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Bio-based products — Guidelines for Life Cycle Inventory (LCI) for the End-of-life phase

National foreword

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Bio-based products - Guidelines for Life Cycle Inventory (LCI) for the End-of-life phase

Produits biosourcés - Lignes directrices relatives à l'inventaire du cycle de vie (ICV) pour la phase de fin de vie

Biobasierte Produkte - Leitlinien für die Sachbilanzierung von Produkten in der Nachnutzungsphase

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Contents

Page

European foreword

This document (CEN/TR 16957:2016) has been prepared by Technical Committee CEN/TC 411 “Bio-based products”, the secretariat of which is held by NEN.

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Introduction

Bio-based products from forestry and agriculture have a long history of application, such as paper, board and various chemicals and materials. The last decades have seen the emergence of new bio-based products in the market. Some of the reasons for the increased interest lie in the bio-based products' benefits in relation to the depletion of fossil resources and climate change. Bio-based products may also provide additional product functionalities. This has triggered a wave of innovation with the development of knowledge and technologies allowing new transformation processes and product development.

Acknowledging the need for common standards for bio-based products, the European Commission issued mandate M/492, resulting in a series of standards developed by CEN/TC 411, with a focus on bio-based products other than food, feed and biomass for energy applications.

The standards of CEN/TC 411 "Bio-based products" provide a common basis on the following aspects:

— Common terminology;

— Bio-based content determination;

— Life Cycle Assessment (LCA);

— Sustainability aspects;

— Declaration tools.

It is important to understand what the term bio-based product covers and how it is being used. The term 'bio-based' means 'derived from biomass'. Bio-based products (bottles, insulation materials, wood and wood products, paper, solvents, chemical intermediates, composite materials, etc.) are products which are wholly or partly derived from biomass. It is essential to characterize the amount of biomass contained in the product by for instance its bio-based content or bio-based carbon content.

The bio-based content of a product does not provide information on its environmental impact or sustainability, which may be assessed through LCA and sustainability criteria. In addition, transparent and unambiguous communication within bio-based value chains is facilitated by a harmonized framework for certification and declaration.

1 Scope

This Technical Report provides guidance on how to compile an inventory for the end-of-life phase in LCA of bio-based products. All the end-of-life treatments here addressed are shown in Figure 1.

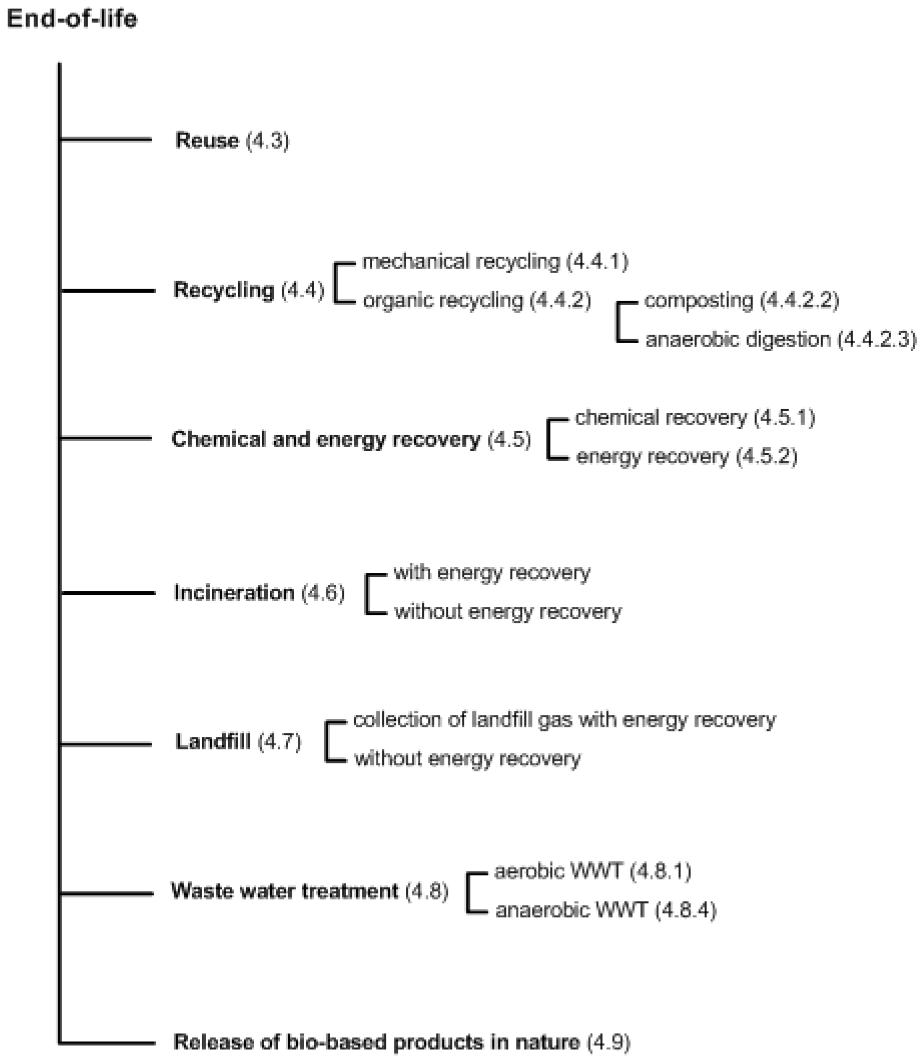

Figure 1 — End-of-life treatments addressed in this TR and related clauses

NOTE The order of the end-of-life options indicated in Figure 1 respect the Directive 2008/98/EC on waste. This list is not exhaustive, but illustrates the content of this Technical Report.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 16575, *Bio-based products - Vocabulary*

EN 16760, *Bio-based products - Life Cycle Assessment*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 16575, EN 16760 and the following apply.

