Guidance on how to consider waste disposal in inventories of waste-producing activities

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Title image Different waste materials (from BAFU 2014, cropped) and a waste bin (https://pngimg.com/image/21709 CC BY-NC 4.0) representing the two most important aspects of inventorying a waste disposal: the waste identity and the disposal pathway. The shown waste materials are (from top left to the right): textiles, food waste, cans, natural materials, batteries, garden waste, composite packaging and diapers, kitchen waste, minerals, non-ferrous metals, plastic containers, cardboard, other paper and tissues, glass, ferrous metals, printed paper.

Declaration This and all previous reports by Doka LCA were created without any use of generative artificial intelligences like ChatGPT or similar. Used were however traditional English-German dictionaries and thesauri.

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Percent is not a unit A value like 100% is mathematically identical to 1, and "33%" is just a way to write the value 0.33 (which one could also write in yet another different format as "$3.3 \cdot 10^{-1}$"). Mere *formatting* does not and should not influence the *magnitude of a value*. There is therefore no need to introduce factors or divisors of 100 in formulas for percentages (see e.g. footnote 8 on page 11) . "Per cent" literally means "per one hundred" and implies the instruction "divide by 100", therefore the mathematical value of the expression "33%" is 33/100 = 0.33 (not 33). In contrast, a formula to calculate a gram value from kilograms must include a factor of 1000, because gram is a *physical unit* (not just a different way to "format" a kilogram value).

Contents

1 Introduction

This is a guidance document for authors of LCI process inventories of waste-producing activities. It shall help to understand how to link waste outputs in life cycle inventories of waste-producing activities to appropriate waste disposal activities, and the structure and granularity those waste disposal activities have in LCA.

A waste-producing activity can basically be any type of activity, a production process, a service process, or also a waste treatment process itself. A waste material output might be a pre-consumer waste product (like product cut-offs, losses or rejects), an auxiliary production waste (like waste lubrication oil), or a post-consumer waste after usage at the end-of-life (like used manufacturing machinery or used packaging).

Two major aspects of waste disposal need to be considered for including waste disposal in inventories of waste-producing activities:

- The **type of waste material**, i.e. composition, content of pollutants, other waste characteristics like burnability or biodegradability. Is it a solid, a sludge, a liquid or wastewater? Or simply "What is the waste material?"
- The **applied disposal technology**, i.e. the way a waste is being disposed of. For instance a plastic material in incineration will have quite different burdens than the exactly same material in a landfill. This is the question "Where is that waste material going to?"

This report highlights details and pitfalls in accurately considering waste disposal in inventories of waste-producing activities. It is based on my decades of experience of coordinating, reviewing, and providing waste disposal activities for LCA, most notably for the ecoinvent database. It also refers to the granularity and features of the suite of free Excel waste tools I provide, which allow generation of waste-specific disposal inventories (Excel workbooks accompanying Doka 2023). These tools are probably the source of most of the available waste disposal inventories available today.

2 Fundamental considerations

The following chapters present in some more detail the two main issues of properly inventorying waste disposal mentioned in the introduction:

- Characteristics of a waste: "*What* is the waste material?"
- Circumstances of waste disposal: "*Where* is a waste going to?"

This usually makes inventorying a required waste disposal more difficult compared to the inventory of a required *input* material. Most or many input materials come from *globally traded goods* and the usual assumption is that the material is sourced from a global average market—or from a constant mixture of the production processes available in a background database. So, inventorying an input material is commonly achieved only by defining the material's identity. With waste disposal, not only the material's identity is relevant, but also the circumstances and the setting of where and how that waste is produced. These two aspects are examined in the following.

2.1 Waste material characteristics

In LCA, the **specific waste material characteristics** are used as a jumping-off point to calculate possible emissions from their treatment or disposal. This is called **waste-specifity**: direct emissions of the treatment of a waste are calculated depending on how that waste is composed in detail. In LCA, waste is specified at least with its content of various different chemical elements like copper, lead, zinc, arsenic, phosphorus, nitrogen etc. So if a waste material has, say, no cadmium content, then the treatment of that waste material will not lead to any direct cadmium emissions in the waste treatment.[1]

This waste-specifity is absolutely crucial in assessing waste disposal. A specific waste material composition can have several orders of magnitude higher or lower environmental impacts than the generic average input waste in a particular treatment technology.[2] It is therefore of paramount importance in LCA to heed and model waste materials properly and specifically with their waste material characteristics and stay away from merely generic average waste compositions, like average mixed municipal solid waste (MSW).

