

CAT-BREVIA – Circularity Analysis Tool for Biomass Resource Valorisation Impact Analysis

Factsheet Pathway *Pig feed*

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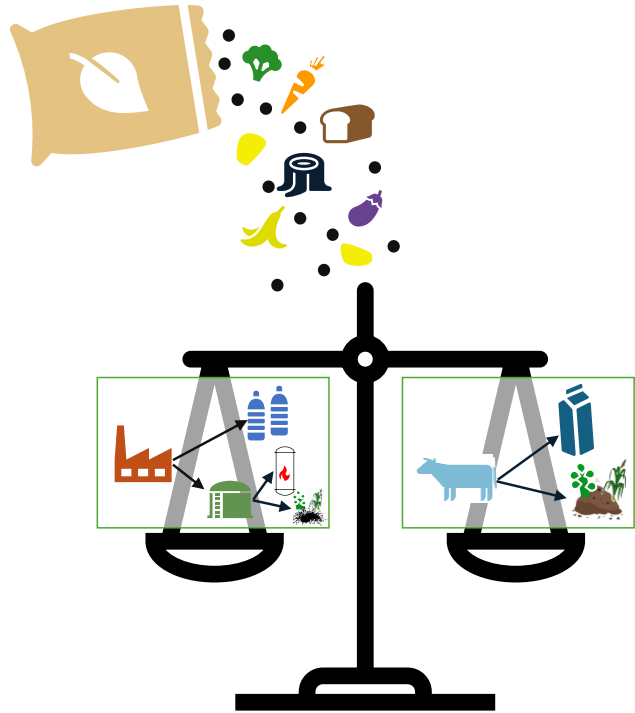
Introduction

The CAT-BREVIA tool facilitates quantitative comparison of environmental benefit of directing residual biomass streams to different valorisation and waste management options.

Effects are quantitatively estimated for two indicators:

- Degree of circularity: an indicator for resource use efficiency that takes into account the yield to food, energy carriers and biobased materials.
- Consequential greenhouse gas (GHG) emissions effect, which accounts for substitution of primary materials/feedstocks by the (residual) material (like substitution of natural gas by biomethane) and other GHG emissions and mitigation effects up to the point of substitution.

This factsheet provides – after a general introduction of the tool – the modelled heuristics for valorisation pathway *pig feed*.



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 valorisation pathways and waste management options.

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 'valorisation 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 valorisation 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 valorisation pathway to an alternative valorisation 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' valorisation:
 - 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 assessing the consequential effect of directing a material to a pathway, 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 valorisation pathway or waste management option is defined as the difference between the *consequential GHG emission effects* of the two 'destinations'.

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 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**.

* In diverse BO projects the foundational method for indicator 'degree of circularity' was developed, including quantitative elaboration of diverse common valorisation 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 valorisation 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.

** In EU Agriloop project, the method was extended with the indicator 'consequential GHG emission effects' and some alternative valorisations, 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).

Key references: Broeze et al. (2024) and Broeze et al. (2025).

Modelling pig feed application in the CAT-BREVIA tool

Application of a residual stream as pig feed contributes to production of food (meat); induced manure can be used for energy production (biomethane from anaerobic digestion) and serves as fertilizer (which subsequently contributes to crop/food production). All these effects are described in the *degree of circularity* indicator.

In the *consequential GHG emissions* accounting, the application of a residue stream as animal feed is modelled as the substitution of primary feed ingredients.

Considered effects in *degree of circularity* assessment

Feed application contributes to circular exploitation of biomass through a combination of products, including:

- production of food (meat)
- (optional) production of green gas (from biogas) via anaerobic digestion of manure
- the application of manure or digestate as an organic fertilizer, providing nutrients and organic matter:
 - Nutrients, like nitrogen, from the material contributes to crop production as a fertilizer.
 - Organic matter is considered highly relevant for soil health, amongst other things for enhancing its structure and retaining moisture. Consequently, the application of persistent organic matter may contribute to crop productivity.

Considered effects in *consequential GHG emission effect* accounting

Substitution of primary feed ingredients (see Figure 1).

Because of the substitution, other effects (like green gas production from anaerobic digestion of manure or N₂O emissions from manure or digestate application) are not quantitatively described (assuming that the feed substitution is based on nutritional characteristics of the residue stream and primary feed ingredients).

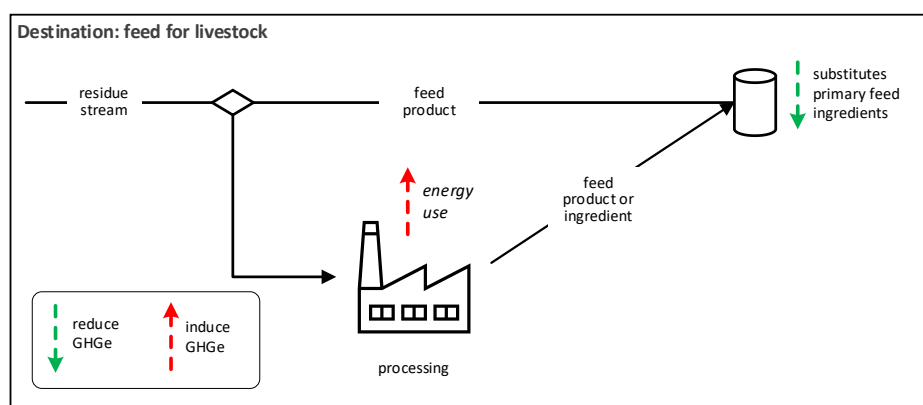


Figure 1 Process flow diagram of feed valorisation pathway, highlighting greenhouse gas emissions and mitigation (reduction) effect.