3.1
chemical recovery
process to recover valuable chemical substances by chemical treatment of used materials by hydrolysis, glycolysis, methanolysis, catalytic reaction, thermal reaction, and other chemical processes

[SOURCE: ISO 18601:2013, definition 3.1, modified - "packaging" replaced by "materials", "process to substitute used packaging for natural resources" deleted.]

4 Modelling end-of-life options for bio-based products

4.1 General

The end-of-life options for bio-based products are in general the same as the options available for non bio-based products. Each end-of-life option has different environmental impacts to be evaluated as part of the LCA.

Life cycle inventory data (e.g. emissions to air, water and soil) related to the bio-based product end-of-life option depends on the type of treatment technology, processing conditions, the local infrastructure for collection (e.g. separate collection of biodegradable waste for composting), sorting and processing, the location (i.e. the contribution of for example the electricity used) and the physical-chemical characteristics of the disposed material such as the chemical composition and the biodegradation behaviour.

The end of life options recycling (mechanical or organic) and chemical recovery can lead to secondary materials, and consequently saving primary materials, keeping the bio-based carbon fixed in the material or preserving nutrients.

NOTE 1 Collection, transportation and sorting of the waste from bio-based products are considered under the LCA but are not detailed in this Technical Report. Regardless of the origin of the process module applied in the LCA study (generic modules from LCA databases, other public data, or modules developed by the practitioner of the LCA study), the parameters shown in Table 1 need to be defined in order to reflect the material properties of the studied bio-based waste.

Table 1 — Properties of waste from bio-based products

Parameters	**Unit**
Combustion characteristics	
Lower Heating Value (LHV)	MJ/kg
Share of biodegradable carbon actually decomposed into inorganic components within a defined time period	
In composting	%
In landfill Time period covered	% years
In incineration	%
In anaerobic digestion	%
Water content	% (weight)
Chemical composition (in dry mass)	
Carbon (fossil) (C)	g/kg
Carbon (biogenic) (C)	g/kg
Hydrogen (H)	g/kg
Oxygen (O)	g/kg
Sulphur (S)	g/kg
Nitrogen (N)	g/kg
Fluorine (F)	g/kg
Chlorine (Cl)	g/kg
Magnesium (Mn)	g/kg
Potassium (K)	g/kg
Calcium (Ca)	g/kg
Arsenic (As)	g/kg
Cadmium (Cd)	g/kg
Nickel (Ni)	g/kg
Cobalt (Co)	g/kg
Chromium (Cr)	g/kg
Copper (Cu)	g/kg
Mercury (Hg)	g/kg
Manganese (Mg)	g/kg
Lead (Pb)	g/kg
Zinc (Zn)	g/kg
Other elements (e.g. Se and Mo)	g/kg

NOTE 2 Very low concentrations (ppm) of some of these elements may have a high impact and therefore need to be included in the LCI.

The quantity of energy contained in a material is generally expressed through the Lower Heating Value (LHV). This parameter points out the maximum energy obtainable from the complete combustion of the material, without considering the heat of the water vapour generated by the combustion. The lower heating value of bio-based product waste can be measured according to EN 15359.

LHV can be estimated using the following formula, based on the chemical composition of the bio-based material.

$$LHV\left[MJ/kg\right] = HHV - H_2O \times 2,2 - H \times 2,2 \times 9$$

where

$$HHV = O \times 9,83 + H \times 124,27 + C \times 34,02 + S \times 19,07 + N \times 6,28$$

where

HHV is Higher Heating Value (MJ/kg material);

O is oxygen (without O from H_2O) (kg/kg of material);

H is hydrogen (without H from H_2O) (kg/kg of material);

C is carbon (kg/kg of material);

N is nitrogen (kg/kg of material);

S is sulphur (kg/kg of material).

NOTE 3 Source: Ecoinvent [15].

The share of biodegradable carbon actually decomposed into inorganic components, along with, chemical composition of the bio-based material guarantee, for example, a closed biogenic carbon balance in the LCA system model of the bio-based product.

4.2 Documentation requirements

The properties of the waste from bio-based products (Table 1) need to be documented along with their data sources to ensure transparency and enable comparability. This is especially relevant in case of cradle-to-grave studies, where those properties are of key importance to correctly model the end-of-life process along the value chain.

Biogenic carbon content in any LCA study of bio-based products/materials should be documented.