It is important to understand that *assessing* different waste materials separately and specifically does not mean they need to be physically separated *in the real world*. The different waste materials can well be disposed as a mixture in the real world. For example, waste paper and waste plastic in incineration

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1 Modelling of disposal processes is based on mass flow accounting of *chemical elements*. The procedural behaviour of individual compounds like hydrocarbons is not modelled. This is done for two reasons. 1.) Chemical elements are conservative, do not degrade and cannot disappear. This makes the elaboration of the employed transfer coefficient models of treatment easier. Modelling the behaviour of compounds—their generation, transformation and elimination during treatment—would be a vastly more demanding and data-intensive endeavour. 2.) Chemical elements capture the largest part of toxicity burdens from disposal. Additional individual organic compounds usually make up a negligible contribution. For instance some individual compounds like Benzene, Penta-chloro-phenol (PCP) or Dioxins are included in a simplified fashion in municipal waste incineration inventories, but make up an utterly negligible contribution of less than a thousandth per mill of the total burden of waste incineration. Even in the open burning model, where the combustion is much more incomplete and flue gas treatment is entirely absent, the sum of individual toxic organic compounds make up only 1.6% of the total burden. Or an estimate for organic compounds emitted from wastewater treatment yielded very low contributions to the total burden of below 0.02% (see Doka 2021, in chapter 19.3 'Relevance of emissions of organic compounds').

2 For instance the range of the assessed 57 different waste materials in waste incineration spread over a factor of over 10'000 or four orders of magnitude. Picking an unsuitable waste material composition can therefore have severe consequences of over- or underestimation.

can be assessed as two separate, waste specific inventories, although in the real world they are incinerated together as a part of a MSW mixture. Waste-specifity is an enhanced modelling granularity in order to attribute a particular waste product its specific burdens, and not assessing just any material in a waste mixture with the same, constant average treatment burdens. Waste-specifity is however very much rooted in real-world data like measured waste compositions and elemental transfer coefficients in the disposal process, which in turn are derived from measured behaviour in real-world disposal facilities.

2.2 Circumstances of waste generation

The **disposal fate**, i.e. where a waste is going to and the way a waste material is disposed of, depends on several of circumstantial aspects.

1. The disposal technologies available in the geographic location a waste material is being generated.
2. Which of these possibilities the operator of the waste-producing activity actually uses in the real world.
3. Association of waste materials in combined products, which can influence disposal fate.

Ad 1, Available disposal technologies (Geography): diverse methods of waste disposal exist in the world. In economically rich countries high-tech disposal technologies like municipal incinerators, sanitary landfills or three-stage wastewater treatment can be available. In poorer countries those technologies might be lacking, and open burning, open dumping, or direct emissions are possible or even likely. Also uncontrolled fires in managed landfills are possible (see frequency estimates in chapter 3.f "Landfill Fires" of Doka 2018-M:13). So the disposal pathway is not determined only by the waste material characteristics and the waste-generating process, but also *where* that waste-generating process is located geographically.

Doka (2018-M) compiled data on disposal of non-recycled mixed *municipal solid waste* for 152 countries in the world. This was based on statistics for instance on presence of waste collection services for households or extent of municipal waste incineration in countries. Some predictors based on Gross National Income (GNI) were also derived. Similar data on treatment (or lack thereof) of wastewater in different countries has been compiled in (Doka 2021). This country data can be used to either directly estimate pertinent treatment options in a country or estimate a likely treatment.

Ad 2, Actually used disposal technologies (Behaviour): Even if a disposal channel is available in a country, an operator of a waste-producing activity might choose not to use it. For instance waste paper might be binned separately into paper recycling. But it might also disposed as mixed municipal waste and incinerated, burned or landfilled, mixed with other waste. What types of waste bins are available depends on the geographic location (see point above, for instance the paper recycling bin vs. mixed municipal waste). What bins are used in reality depends on the actions of the operator of the waste-generating process. This is the aspect of the operator's **binning behaviour**. Also the illegal choices to litter one's waste, or burn it uncontrolled in open fires, or put hazardous wastes like electronics in municipal solid waste constitute the real world choice of a 'bin'.