Comment: Yield factors for animal feed implemented in the tool were derived primarily from performance data for Dutch intensive production systems. Consequently, the assumed factors may be inaccurate for practical average values observed in other geographic regions or production systems. Inaccurate yield factors may affect the quantitative result obtained for both indicators:

- Calculated *degree of circularity* value will be too high for situations with lower animal productivities.
- Calculated *consequential GHG emission effect* will still be quite adequate, under the assumption that the nutritional values of the material and substituted products are not strongly affected by the farming system.

Upon request, the authors may consider incorporating yield factors for alternative regions or production systems, provided that the necessary data are available.

Appendix: Quantitative model of pig feed in the CAT-BREVIA tool

This appendix gives an overview of data, calculations and assumptions underlying this valorisation pathway as incorporated in the tool.

Degree of circularity

Yield to food production

In practice the yield to food strongly depends on amongst others the diet composition and production system. Below typical yield factors are derived.

To estimate yields to meat from animal feed, feed nutritional values are used that have been mapped for many residue flows (CVB 2023 and Feedipedia.org). For missing values, estimators are formulated based on macro-nutrient composition.

Protein via pig feed to food

Protein retention ratio of pigs is estimated at 43% (Millet et al., 2017).

Of the retained proteins, only a fraction ends as food; this fraction is estimated from two factors:

- The slaughter yield (live weight to carcass ratio): typically 70 to 80% (Bertol et al., 2015).
- The carcass-to-food yield: 85 to 90% of the carcass is edible (estimated from data provided by Hoste et al. (2004) and Astruc (2014)).

Assuming that all factors provided on wet basis are proxy's for DM mass balances, the net protein yield from feed to food is estimated at $43\% \times 75\% \times 88\% \approx 28\%$.

Energy via pig feed to food

Considering that pig feed energy analysis is often expressed in nutritional energy (NE) – see e.g. CVB (2023) – here this indicator for feed energy value is adopted. For materials for which no NE value is available, following equation was estimated from Blok et al. (2015):

$$NE = 11.7 \times \text{Protein} + 35.74 \times \text{Lipids} + 12.0 \times \text{Starch} + 11.3 \times \text{Sugars} + 9.8 \times \text{Other_carbs} \text{ (MJ/kg)}$$

where the components are specified as kg/kg, and $\text{Other_carbs} = \text{Total carbohydrates} - \text{Starch} - \text{Sugars} - \text{Lignin} - \text{Cellulose} - \text{Hemicellulose}$.

Yield from feed nutritional energy in pig fattening is estimated by Noblet et al. (2004) at 1/30.4 kg weight gain per MJ NE.

Taking in consideration aforementioned slaughter yield and carcass-to-food yield, the total yield to food is estimated at $(1/30.4) \times 75\% \times 88\% \approx 0.0217$ kg edible product per supplied MJ NE.

The edible fraction is partitioned at approximately 65% muscle and 35% fat (Astruc, 2014). Muscle meat contains 15 to 20% protein (estimated average 17.5%) and 15 to 32% fat (estimated average 18%) (Răducu et al., 2015), from which the average heat of combustion is estimated at $0.175 \times 23.9 + 0.18 \times 39.8 \approx 11.3$ MJ/kg.

Altogether, the yield to food is estimated at $0.0217 \times 11.3 \approx 0.246$ MJ heat of combustion per MJ NE.

Yields via manure

Nitrogen: For yield of N to pig manure a comparable yield heuristic as for cattle manure is assumed: 80% of the (protein) nitrogen that is not converted to 'pig' ends in applied manure: $80\% \times (100\% - 43\%) \approx 46\%$.

For pig manure the actual utilization coefficient of N (including residual effects on the longer term) highly depends on the specific situation (e.g. soil type) and manure management practices. In this work, an average N utilization coefficient of 60% was assumed, based on the values reported by Van Dijk et al. (2005).

Other components: It is assumed that cellulose and hemicellulose are partly broken down.

For a further explanation of adopted heuristics on the yields of these components to food product: see *Factsheet Valorisation Not harvested / Land application*.

Climate impact effects: substitution of primary feed ingredients

For pig, wheat and soybean meal are considered substitution products. Substitution ratios are derived from the (estimated) nutritional energy and protein content.

The following values for carbon footprints of the substituted materials are assumed in the CAT-BREVIA tool:

- Soybean meal: 2.0 kg CO₂-eq/kg DM¹
- Wheat: 0.61 kg CO₂-eq/kg DM²

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¹ Value for 'reference soybean meal' Donau Soja (2025) https://www.donausoja.org/wp-content/uploads/2025/05/202502_Factsheet_DS_BAG_Soymeal_and_oil.pdf

² <https://apps.carboncloud.com/climatehub/agricultural-reports/benchmarks/599fd34b-0943-4b92-87af-95b50b90c987>, accessed 2026-04-26, with assumed dry matter content 89%.