Biogenic carbon emissions (carbon dioxide, methane), originating from decomposition or combustion, of bio-based material need to be documented separately from non-bio-based carbon emissions in order to allow a consistent biogenic carbon balance over the full lifecycle of a bio-based product.

4.3 Reuse and/or preparation for reuse

Reuse means any operation by which products or components that are not waste are used again for the same purpose for which they were conceived. Preparing for reuse means checking, cleaning or repairing recovery operations, by which products or components of products that have become waste are prepared so that they can be reused without any other pre-processing.

Important aspects to consider in the LCA study are the energy use from transportation to collection and logistic points and the use of resources for the preparation for reuse (e.g. water use, cleaning agents, energy, etc.).

NOTE See also Annex C of ILCD Handbook [17].

4.4 Recycling

4.4.1 Mechanical recycling

4.4.1.1 General

In mechanical recycling, waste material is reclaimed in order to enable use of the material in manufacture of a new product. During mechanical recycling, waste for example is ground, cleaned and eventually recycled (e.g. for plastics recycled into flakes or pellets). The quality of the recycled materials differs depending on original material properties and recycling processes applied.

This waste treatment pathway is open to bio-based materials. Prerequisite for a valuable mechanical recycling of bio-based material is (a source-separated) waste collection and subsequent sorting.

Recycled bio-based material maintains the CO_2 fixed from the atmosphere during plant growth within the technical material cycle. This might be accountable as a type of carbon sequestration. In such case bio-based carbon may therefore be considered as sequestered in the recycled bio-based material until the recycled material (after one or more recycling “loops”) ends up in a final treatment (incineration, composting or anaerobic digestion process).

4.4.1.2 Parameters specific for bio-based waste

The key parameters for modelling bio-based waste recycling are listed in Table 2.

Table 2 — Parameters required for recycling model

Energy demand – electrical	kWh/t waste input
Energy demand – thermal	kWh/t waste input
Energy demand – mechanical	kWh/t waste input
Operating supplies (e.g. water, detergents)	
Recycling efficiency (dry weight of waste) (%)	kg output materials/ kg input materials x 100
Amount of non-recycled fraction (kg) and its end-of-life	

Depending on the LCA modelling approach to be used, information on what is substituted, the end use market or the quality of the recycled material may be needed.

4.4.1.3 Documentation requirements

Bio-based carbon content that is fixed in recycled material needs to be documented in order to guarantee a consistent biogenic carbon balance over the lifecycle.

Inventory and impact assessment results need to be presented transparently, separately indicating contributions of recycling processes and any associated credits (e.g. credits for replacement of virgin materials).

4.4.2 Organic recycling

4.4.2.1 General

During organic recycling, biodegradable materials are exposed to the action of microorganisms. A fundamental change in the molecular structure of the materials occurs. The process can be aerobic (with air) or anaerobic (without air). In the first case, which corresponds to composting operations, biodegradable materials will be degraded into CO_2, water and other components. In the second case, methane will be also produced.

Organic recycling can provide valuable materials such as soil amendment and biogas.

NOTE If LCA studies are performed including composting as a possible end-of-life option then the study should not focus on the isolated packaging or food service items (cutlery, plates, cups), but on the complete waste stream, so also including the food waste. With this the actual benefits of composting will be captured.

4.4.2.2 Composting

4.4.2.2.1 General

Composting is a waste treatment option for biodegradable/compostable waste. The biodegradable waste is typically converted into carbon dioxide, methane, water, Non Methane Volatile Organic Compounds (NMVOC) and a residual fraction (the latter is the compost product). The compost product can serve as a soil amendment, maintaining the soil carbon stock and can replace fertilizers.

Composting is an aerobic biodegradation process. It can be classified into a) home composting and b) industrial composting. Home composting is a simple, one-stage, open-pile composting process of which the parameters (temperature, humidity, availability of microorganisms and oxygen, residence time) can vary widely, resulting in a process of which the average composting rate and performance is less predictable. On top of this, emission control does not exist at home composting. In contrast to this, industrial composting is typically is a two-stage process (main composting step and an after-composting step) of which the conditions (oxygen availability, temperature, humidity, availability of microorganisms and residence time) are controlled leading to a process of which the composting performance is much more stable and guaranteed.

Often, e.g. in case of biodegradable polymer waste materials, the degradation process is started by a chemical/physical degradation (e.g. hydrolysis). In a second step, hydrolyzation products (monomers in case of hydrolyzed polymers) are subject to biodegradation by microorganisms present in the composting environment.

Industrial composting offers options for emission control measures, as one or two composting stages may take place in encapsulated systems instead of open piles. In encapsulated systems, air emission abatement can be achieved, e.g. by the installation of biofilters.

Prerequisite for a composting treatment is the compostability of the bio-based material under study. The property may be assessed using, e.g. EN 13432 and EN 14995.

4.4.2.2.2 Parameters specific for bio-based waste

Regardless of the origin of the process module applied in the LCA study (from LCA databases, other public data, or modules developed by the practitioner of the LCA study), the mineralization rate in composting process and chemical composition (i.e. Table 1) need to be adjusted to material properties of the studied bio-based waste. If default composting modules are used, as a minimum requirement they should at least allow adaptation of (biogenic) carbon content of waste material. The latter is required to guarantee a consistent biogenic carbon balance over the full lifecycle of the bio-based product.

