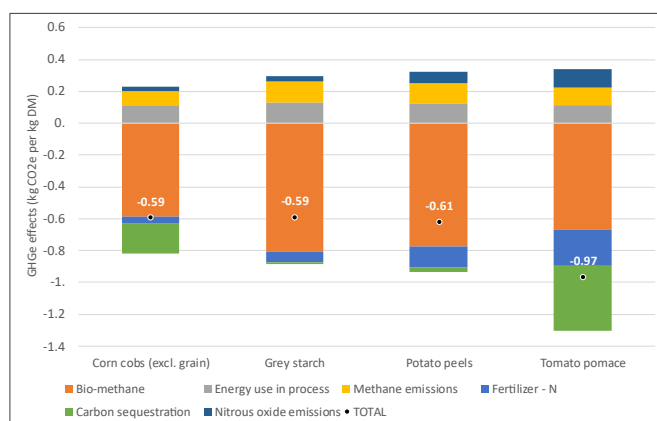


Figure 7. Breakdown of Consequential GHG emission effects in destination pathway Anaerobic digestion.

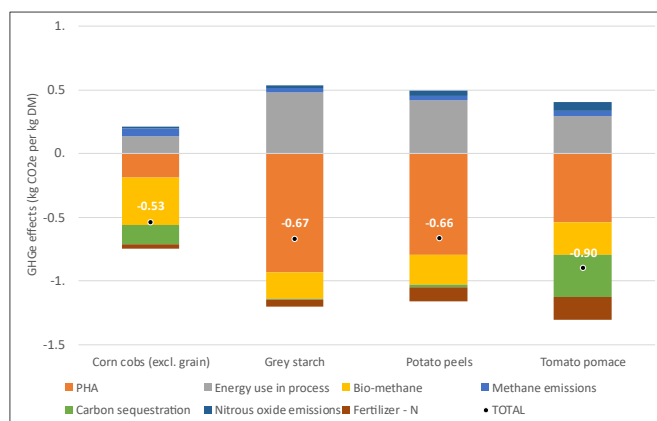


Figure 8. Breakdown of Consequential GHG emission effects in destination pathway PHA production.

Conclusions

The results from the comparative show that in the comparison of environmental performance of residue valorisation, the functionality of the material for the destination should be taken in account. Consequently, conclusions regarding the most environmentally beneficial valorisation option for a residue stream, when derived from a comparative analysis of a specific material type, should not be generalized across all residue streams. The preferent destination (in terms of considered environmental performance) depends on characteristics of the residue stream.