

Comparative assessment of environmental impacts of food waste management options

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Introduction

It is broadly recognized that landfilling food waste induces substantial environmental burden, specifically greenhouse gas (GHG) emissions. Other valorisations (varying from waste management options up to valorisation of dedicated streams as feed for livestock) are considered to have lower impacts or even – through recycling – contribute to GHG emission mitigation.

Historically, in GHG emission accounting of food waste commonly fixed emission factors were assumed per food waste management and feed application option. More recent approaches¹ account for the chemical composition of the waste stream, most notably its carbon content, with average values at the product-category level. The approach used here (CAT-BREVIA, see next page) further increases the level of understanding by accounting for comprehensive material-specific compositional data, enabling more accurate estimation of parameters that are critical in the valorisations, such as nutritional value in feed application, biomethane potential and induced nitrous oxide emissions.

Presented methodology is most accurate but most data-intensive of the range of options for calculating the GHG contributions of FLW². However, through CAT-BREVIA this is maximally simplified.

Exemplary results for selected products are presented below.

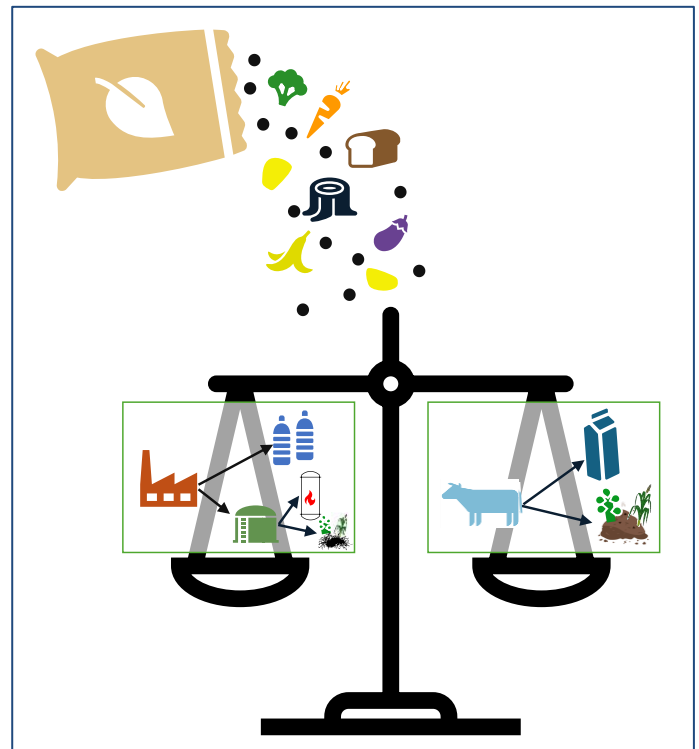
Remark:

The product-specific *Consequential GHG emission effect* result provided by the CAT-BREVIA tool cannot be directly used as a waste management GHG emission factor for losses in product lifecycle footprint accounting.

For valorisations involving recycling or recovery processes, such as composting, energy recovery, or feed applications, the effects of recycling or recovery are included in the *consequential GHG emission effect* indicator. In accounting for effects of losses and waste in product lifecycle carbon footprint accounting, however, these benefits are allocated to the subsequent user of the recovered product rather than to the generator of the waste stream. Consequently, for waste management options including recycling or recovery the *consequential GHG emission effect* result should not be used as a waste-management emission factor in product carbon footprinting, as this would result in double counting of the recovery or recycling benefits at system level.

Nevertheless, material-specific waste management GHG emission factors for product life-cycle footprint accounting can be derived from the detailed results generated by the tool. At the end of this document, for one food waste stream GHG emission effect values excluding effects of recovery or recycling are presented, calculated with the CAT-BREVIA's heuristics. Values calculated in this way are considered appropriate as material-specific waste management emission factors in product carbon footprinting.

A dedicated variant of the tool – specific for deriving material-specific waste management GHG emission factors for product life-cycle footprint accounting – can be provided on request.



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 (funded by the Dutch ministry of LNV) the foundational method for indicator 'degree of circularity' was developed, including quantitative elaboration of diverse common waste management options and valorisation pathways (including feed for diverse livestock types). In the KomCirc project the method was applied for diverse specific pathways (including parameterisation of dedicated alternative 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).

¹ E.g. in EPA's WARM model (<https://www.epa.gov/waste-reduction-model>) and the Impact Calculator for food waste by ReFED/Quantis (<https://insights-engine.refed.org/impact-calculator>).