4.4.2.2.3 Parameters specific for composting models

Regardless of the origin of the process module applied in the LCA study (from LCA databases, other public data, or modules developed by the practitioner of the LCA study), those parameters need to be adjusted as far as possible to scope of the LCA study (regarding geographical, technical scope and time period under study).

Table 3 specifies relevant parameters for composting models.

Table 3 — Parameters required for composting models

Specification/description of composting technology used	
Emissions to air	
CO_2	g/kg of dry waste
CH_4	g/kg of dry waste
NMVOC	g/kg of dry waste
N_2O	g/kg of dry waste
NH_3	g/kg of dry waste
Emissions to water	
N	g/kg of dry waste
BOD	g/kg of dry waste
P	g/kg of dry waste
Energy demand (waste handling, capture installations etc.)	
electrical	kWh/t waste
thermal	kWh/t waste
mechanical	kWh/t waste
Fertilising value of compost	
C, N, P, K and ash content	g/kg of dry weight
Conversion ratio	kg output compost (dry content) / kg input waste (dry content)

NOTE 1 The time frame for the compost handling should be 100 years so the field emissions also need to be taken into account.

For home composting, the parameters in Table 3 should be considered and adapted in the light of the different conditions including:

— composting is done in one step, with lower temperatures (typically at 20 °C to 30 °C) than in industrial composting, the actual biodegradation rate should reflect this; and

— home composting is an open composting process, which means there are no emission abatement measures.

NOTE 2 A French standard on home composting of plastics has been published (NF T51–800).

4.4.2.2.4 Documentation requirements

Inventory and impact assessment results need to be presented transparently, separately indicating contributions of compost and any associated credits with its use (e.g. replaced peat, replaced mineral fertilizers, organic matter in soil and carbon sequestration, biodiversity).

4.4.2.3 Anaerobic digestion

4.4.2.3.1 General

Anaerobic digestion is a biological waste treatment process suitable for biodegradable waste, but in contrast to composting it is an anaerobic process.

The waste material is converted into biogas (a mix of methane, carbon dioxide, NMVOC, N_2 and H_2S), water, and a residual fraction called digestate. The main components of biogas are carbon dioxide and methane. Due to its high greenhouse gas potential, biogas needs to be managed in order to avoid its release to the atmosphere. Energy may be recovered from generated methane gas. The digestate may undergo a subsequent (aerobic) composting process (in this case, statements above related to composting are also valid for composting of digestate). Emission abatement in encapsulated digestion plants may be achieved by biofilters and scrubbers.

NOTE Depending on the input material's composition, biogas can contain H_2S which needs to be captured and treated.

Prerequisite for a digestion treatment is at least the biodegradability of the bio-based waste. The property may be assessed by, e.g. biodegradability standards such as ISO 15985, ISO 14853 and OECD No. 311 or composting standards (such as EN 13432 and EN 14995) (the latter also include the biodegradability requirements).

4.4.2.3.2 Parameters specific for bio-based waste

Regardless of the origin of the process module applied in the LCA study (from LCA databases, other public data, or modules developed by the practitioner of the LCA study), the mineralization rate in anaerobic digestion process and chemical composition (i.e. Table 1) need to be adjusted to material properties of the studied bio-based material. If default anaerobic digestion modules are used, as a minimum requirement they should at least allow adaptation of (biogenic) carbon content of waste material. The latter is required to guarantee a consistent biogenic carbon balance over the full lifecycle of the bio-based product.

4.4.2.3.3 Parameters specific for biogas models

Regardless of the origin of the process module applied in the LCA study (from LCA databases, other public data, or modules developed by the practitioner of the LCA study), those parameters need to be adjusted as far as possible to the individual LCA study.

Table 4 specifies relevant parameters for biogas models.

Table 4 — Parameters required for biogas models

Specification/description of AD technology used	
Total methane production	g/kg of dry input weight
Energy content of the biogas	MJ/m³ biogas
Biogas composition	
CO_2	%
CH_4	%
H_2S	%
N_2	%
NMVOC	%
Emissions to air	
e.g. CH_4, CO_2, N_2O, NH_3)	g/kg of dry input weight
Fertilizing value of digestates	
C, N, P, K and ash content	g/kg of dry weight
Energy demand (waste handling, capture installations, etc.)	kWh/t waste

NOTE 1 The products of anaerobic digestion are biogas and digestates. The digestate can be converted to fertilizer by composting. The biogas can be upgraded for use together with natural gas, converted to fuel or used for electricity production.

NOTE 2 When biogas is converted to electricity at the biogas plant, then the energy recovery refers to the net energy produced by the biogas plant.

NOTE 3 The time frame for the biodigestate handling should be 100 years so the field emissions also need to be taken into account.

4.4.2.3.4 Documentation requirements

Energy recovery efficiency a) as electric energy and b) as thermal energy are critical parameters to be documented.

