

Factsheet Pathway *Incineration*

Jan Broeze, Wageningen Food & Biobased Research, 22 September 2026

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.

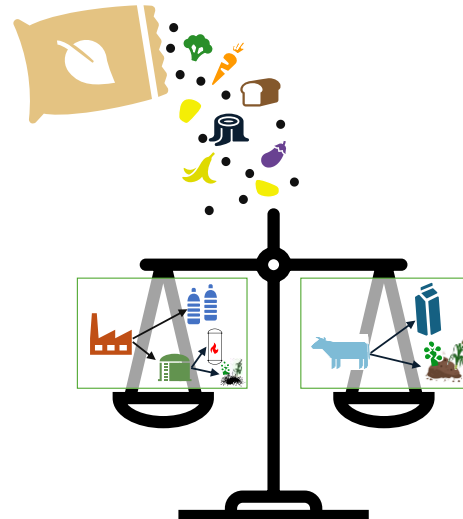
This factsheet provides – after a general introduction of the tool – the modelled heuristics for valorisation pathway *incineration*.

Incineration is a common valorisation for municipal solid waste and other waste streams.

Environmental impact of incineration strongly depends on the technology level, specifically energy recovery and flue gas management and characteristics of the feedstock.

In the CAT-BREVIA tool the following technology scenarios are considered:

- no energy recovery;
- recovery of combustion heat to electricity and heat;
- recovery of combustion heat, assuming that no heat is spent on water removal (i.e. the material was pre-dried through a residual heat source)



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), an additional weighting factor is assigned to proteins in food.
- 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).

Modelled effects: incineration

Considered effects in indicator *Degree of circularity*

This pathway contributes to circular exploitation of a material through the production of electricity and heat. The circularity effect is derived from the *gross* production of these energy carriers, considering that in circularity assessment to other products, energy consumption of the process is not considered.

Generated ash does not fill a (positive) market demand; therefore it is considered not to contribute to degree of circularity.

Considered effects in indicator *Consequential GHG emission effects*

Various effects of the pathway contribute to or mitigate GHG emissions (see *Figure 1*); CAT-BREVIA describes:

- substituting of electricity, which reduces GHG emissions,
- substituting heat, which reduces GHG emissions,
- nitrous oxide emissions, which increases GHG emissions.

Methane emissions are considered negligible in incineration (IPCC, 2019).

Energy use in the processing facility is included in the analysis through describing the net energy production (vs. gross energy production in circularity assessment).

Quantitative details as modelled in the CAT-BREVIA tool are provided in the Appendix.

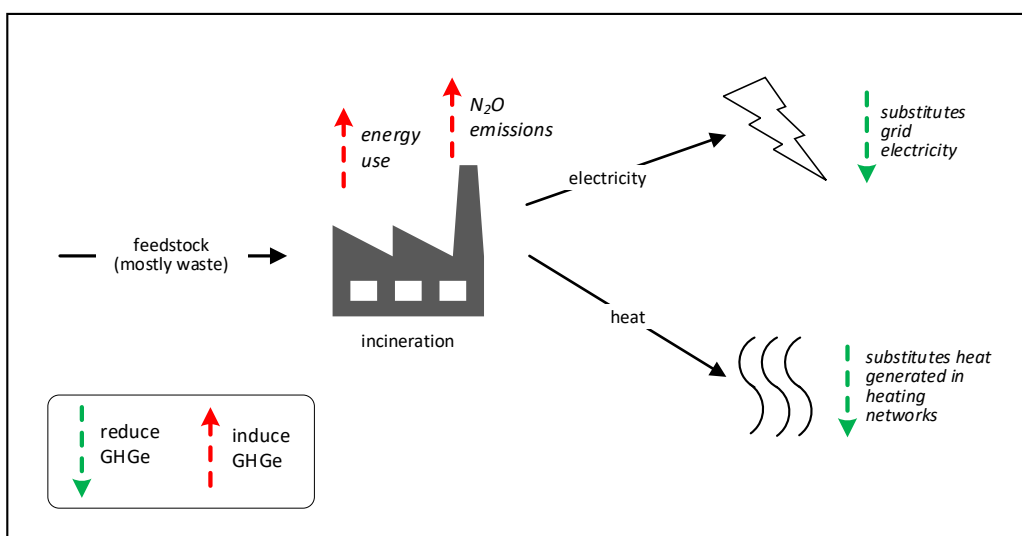


Figure 1 Process flow diagram of the pathway, highlighting impacts on greenhouse gas emissions and mitigation (reduction) effects.

Appendix: Quantitative model of incineration in the CAT-BREVIA tool

This appendix gives an overview of data, calculations and assumptions underlying the pathway as incorporated in the CAT-BREVIA tool.

Degree of circularity

Heat and electricity generation from incineration

Combustion heat of the material is estimated from the macro-nutrient composition (*Table 1*).

Table 1. Combustion heat (HHV) per macro-nutrient

Macro-nutrient	Specific combustion heat (MJ/kg)
Protein	23.9
Lipids	39.8
Sugar	17.2
Starch	17.2
Cellulose	17.5
Hemicellulose	17.5
Lignin	25
Other carbohydrates	17

After subtracting heat use for water removal (not applicable for scenario where the material is pre-dried on residual heat), the heat is converted to electricity and heat (for scenarios with energy recovery).

Considering that in circularity assessment to products, energy consumption of the process is not considered, for energy production valorisations, the gross energy production is considered. Average gross efficiency to electricity and heat is estimated at 15% and 37% respectively (Zero Waste Europe, 2023).

References

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- IPCC (2019) Chapter 5. Incineration and open burning of waste, in: 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 5: Waste.
- Park S, Choi JH, Park J. The estimation of N₂O emissions from municipal solid waste incineration facilities: The Korea case. Waste Manag. (2011) 31(8):1765-71. doi: 10.1016/j.wasman.2011.03.010.
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Consequential GHG emission effects

- Energy production from digestate incineration**
Net energy use in the process is taken in consideration through accounting for net energy production by the process. Assumed net energy yield factors are 11.4% (electricity) and 31% (heat) (both: after subtracting required heat for evaporating contained water; here it is assumed that prior to incineration the digestate is mechanically dewatered to dry matter content of 50%).
- Emissions of other greenhouse gasses from incineration:**
Methane emissions from incineration are neglected (IPCC, 2019).
In contrast to methane emissions, nitrous oxide emissions are considered significant.
The type of incineration facility, waste composition and flue gas cleaning have a significant effects on N₂O emissions. Commonly, a lump-sum approach is adopted (N₂O emissions per ton waste; not considering N content of the waste). In the CAT-BREVIA methodology a typical emission factor is used so that the estimated emissions are directly linked to the material's chemical composition.
The actual number of publication found that enable linking compositional information of the material/waste (specifically N content) with N₂O emissions is very limited. Most adequate reference found was from Park et al. (2011). From their data the N₂O emission factor was estimated at 0.01 kg N₂O-N per kg N in the material.