² see Table 4 in https://flwprotocol.org/wp-content/uploads/2021/10/ConnectingFLWGHG-Emissions_GuidanceForCompanies.pdf

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 comparing different valorisation pathways and/or waste management options, 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 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^{##}.

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 (NKRDPIC).

Addressed consequential GHG emission effects in considered waste management options

Landfilling:

- Methane emissions resulting from the anaerobic degradation of biodegradable organic matter.
- Nitrous oxide emissions originating from aerobic zones within the landfill and from aerobic treatment of leachate.
- The capture and management of landfill gas, which can substantially reduce methane emissions. Captured landfill gas may be utilized as a renewable energy source, thereby offsetting the use of fossil fuels and contributing to greenhouse gas mitigation.
- The long-term sequestration of carbon.

Different typologies of landfills are represented in the tool, as categorized by IPCC³ and UNFCCC⁴.

Incineration:

Various categories are described, with and without energy recovery (with typical recovery factors. Addressed effects:

- substituting of electricity,
- substituting heat,
- nitrous oxide emissions.

Composting:

- nitrous oxide and methane emissions from the composting process,
- energy use in composting,
- the substitution of synthetic nitrogen (N) fertilizer by nitrogen in the compost,
- the supply of persistent organic matter to the soil through applied compost, which may contribute to crop production; this mitigates other crop production,
- sequestration of carbon (in persistent organic matter of the compost) in the soil,
- nitrous oxide and methane emissions from applied compost in the field.

Anaerobic digestion, with production of green gas and use of the digestate as fertilizer:

- production of renewable energy; either
 - the substitution of natural gas by biomethane,
 - the substitution of electricity,
- slip of CH₄ from the digester and biogas upgrading,
- energy use in anaerobic digestion and in biogas upgrading,
- the substitution of synthetic nitrogen (N) fertilizer by nitrogen in the digestate,
- the supply of persistent organic matter to the soil through applied digestate, which may contribute to crop production; this mitigates other crop production,
- sequestration of carbon (in persistent organic matter of the digestate) in the soil,
- CH₄ and N₂O emissions from applied digestate in the field.

Combined composting with anaerobic digestion

Increasingly, composting is combined with anaerobic digestion. In order to maintain sufficient biodegradable organic matter for composting, generally this is applied to part of the material. Here it is assumed that 50% is anaerobically digested prior to composting.

For this waste management option, heuristics of composting and anaerobic digestion are combined.

Application as animal feed:

For this waste management option, it is assumed that primary feed ingredients are substituted, with typical GHG emission factors. Substitution factors are based on feeding nutritional values.

Details – including modelling parameter values – per waste management option are provided in factsheets (<https://circular-biomass-valorisation.com/quantification>).

In the calculations underlying the results presented below, the average EU grid greenhouse gas (GHG) emission factor was assumed for electricity generation. Material and mass balances for the assessed pathways were based on representative values for intensive systems.

Since logistics are very situation-dependent, effects of logistic operations are not included in below results. Such effects may be calculated with the ACE calculator (<https://circular-biomass-valorisation.com/posts/ace-calculator>).

³ IPCC (2019) Towprayoon, S., Ishigaki, T., Chahiemchaisri, C., Osama Abdel-Aziz, A., Hunstone, M. E., Jarusutthirak, C., Ritzkowski, M., & Thomsen, M. (2019). Solid waste disposal. In 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Volume 5 : Waste <https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html>.

⁴ UNFCCC CDM Executive Board (2012) Approved baseline and monitoring methodology AM0083 "Avoidance of landfill gas emissions by in-situ aeration of landfill" AM0083 / Version 01.0.1 <https://cdm.unfccc.int/UserManagement/FileStorage/2TQ3BG6MPVJXWULEFZ54RSC71DIYAH> (accessed 2025-06-05).

Results

Below, results are presented for a mixed food waste stream. In order to illustrate the relevancy of the materials' composition, furthermore results for two food products with significant different chemical composition are provided. A short reflection on the results and concluding remarks are provided on the last page. For information purposes, the last page also provides calculated GHG emission effect excluding the accounting of benefits associated with recovery and recycling; values derived using this approach are considered adequate for waste-management emission factor in product carbon footprinting.

Results for a mixed food waste stream

In this case analysis, a typical chemical composition of 'mixed consumer food waste' was estimated from food waste statistics in the Netherlands.

