

Factsheet Pathway *Cattle feed*

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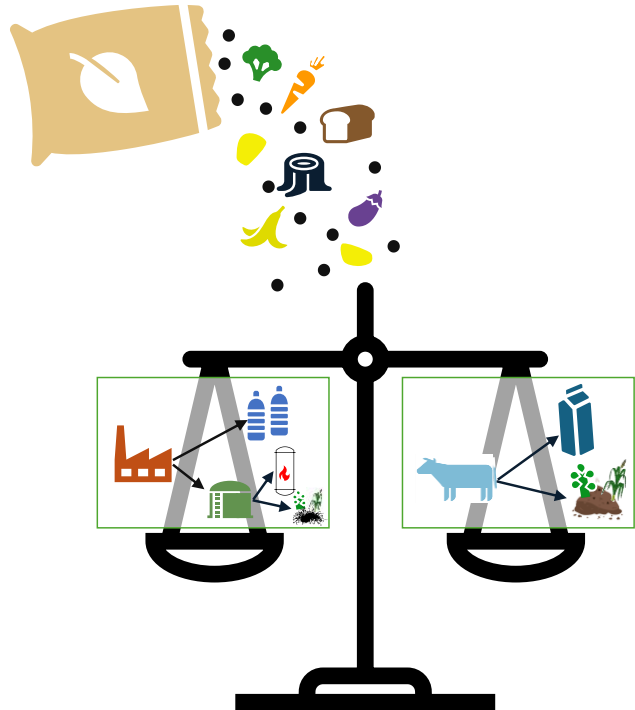
Introduction

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 *cattle feed*, which describes the application as feed for dairy cattle.



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 directing 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 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 feed application in the CAT-BREVIA tool

Application of a residual stream as cattle feed contributes to production of food (milk, 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 circularity assessment

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

- production of food (milk, 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 GHG emissions 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).

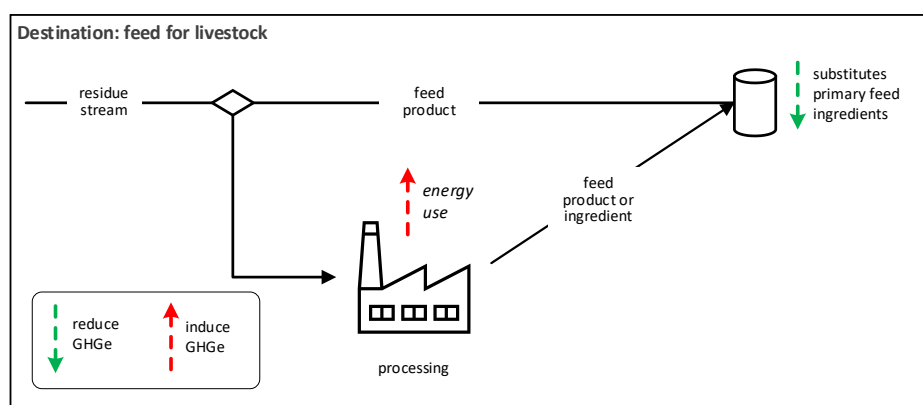


Figure 1 Process flow diagram of feed valorisation pathway, highlighting greenhouse gas emissions and mitigation (reduction) effect.

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 cattle feed in the CAT-BREVIA tool

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

Degree of circularity

Yield to food production

To estimate yields to milk and meat from animal feed, for diverse 'residual streams' feed nutritional values have been (CVB 2023 and Feedipedia.org). For missing values, estimators are formulated based on macro-nutrient composition.

Protein via cattle feed to food

Protein is converted back into a food protein with a certain efficiency. We estimate the efficiency towards food protein through two methods¹:

1. Based on literature study: For dairy cattle, efficiencies of conversion from N in feed to N in milk were found between 16 and 36% (Powell et al., 2010). For intensive production systems such as in the Netherlands, the efficiency is at the lower end of this range: Aarts et al. (2010) report values between 16 and 24%; if meat production is also included, N-efficiencies between 20% (for conventional commercial companies) to 25% (test farm De Marke, year with highest N-efficiency) are found. Oenema et al. (2012) measure efficiencies between 22 and 27% for companies participating in the "Cows and Opportunities" program.
2. Based on protein-efficiencies of animal feed: For 94 feed materials from the CVB Animal feed table (2023), a protein rating is available for all 4 animal species (cattle, fattening pigs, laying hens and broilers). For cattle, the average protein efficiency is around 40% (Spek, 2021). For a productive cow, slightly over 1/3 is for maintenance; in addition, maintenance is also necessary outside the lactation period and for bulls. Remark: in this approach, variations in protein digestibility between materials are neglected. This will inevitably result in certain inaccuracy. However, considering that the tool is intended for generic purposes and that for diverse materials this level of product information is not available, this pragmatic approach was chosen.

