

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

Factsheet Pathway *Microbial proteins production*

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Introduction

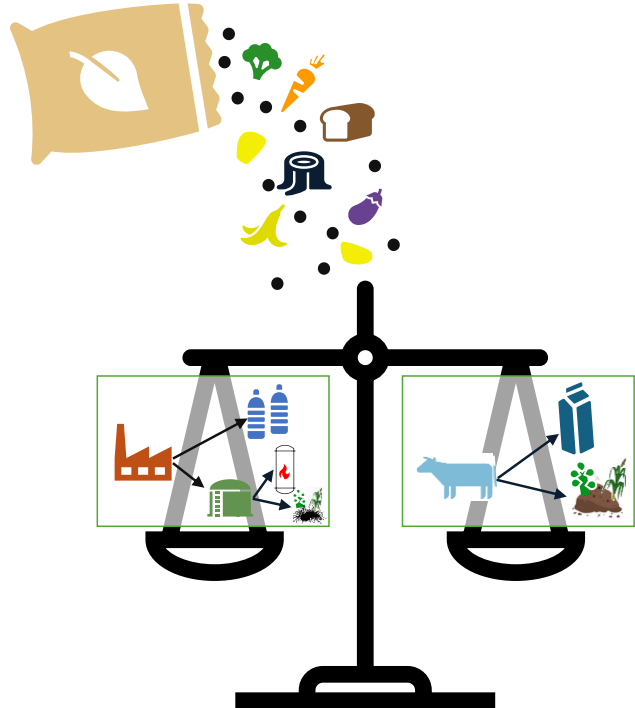
The CAT-BREVIA tool facilitates quantitative comparison of environmental benefit of directing residual biomass streams to different valorisation pathways and waste management options. Effects are quantitatively estimated for two indicators:

- 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.

Within the Agriloop¹ project, novel pathways for the high-value valorisation of agricultural residues were further developed. Among the pathways investigated was the production of microbial proteins (MP), with anticipated application in fish feed. To enable early assessment of the environmental performance of this valorisation pathway in comparison with other valorisation pathways, and to support the identification of the most suitable residue streams, a MP pathway was incorporated into the tool.

Given that MP production processes are still at a relatively early stage of development – with expected substantial improvements in process performance expected in the future – whereas many conventional valorisation routes for agricultural residues are represented in the tool using performance factors derived from current, largely optimized systems, the MP pathway was modelled using prospective yield factors. This approach is considered the most appropriate for supporting decision-making on the future utilisation of residual biomass streams.

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



¹ 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 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* for 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).

Effects of the MP production pathway described in the CAT-BREVIA tool

The MP production pathway described in the tool involves the biological production of microbial proteins. The microbial proteins serve as fish feed. It is assumed that the residue is treated as waste water, involving an UASB reactor.

Considered effects in circularity/resource-use-efficiency assessment

The pathway of MP production contributes to circular exploitation of biomass through production of food via fish feed. Furthermore, a (relatively) small effect is obtained through biogas production in the UASB waste water treatment.

Considered effects in consequential GHG emissions accounting

The pathway will affect total GHG emissions through diverse effects, including:

- the substitution of primary fish feed ingredients;
- the substitution of natural gas by green gas;
- the use of energy in MP production, in UASB waste water treatment and in upgrading the biogas to green gas;
- the use of other processing inputs.

Appendix: Quantitative model of MP production pathway in the CAT-BREVIA tool

This appendix gives an overview of data, calculations and assumptions underlying the valorisation pathway *MP production* as incorporated in the tool. The described pathway is largely based on Spiller et al. (2020).

Yield factors to microbial proteins

Diverse pathways for microbial protein (MP) production exist, based on different micro-organisms and technologies. Here we briefly describe mass balance equations for aerobic heterotrophic bacteria (AHB) system.

MP production through aerobic heterotrophic bacteria (AHB)

For the AHB system, based on we have estimated mass balances from Spiller et al. (2020), with the following estimated yield characteristics:

- 75% of the feedstock's proteins end in the MP product,
- 0.30 g protein is produced per gram simple carbohydrates in the feedstock, of which 75% ends in the MP product.

The total effect is described through the following formula:

$$Y_{protein,MP} = 0.75 \times (M_{protein} + 0.3 \times M_{starch} + 0.3 \times M_{sugar})$$

where $Y_{protein,MP}$ is the protein yield in the MP product and $M_{protein}$, M_{starch} and M_{sugar} are the amount of proteins, starch and sugar respectively in the feedstock.

From the reference we could not derive yield factors to the MP product for other macro-nutrients. As a proxy, here it is assumed that with the same factor as above (75%) of lipids in the feedstock end in the MP product (without conversion) and that potentially remaining simple carbohydrates end in the residue stream. Fate of the fibre components is not considered relevant, assuming that fish cannot digest these.

Remark: Because of limited information on used feedstock's characteristics, above yield factors may be inaccurate. Furthermore, for lipids no yield factors were found. Consequently, the actual yield to protein may be underestimated through above factors.

Yield to the waste water stream

From Spiller et al. (2020) and Tian et al. (2023) it is estimated that 20% of the COD ends in the waste water fraction. Considering that these studies had little complex carbohydrates – which are not converted to MP – in the feedstocks, higher yield factors for these compounds to the waste water are assumed.

Yield factors from MP to food via fish feed

Protein conversion efficiency was derived from Fry et al. (2018), who estimate protein retention ratio for Atlantic salmon at 28%. It is assumed that this yield factor is also valid for lipids in the MP product.

The total yield from the material to food is estimated as the combined effect from material to MP product and from the MP product in the fish feed to food.

Yield factors for biomethane in UASB waste water treatment process

It is assumed that biomethane yield in UASB reactors is 80% of the biomethane potential of the material (IPCC, 2019). See factsheets on anaerobic digestion for details of assumed biomethane yield factors.

Consequential GHG emission effects of this pathway

Substitution of primary fish feed ingredients

Considering the high protein content of microbial proteins, it is assumed that the MP product substitutes 80% soybean protein concentrate (SPC) and 20% fish meal in fish feed. Substitution ratios are derived from the protein content of the products (assumed 92.5% in SPC and 65% in fish meal).

Assumed GHG emission intensities of these substitution products:

- SPC: 6.8 kg CO₂e/kg DM²
- Fish meal: 1.08 kg CO₂e/kg DM (Wang et al., 2022)

Substitution of natural gas by green gas

See factsheets on anaerobic digestion for details.

Use of N source in MP production

Based on Spiller et al. (2020), it is assumed that used N-source is di-ammonium sulphate. Dosage ~0.16 kg per kg converted simple carbohydrate.

Assumed GHG emission intensity: 0.62 kg CO₂e/kg (Vidovic et al., 2023).

Use of energy in MP production

Estimated at 0.6 kWh electricity per kg DM feedstock and 8.8 MJ per kg protein in the MP product.

Use of energy in UASB waste water treatment

Estimated at 0.3 kWh electricity and 5 MJ heat per kg DM entering the waste water treatment process (assumed 25% of the original material DM). The electricity use factor was derived from Lopes et al. (2018). Heat demand is estimated based on assumed heating from 15 to 25°C, 20% heat loss and 1% DM of the waste water.

Use of energy upgrading the biogas to green gas

See factsheets on anaerobic digestion for details.

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² value for Brazilian SPC (https://www.donausoja.org/wp-content/uploads/2022/03/Donau-Soja-Factsheet_Salmon-feed-in-Norway_EN.pdf)