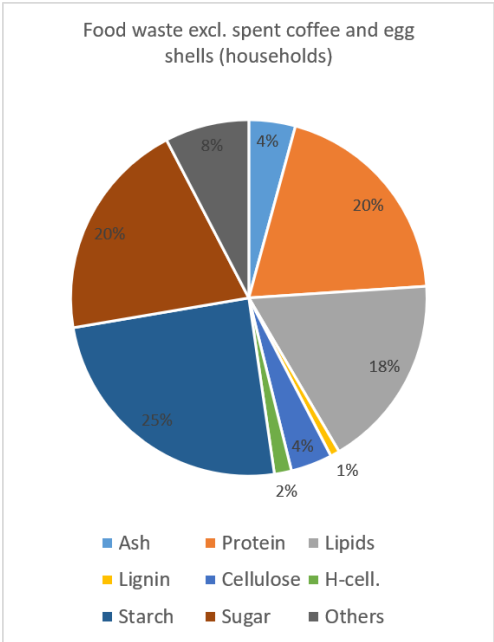


Figure 1. Assumed composition (dry matter)

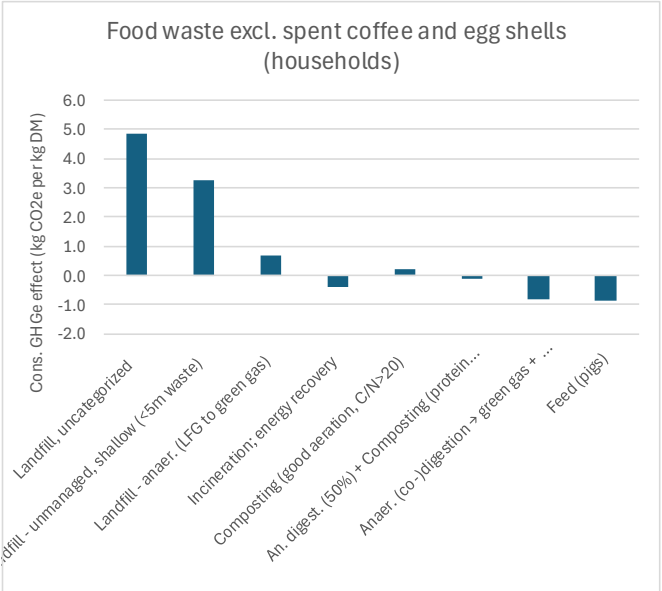


Figure 2. Consequential GHG emission effects, per kg dry matter.

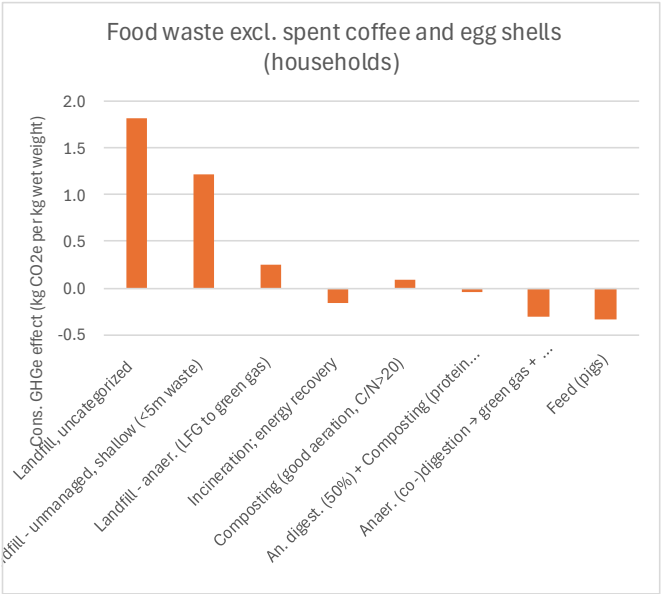


Figure 3. Consequential GHG emission effect, per kg material, wet basis.