Both rationale point at an approximate conversion yield from protein in animal feed to food protein around 24%. The largest part is milk protein (here estimate at 22%); the remainder (2%) is meat protein.

Energy via cattle feed to food

In addition to protein, dairy cattle also produce fat and (milk) sugar. For cattle the indicator VEM is used to describe the digestible energy from feed. For a large number of common dairy feeds this indicator is reported by amongst others CVB (2023).

The amount of VEM required for the production of 3MJ milk (in terms of heat of combustion) was estimated from ILVO (2011) at 460 VEM. From ILVO (2011) it is furthermore estimated that 37% of consumed energy is for maintenance of the animal. Altogether it is estimated that producing 3MJ heat of combustion energy requires $460 \times (1/63\%) = 727$ VEM.

For feedstocks for which no VEM value was available, an estimation equation was derived from CVB (2023):

$$VEM = \frac{6}{69} \times \left(1 + \frac{4}{10} \times \left(\frac{15,90 \times CP + 37,66 \times CFAT + 13,81 \times CF + 14,64 \times OC - 0,63 \times SUG}{24,14 \times CP + 36,57 \times (0,9 \times CFAT - 2,5) + 20,92 \times CF + 16,99 \times OC - 0,63 \times SUG - 0,57} \right) \right) \times 0,9752 \\ \times (15,90 \times CP + 37,66 \times CFAT + 13,81 \times CF + 14,64 \times OC - 0,63 \times SUG)$$

where CP = crude protein content, CFAT = crude fat, CF = crude fibres, SUG = sugars and OC = other carbohydrates.

Yields via manure

Nitrogen: Nitrogen ends in manure in the form of indigestible forage proteins, proteins from the metabolism of rumen bacteria and in inorganic nitrogen molecules such as ammonia. About 2/3 of the nitrogen from the feed ends up in manure (Hindrichsen et al., 2006). Part of this disappears during storage, Dijkstra et al. (2018) mention 10% during 4 months of storage. From these figures we deduce that about 60% of the nitrogen in manure is applied as fertilizer.

For dairy 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: Lignin is not or hardly broken down by the cow (Pigden & Heaney, 1969).

Cellulose and hemicellulose are partly broken down: it is assumed that values for horses can be used: they break down cellulose by 40% and hemicellulose by 50%².

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

Circularity contribution of biogas production through anaerobic digestion of manure

As explained above, a substantial fraction of cellulose and hemicellulose in feed ends in manure. Also part of the proteins and fats are retained in manure (Møller et al., 2014). In anaerobic digestion these components contribute to biogas production; the yield to biomethane is explained in the *Factsheet Valorisation Anaerobic (co-)digestion*.

Appreciation of products in Degree of circularity

In quantitative assessment of degree of circularity, diverse indicators for yield can be used (like mass or energy). Because actual value is often linked with energy density (e.g. nutritional energy of food products, combustion energy of fuels), here yield are derived from energetic content of the substrate and products.

A few refinements were incorporated in the formula for degree of circularity:

- In food, proteins are valued higher than carbohydrates: considering higher land occupation intensity of protein crops and higher prices of protein feed ingredients compared to carbohydrate counterparts, proteins in food are appreciated 3x higher than other components.
- The (societal) preference for food (vs. fuel) is reflected by relatively low prices for substrate for anaerobic digestion (compared to feed for livestock). In order to reflect the lower appreciation for production of energy carriers compared to food production, including compensation for averagely high yield of conversion to energy carriers compared to food production via livestock, energy carriers are appreciated at 25% compared to food products.
- For biobased final material products (like PHA) an appreciation factor is derived from the factor for energy carriers. Since the product may be recycled – with multiple use cycles – the factor is multiplied by the estimated number of uses (assumed recycling ratio: 2 to 3 times). Furthermore, in the end-of-life waste management, the products contributes to energy production. Altogether, the appreciation is set to 3 times the value for energy carriers, that is 75% compared to food products.

¹ The actual utilisation efficiency will depend strongly on the feeding ration and livestock management; here the average based on these rationales are used.

² <http://www.voervergelijk.nl/informatie/69/energiebronnen-voor-paarden>

Consequential GHG emissions effect: substitution of primary feed ingredients

For cattle, residue streams can serve as roughage (assumed for e.g. vegetables) or as compound feed (assumed for materials with relatively high dry matter content). For roughage, assumed substituted primary inputs are grass silage and soybean meal, whereas for compound feed the assumed substituted products are wheat (soft) and soybean meal. Substitution ratios are derived from the (estimated) nutritional energy (VEM factor) 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 DM³
- Wheat: 0.61 kg CO₂-eq/kg DM⁴
- Grass silage: 0.5kg CO₂-eq/kg DM (Hendriksson et al., 2012)

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³ 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

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