Inventory and impact assessment results need to be presented transparently, separately indicating contributions of anaerobic digestion (e.g. emissions to air and water during process, storage and application e.g. NO_2, NH_4, CH_4) and any associated credits (recovered energy that replaces electricity and/or thermal energy).

4.5 Recovery

4.5.1 Chemical recovery

Chemical recovery may be a suitable process to recover valuable chemical substances from used bio-based materials. For example, this treatment is appropriate for plastic waste where polymers are broken down to its monomer building blocks, which can then be used to replace virgin polymers or in other materials.

The chemical recovery parameters, specific for bio-based waste, and the documentation requirements are identical to the mechanical recycling parameters and requirements, described in 4.4.1.2 and 4.4.1.3.

NOTE Further guidance for packaging can be found in ISO/TR 16218:2013.

4.5.2 Energy recovery

4.5.2.1 General

Regardless of the origin of the process module applied in the LCA study (from LCA databases, other public data, or modules developed by the practitioner of the LCA study), those parameters need to be adjusted as far as possible to an individual LCA study.

NOTE Typical examples of the end-of-life route called "Energy Recovery" are the combustion of bio-based waste in a blast furnace (metal industry) or in a cement kiln. The end-of-life route "Incineration with energy recovery" focuses on the incineration of bio-based products in municipal waste incinerators.

More details regarding energy recovery can be found under the specific end-of-life treatments.

Table 5 specifies parameters for energy recovery models.

Table 5 — Parameters required for energy recovery models

Energy recovery	
electric	MJ/kg waste
heat	MJ/kg waste
Emissions to air	
e.g. CO_2, CH_4, NO_x	

4.5.2.2 Documentation requirements

Energy recovery efficiency expressed as electric and thermal energy recovery is a critical parameter to be documented.

Biogenic carbon emissions (carbon dioxide) need to be documented separately from non-bio-based carbon emissions in order a consistent biogenic carbon balance over the full lifecycle of a bio-based product.

Inventory and impact assessment results need to be presented in a way separately indicating contributions of incineration/co-combustion processes and their possibly associated credits (such as e.g. electricity or steam generation credits).

4.6 Incineration

4.6.1 General

Solid waste incineration (with and without energy recovery) includes a combustion process of a waste material.

In a combustion process, chemical elements and compounds present in the waste material are converted into combustion (more precisely oxidation) products, e.g. a bio-based product is fully or partially converted into carbon dioxide, sulphur oxides (if the polymer material contains sulphur), nitrogen oxides (nitrogen either from polymer material or from air nitrogen or both), etc.

If the combusted material also contains metals (Table 1), those are also released in the combustion process. Inert parts of the waste material end up in an ash and slag residue fraction. Combustion products are either released directly to the air, or undergo a flue gas cleaning process in which emissions actually released to the air are abated.

Energy contained in the waste material (i.e. LHV in Table 1) may be recovered as electric or thermal energy or both in SWI and co-combustion processes. Abatement of air emissions depends on the existence and efficiency of flue gas cleaning devices.

4.6.2 Parameters specific for bio-based waste

Regardless of the origin of the process module applied in the LCA study (from LCA databases, other public data, or modules developed by the practitioner of the LCA study), the chemical composition and the LHV need to be adjusted to material properties of the studied bio-based material (Table 1). For example in case of sulphur, the calculation of combustion product SO_2 before flue gas cleaning based on sulphur content of waste material is according to the following formula:

$$SO_2 = m_{Waste} \times C_{Sulphur} \times M_{SO2} / M_S$$

where

SO_2 is the amount of combustion product SO_2 [g];

m_{Waste} is the amount of waste burned [kg];

c_{Sulfur} is the sulphur content of waste [g/kg];

M_{SO2} is the molar mass of SO_2 = 64.07 [g/mol];

M_{S} is the molar mass of sulphur = 32.07 [g/mol].

If default incineration/co-combustion modules are used, as a minimum requirement they should at least allow adaptation of (biogenic) carbon content of waste material, required to guarantee a closed biogenic carbon balance in the LCA system model of the bio-based product, and the energy content since it can affect possible credits (e.g. electricity or steam generation).

Combustion efficiency and flue gas cleaning efficiency should be taken into account.

4.6.3 Parameters specific for incineration models

Table 6 specifies parameters of incineration models.

Table 6 — Parameters required for incineration models

Energy recovery	
electric	MJ/kg waste
heat	MJ/kg waste
Water content	kg/kg waste
Air emissions	
CO_2	g/kg dry waste
CH_4	g/kg dry waste
Other emissions (e.g. NO_x and SO_x)	g/kg dry waste

NOTE Energy recovery (i.e. electricity and/or thermal) refers to the net energy exported by the incineration plant. The energy produced by the plant can be electricity to the grid or heat for district heating.

4.6.4 Documentation requirements

Biogenic carbon emissions (carbon dioxide) need to be documented separately from non-bio-based carbon emissions in order a consistent biogenic carbon balance over the full lifecycle of a bio-based product.

Inventory and impact assessment results need to be presented transparently, separately indicating contributions of incineration/co-combustion processes and any associated credits (e.g. electricity or steam generation credits).