Ad 3, Materials associations (Aggregations): input materials can be combined with other materials to form product associations and conglomerates, which influence disposal pathways. The constituting materials of a product are then strongly associated with one another and this will influence the realistic resulting disposal pathway. For instance, paper fibres might be used as reinforcement in gypsum panel production. Any of that paper material—either as production waste, or post-consumer waste—will not be nice, isolated paper, but finely dispersed fibres embedded in a gypsum board, and thus follow the disposal pathway of that gypsum board. Inventorying this waste paper material as waste into paper recycling is unrealistic (at least outside of a specific gypsum board waste recycling process). More likely is a disposal as inorganic building waste, and ultimately landfilling as a fine fraction. A similar example is glass-reinforced polymer, where it is unlikely the glass can be isolated and recycled. More likely the product will be discarded as waste and incinerated or landfilled (or burned or dumped uncontrolled, depending on the location). So, strong material associations can influence the realistic disposal pathways and you need to be aware of them.

All these three aspects—Geography, Behaviour, Aggregations—are not determinable by looking at the waste material characteristics by themselves. That something is a "paper waste" does not already tell me how it will be disposed. It is therefore often not accurate to assume a treatment technology based on the waste material characteristics alone. The *circumstances* a waste material is generated in must be considered too.

3 Detailed considerations of waste disposal inclusion

In the previous chapter the crucial aspects of the inclusion of waste disposal were outlined to revolve around the two basic aspects of "What is the waste material?" and "Where is a waste going to?".

In the next sections those aspects are presented in more detail.

3.1 Characterising a waste

3.1.1 Waste-specific parameters

The suite of Excel waste tools already contains a great many entries of researched waste compositions. Maybe for your inventory, these materials suffice and you can repurpose them, see list in chapter 3.1.2 on page 16. But maybe your waste is very different from the available ones and you need to define a new waste material. The following sections outline the required information to define a new waste material.

Waste fractions: Keeping different materials separate

The suite of Excel waste tools calculate emissions from waste disposal based on the waste characteristics. They try to do this as specifically as possible. A specific waste material is the input to a treatment inventory. But a waste *material* of a treatment inventory can be composed of one or several waste *fractions*. A waste fraction is best described as a uniform material with homogenous properties, especially regarding burnability or degradability. The reason to separate heterogeneous materials into several waste fractions is better waste specificity in the created inventories.[3] Distinctions in the disposal process models were introduced, particularly in the incineration models and the landfill models.

For waste in incineration a binary distinction is made whether a waste is burnable or unburnable and that choice leads to different emissions. Similarly, the emissions from landfilling are modelled in dependence of the *degradability* of a waste. Degradability (within 100 years) is a continuous parameter between 0% and 100%.

In order to perform these modelling distinctions it is important to keep the waste composition definitions separate with regard to their *burnability* and *degradability*. A waste homogenous in its burnability and degradability is called a waste *fraction*. The definition of waste compositions should initially be based on such homogenous waste fractions, not mixed-up conglomerates of heterogeneous waste.

At a subsequent stage, the Excel tools can *combine several waste fractions* into one waste material and create a single disposal inventory for a waste material consisting of several waste fractions.[4]

3 See footnote 4 for an example.

4 You are able to combine for example two fractions into a heterogeneous waste and the treatment model will treat each of the fractions correctly. For example you can define a glass bottle with a paper label. The paper label is burnable and degradable, while glass is unburnable and hardly degradable. To heed this distinction, you need two *separate* fractions for "glass" and "paper" (not a single composition for the whole bottle). If you were to define a single elemental composition containing *both* those different materials, you would create unrealistic modelling results: If you were to characterise that single composition

In the following the required data for the definition of a waste fraction, homogenous in its burnability and degradability, is presented. In contrast, the term "waste material" is used for waste defined as the combination of one or more waste fractions.