Bananas

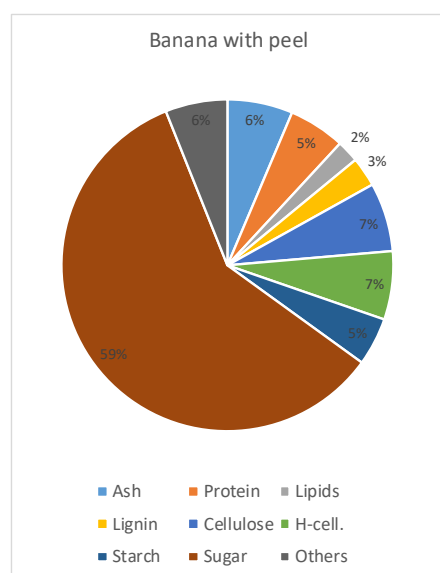


Figure 4. Assumed composition (dry matter)

Soya beans

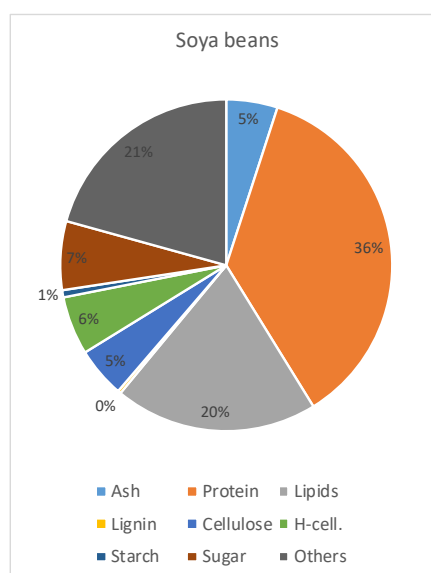


Figure 7. Assumed composition (dry matter)

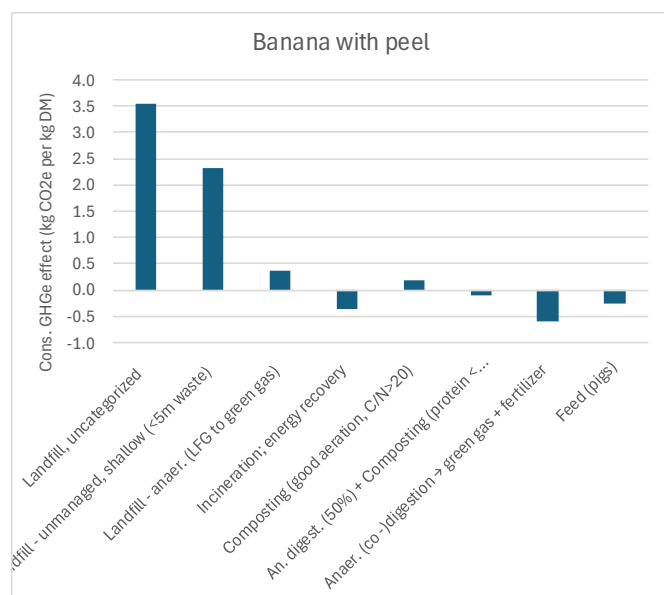


Figure 5. Consequential GHG emission effects, per kg dry matter.

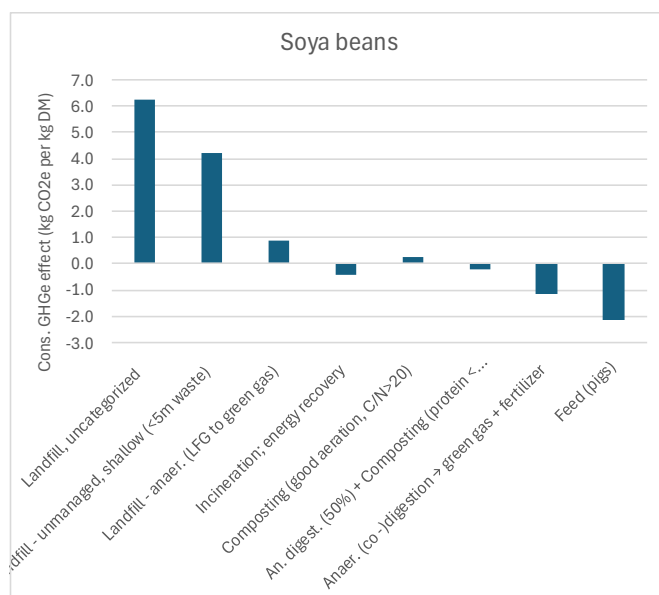


Figure 8. Consequential GHG emission effects, per kg dry matter.