Energy recovery efficiency expressed as electric and thermal energy recovery is a critical parameter to be documented.

4.7 Landfill

4.7.1 General

A landfill is a site where waste materials are buried in the ground. It can in principle be managed (e.g. it is covered) or unmanaged, however within Europe many landfills are of the managed type.On a landfill mixes of inert, aerobic and anaerobic conditions can be found, so aerobic and anaerobic biodegradation processes may take place depending on the characteristics of the waste material (its biodegradability), site-specific landfill conditions (temperature, rainfall, level of coverage, microbial activity) and the applied processes (e.g. technical measures to stimulate biodegradation). Biodegradation processes lead to the formation of landfill gas (main components are biogenic methane and biogenic carbon dioxide in case of biodegradable bio-based waste). As the landfill gas moves from the inner part of the landfill upwards through surface layers, methane can partly undergo oxidation processes to carbon dioxide. Besides the emission of decomposition products to air, also emissions of decomposition products to water are generated by leaching (water emissions via landfill leachate). Technical measures can be carried out in order to capture landfill gas and to prevent the formation of landfill leachate and to capture landfill leachate. If landfill gas is captured, it can be flared (thus methane undergoes oxidation to carbon dioxide) or combusted with energy recovery (e.g. in a gas engine). Both processes generate combustion products fully or partly released as air emissions (see also 4.6). Further air emissions are associated with fuel combustion in order to supply energy for the landfill system. Captured leachate can undergo wastewater treatment.

4.7.2 Parameters specific for bio-based waste

Regardless of the origin of the process module applied in the LCA study (generic modules from LCA databases, other public data, or modules developed by the practitioner of the LCA study), the chemical composition and the mineralization rate of the bio-based product in landfill (i.e. Table 1) need to be defined. If default landfill modules are used, as a minimum requirement they should allow adaptation of (biogenic) carbon content of waste material and to consider the possibility that no or only a fraction of the bio-based product is actually decomposed under landfill conditions. These parameters will ensure a consistent biogenic carbon balance in the LCA system model.

The difference between elementary contents (e.g. bio-based carbon content) and the share of actually decomposed elementary contents (e.g. carbon degraded into CO_2, CH_4 and possibly intermediates, e.g. NMVOC) is the part of the material that remains in the landfill. Depending on timescales to be addressed, the non-degraded bio-based carbon may be considered as sequestered.

4.7.3 Parameters specific for landfill model

Regardless of the origin of the process module applied in the LCA study (from LCA databases, other public data, or modules developed by the practitioner of the LCA study), the parameters shown below in Table 6 need to be adjusted as far as possible to a specific LCA study.

Biodegradation of organic compounds on landfills is mostly affected by microbial activity and only to a minor extent by physical or chemical impact. Presence or absence of water or temperature conditions may be issues supporting or inhibiting microbial degradation, respectively.

Furthermore, biodegradation depends also on the landfill type where the bio-based material waste is disposed of. IPCC (2006) distinguishes two landfill types within the "managed landfill" category: managed-anaerobic and managed semi-aerobic. Those landfill types will differ in the degree of biodegradation that actually happens. In some countries, unmanaged landfills still exist.

Table 7 specifies relevant landfill parameters.

Table 7 — Parameters required for landfill models

Location (country)	
Specification/description of landfill system: unmanaged; managed-anaerobic or managed semi-aerobic.	
Described (bio)degradation behaviour of bio-based material in landfill: stable; partly biodegrades; easily biodegrades. (Refer to studies supporting this.)	
Landfill surface area	m^2
Climatic conditions (annual precipitation)	mm
Timescale to be addressed	
Biogas production	m^3/t waste
Energy content of the biogas	MJ/m^3 biogas
Biogas composition	
CO_2	%
CH_4	%
H_2S	%
N_2	%
Leachate production	m^3/t waste
Leachate COD after treatment	mg/l
Efficiency of landfill gas capture	%
Type of treatment of landfill gas (flaring, combustion in an engine with energy recovery)	Yes/no/% share with gas capture
Efficiency of leachate capture	% of generated leachate captured
Treatment of captured leachate (wastewater treatment plant?)	Yes/no/% with leachate capture
Methane oxidation in surface layers	%
Energy demand (waste handling, capture installations etc.) - electrical	kWh/t waste
Energy demand (waste handling, capture installations etc.) - thermal	kWh/t waste
Energy demand (waste handling, capture installations etc.) - mechanical	kWh/t waste
Energy recovery from landfill gas – electric energy	kWh/t waste
Energy recovery from landfill gas – thermal energy	kWh/t waste

NOTE Energy recovery (i.e. electricity and/or thermal) refers to the net energy produced by the landfill (i.e. recovered energy from landfill gas capture).

Ideally in process modules of landfills, not only emission factors of emissions to air, but also emissions factors of emissions to water from landfill leachate should reflect the elementary composition of bio-based waste disposed of on the landfill (e.g. sulphate emissions can be related to sulphur content of bio-based waste). However, those causalities are often unknown for landfills – in this case, average leachate emission factors (per kg waste disposed of – derived from leachate amount and chemical composition combined with total mass of waste disposed of) is an alternative approach.