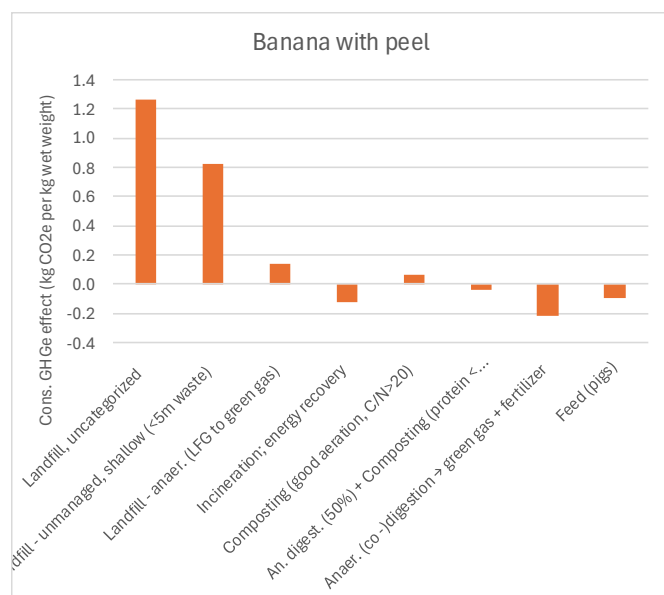


Figure 6. Consequential GHG emission effect, per kg material, wet basis.

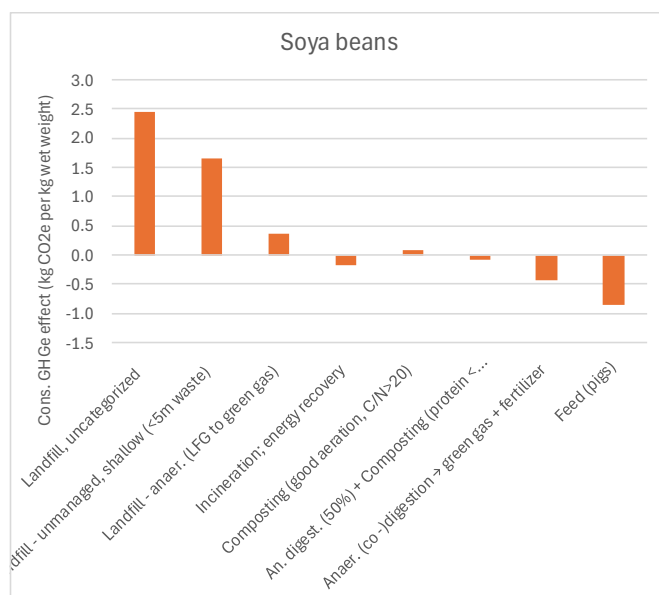


Figure 9. Consequential GHG emission effect, per kg material, wet basis.

Preliminary validation

Results obtained with the method for appear quite comparable to values provided by others¹. Differences are related to modelling choices (such as the assumed substitution products in feed), different/updated emission factors for inputs and substituted products, different type of landfill considered and the more comprehensive set of effects addressed in our method. This is illustrated in Figure 10, which for instance shows that

- nitrous oxide emissions (commonly overlooked in waste management emission factors) significantly contribute to the emissions in some described waste management options,
- Food waste is largely broken down on organic waste management options; the residue hardly contributes to carbon sequestration in soil.

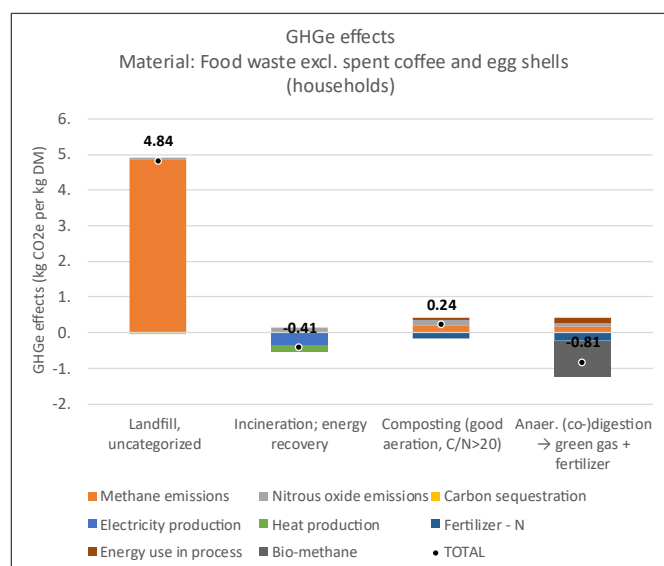


Figure 10. Breakdown of GHG emission effects for a selection of the presented waste management options.

Conclusions

The comparative analysis substantiates that landfilling has, by a considerable margin, the highest climate impact among the assessed waste management options.

The comparison of results for different material types shows that the net climate impact in a valorisation pathway depends on material-specific characteristics, leading either to net GHG emissions or to GHG emission mitigation.

The CAT-BREVIA method can support the identification of environmentally beneficial valorisation(s), including the quantification of the environmental effects associated with reallocating material flows from one valorisation to another.

Dedicated assessments, e.g. with evaluations based on alternative substitution scenarios and including scientific underpinning, can be conducted upon request.

GHG emission effect excluding recovery or recycling

As explained above, for waste-associated accounting in product carbon footprinting, the effect of substituting primary materials by recovered or recycled products from a waste management may not be included. In order to estimate the waste-management associated GHG emissions, we subtracted the effects of the recycling process. The results of this, provided below for the mixed waste stream, can be considered adequate as material-specific waste-valorisation emission factor in product carbon footprinting. Remark: these factors exclude effects of logistic operations (waste collection and handling).

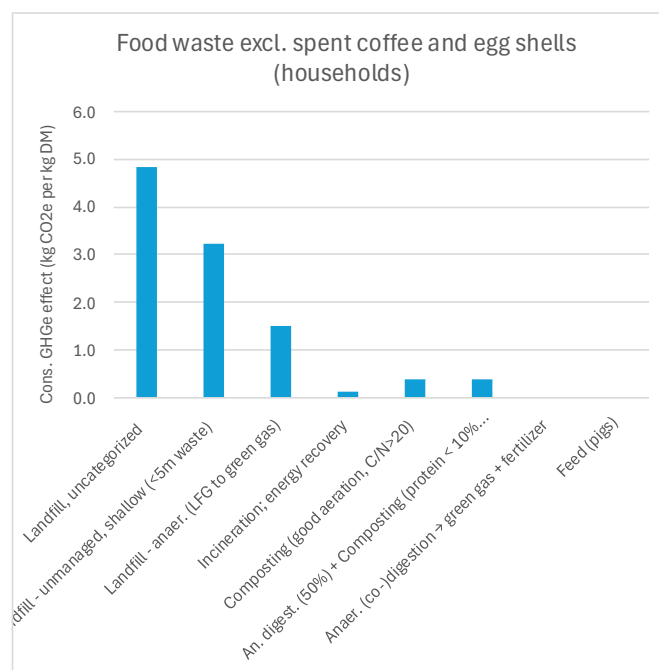


Figure 11. Total GHG emission effect excl. accounting for recovery or recycling; expressed per kg food waste (dry matter).

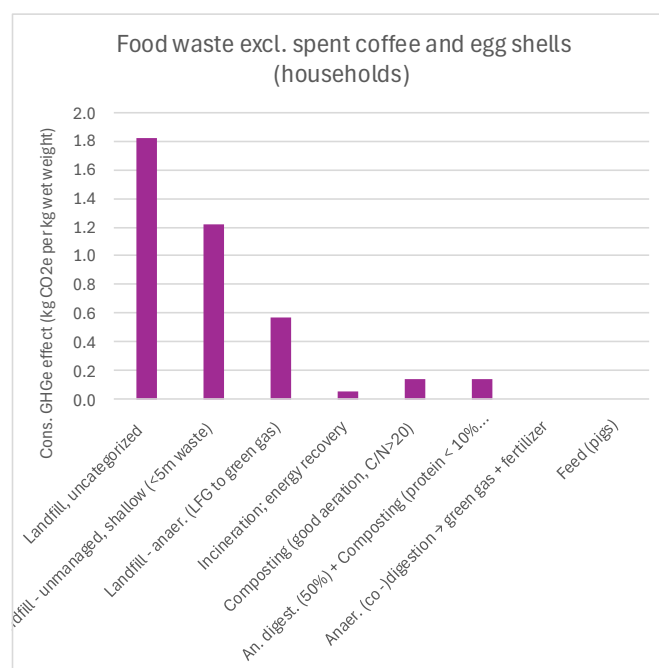


Figure 12. Total GHG emission effect excl. accounting for recovery or recycling; expressed per kg as-is food waste.

Above results were derived using the tool's heuristics but are not derived automatically by the tool. Dedicated product-specific factors can be generated upon request.