Carbon sequestration in landfills is a function of time. It therefore depends – in a technical sense – on the activity periods of landfills and – in a more general sense – on the accounting period. Biological activity and thus degradation in managed landfills comes to an end approximately after 80 years of operation. Technically, carbon not degraded after this period may considered as being sequestered. Unmanaged landfills show a different situation regarding that aspect – biological activity may take longer and it is unclear whether and how carbon sequestration would be accountable in this case.

4.7.4 Documentation requirements

Efficiency of landfill gas capture is a critical parameter to be documented. This also applies if the landfill model is taken from LCA databases or other literature sources.

Inventory and impact assessment results need to be presented transparently, separately indicating contributions of landfilling and any associated credits (e.g. electricity or steam generation credits for energy recovered from landfill gas).

4.8 Wastewater treatment (WWT)

4.8.1 Wastewater aerobic treatment

4.8.1.1 General

In this Technical Report, wastewater refers to any water that has been adversely affected in quality by disposal of biodegradable bio-based (e.g. liquid like shampoo or detergent or solid like hygienic paper or scrubbing agent in cosmetics) products. Municipal or industrial wastewater plants are generally used to treat such a polluted water that reaches them via pipe.

There are numerous processes and technologies that can be used to clean up wastewaters depending on the type and extent of contamination, however, most wastewater is treated in large scale plants which include physical, chemical and biological treatment processes.

The most important aerobic treatment system is the activated sludge process, based on the maintenance and recirculation of a complex biomass composed by microorganisms able to adsorb, absorb and degrade the organic matter carried in the wastewater. In particular any oxidizable material present in wastewater is oxidized both by biochemical (bacterial) or chemical processes. The result is that the oxygen content of the water will be decreased. Basically, the reaction for biochemical oxidation may be written as:

Bio-based material + bacteria + nutrient + O_2 → CO_2 + H_2O + organic sludge + oxidized inorganics such as NO_3- or SO_4–

Prerequisite for a wastewater treatment is the biodegradability of the bio-based material under study in water. This property may be proven by certification according to, e.g. aerobic biodegradation in water standards such as ISO 14852 and EN 14987.

4.8.1.2 Parameters specific for bio-based waste

The system boundary of the wastewater model should include all the main treatments that occur within WWT plant and required chemicals. A widespread technology consists of: preliminary treatment (mechanical), secondary treatment (biological) and third treatment (chemical). Inventory data for WWT should be worked out considering material-specific parameters (e.g. C content in the bio-based product that influences the TOC of the wastewater) and those WWT technology-specific (e.g. electricity consumption, type and amount of chemicals[1], produced sludge, etc.). For the latter parameters average municipal large scale data can be used if no primary data are available, whereas product-specific emissions to air (e.g. CO_2) and to water (e.g. NO_3) can be derived from algorithms, present in literature, that associate product composition with emissions to air and to water (i.e. pathways figures below). Since some WWT plants perform a sludge digestion with production of biogas two by-products with recovery potential are here produced: biogas for direct (e.g. boiler, cooking, transport) or indirect use (electricity generation, monomer for chemical industry) and sludge as soil amendment. The quality of sludge must be checked (chemical, microbiological and physical characterization) in case of agricultural use.

4.8.2 Parameters specific for aerobic WWT models

Process specific parameters include the following aspects:

a) specific or generic data for infrastructure of waste water treatment: plant, construction, reinvestments and dismantling and maintenance materials (if relevant);

b) operation stage: energy consumption, manufacture chemicals, resources consumption for the whole WWT process (i.e. primary, secondary and tertiary treatments);

c) mix of electricity: specific data for the generation of electricity or generic data;

d) chemicals and/or materials process-related transports; and

e) amount of produced sludge; primary and secondary.

If no primary data are available for WWT process, documented average data may be used.

4.8.3 Product specific parameters

Product specific parameters are those related air and water emissions deriving from bio-based product WWT. They can be easily worked out by applying transfer coefficients found in literature, as long as, waste water amount and characteristics like TOC, BOD, metals, etc. in which the (liquid) biodegradable product is dissolved are known.

According to waste water characteristics and transfer coefficients for WWT it is possible to determine inventory data of bio-based (liquid) product disposed of in WWT plants. Transfer coefficients describe the fate of a substance within WWT process, see Annex A.

4.8.4 Anaerobic primary sludge treatment

Anaerobic digestion is the most common process for dealing with wastewater sludge containing primary sludge. Primary sludge is the solids which settle out of the wastewater in the sedimentation tanks just after the wastewater passes through the grit chambers. The settled material represents 40 %

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[1]) Strictly speaking the amount of chemicals used for treating wastewater depends on its characteristics, however, in this European Technical Report typical chemicals consumption is considered.

to 60 % of the suspended solids that exist in the wastewater. This represents 25 % to 35 % of the BOD in the wastewater.

4.9 Release of bio-based products in nature

The release of bio-based products in nature may occur either controlled or uncontrolled. Products can be either designed for release in nature or not. See examples in Table 8.

Table 8 — Examples of different releases to nature

	Controlled release	**Uncontrolled release**
Products designed for biodegradation in nature	Soil biodegradable products, e.g. mulching films Bio-lubricants	Littering
Products not designed and intended for release in nature	-	Littering, unmanaged landfills

In both cases, several different situations can be encountered which are difficult to include within a precise framework. For this reason the inventory modelling for controlled and uncontrolled releases in the environment, may be addressed on a case by case approach on conditions that the mass balance principle is met.

The model on which the inventory data are derived from along with hypothesis and assumption done needs to be clearly documented and reported in the study. Also product characteristics such as mineralization rate, composition, etc. (i.e. Table 1) needs to be reported. Biodegradation rate needs to be reported and adapted to local climate (t° and rainfall regime). Experimental models and/or data may be used as long as scientifically robust.

Annex A
(informative)

Examples of pathways

A.1 General

The figures below describe different pathways. These figures are based on data from Ecoinvent [15], which is used with their permission.

These data can be used when specific data are not available.

A.2 Carbon pathway

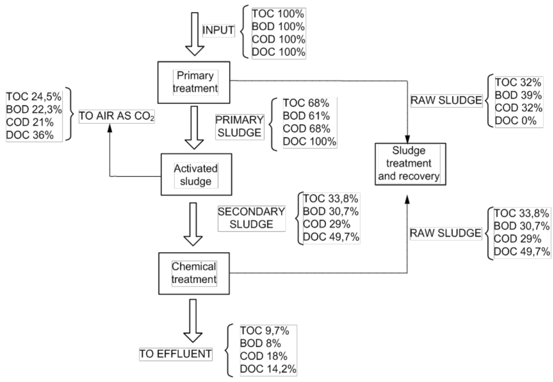

Figure A.1 — Carbon pathway

A.3 Sulphur pathway

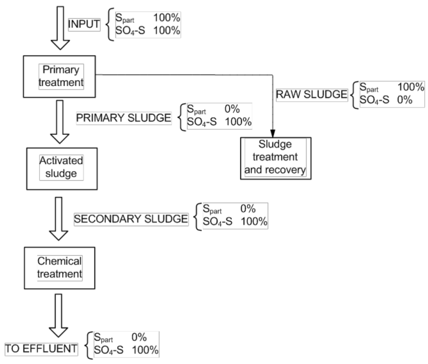

Figure A.2 — Sulphur pathway

A.4 Phosphorous pathway

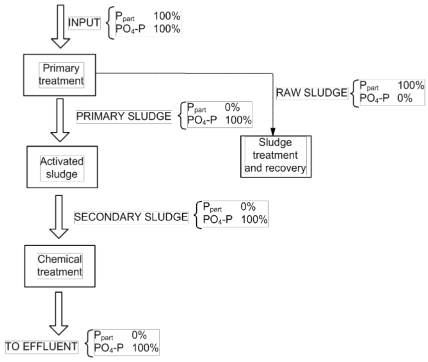

Figure A.3 — Phosphorous pathway

A.5 Heavy metals pathway

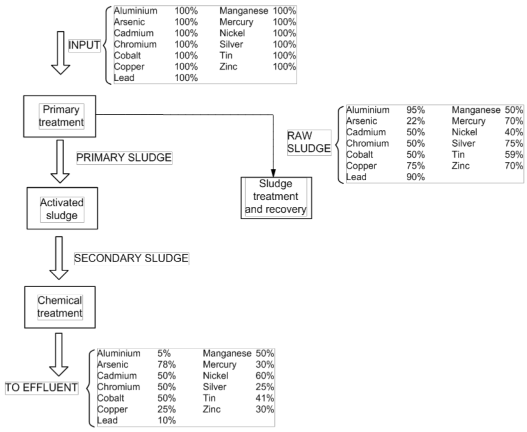

Figure A.4 — Heavy metals pathway

A.6 Nitrogen pathways

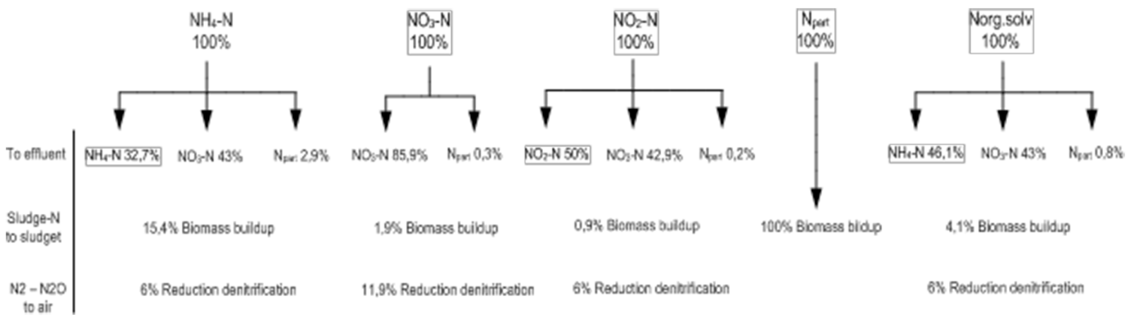

Figure A.5 — Nitrogen pathways

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