Composition data

Waste fractions need to be quantified regarding their composition. The level of detail is single chemical elements, like carbon, cadmium, arsenic, phosphorus etc. The composition data is in "per 1 kilogram of wet waste", which is also the functional unit of most waste disposal processes.[5] The compositional data thus includes any water contained in the waste, such as it is disposed. "Water" is heeded as a separate compositional entry, while "oxygen" and "hydrogen" should be the amounts without those elements contained in water. Also uncritical, non-toxic elements like oxygen are included for completeness.

Different waste materials have different elements of relevance, but elements frequently of importance are organic carbon, nitrogen, sulfur, phosphorus, the "seminal" heavy metals (Cd, Cr, Cu, Hg, Ni, Pb, Zn) and other toxic elements (As, Ba, Mn, Mo, Sb, Se, Sr). Water content can be relevant, as it dilutes the dry matter where the relevant pollutants are contained. Calcium is important in tailings and the impoundment model to determine the material's pH buffer capacity.

Below are the chemical elements distinguished in the Excel waste tools by Gabor Doka. The arrangement of the elemental vector is as follows: common major bulk elements (or macro elements), other non-metals, halogens, heavy metals and semi-metals, prominent ash elements.

Water content	H_2O
Oxygen (without O from H_2O)	O
Hydrogen (without H from H_2O)	H
Carbon, organic	C
Sulfur	S
Nitrogen	N
Phosphor	P
Boron	B
Chlorine	Cl
Bromium	Br
Fluorine	F
Iodine	I
Silver	Ag
Arsenic	As

Barium	Ba
Cadmium	Cd
Cobalt	Co
Chromium	Cr
Copper	Cu
Mercury	Hg
Manganese	Mn
Molybdenum	Mo
Nickel	Ni
Lead	Pb
Antimony	Sb
Selenium	Se
Tin	Sn
Vanadium	V

Zinc	Zn
Beryllium	Be
Scandium	Sc
Strontium	Sr
Titanium	Ti
Thallium	Tl
Tungsten	W
Silicon	Si
Iron	Fe
Calcium	Ca
Aluminium	Al
Potassium	K
Magnesium	Mg
Sodium	Na

as unburnable, the model result would contain no air emissions, implying unburnable paper. But if you were to characterise it as burnable, it would generate too much air emissions, because a significant part of the glass would be unrealistically modelled to enter the raw flue gas stream. With a complex waste consisting of two separate fractions glass and paper, the glass remains unburnable, and the paper burnable and appropriate emissions are calculated. The same distinction applies to degradability and the landfill model, where the elements in paper degrade much quicker than in glass, and therefore can contribute to landfill gas formation, while elements in glass will not.

5 For wastewater, since 2021 the *composition* is also defined by the user as "kg element per kg wet waste, i.e. kg wastewater" in the Excel tools—same as solid or sludge wastes out of convenience—, but the disposal inventories of wastewater treatment are scaled up to a *functional unit* of "1 m^3 wastewater" which corresponds to 1000 kg, i.e. a factor 1000 larger.

Also noteworthy is that carbon is considered to be carbon in *organic* compounds, but without inorganic carbon. Inorganic carbon is commonly present as carbonates ($R\text{-}CO_3$) and is of little relevance in LCIA. Advice on how to include inorganic carbon for the Excel waste tools in section 'Making mass balances complete' on page 13.

Inventoried waste mass amount

Waste disposal inventories are either per "1 kg wet waste" for solid waste materials, and "1 m^3 liquid" for wastewaters. The amount of waste output in your waste-producing inventory should be compatible with the inventoried waste composition. Especially water content can be variable. Waste materials already established in the Excel waste tools are defined with the water content pertinent to the disposal process, not necessarily how they are outputted at the waste-producing source.[6] For instance relatively dry paper can take up humidity when disposed together with mixed municipal solid waste. Water content plays a role in the amount of energy utilisation in incineration.[7]

If your waste-producing process has for instance an output of 500 kg of waste wood with a water content of 30%, but the waste incineration process has a waste wood composition with 17% water content, you need to *reduce* the inventoried waste mass to the water content used in the disposal process, in this case to 422 kg.[8] I.e. the assumption is made that the dry mass amount is retained. Without this you are in this example overestimating the dry mass input to disposal and therefore the disposal burdens.

If you are using an existing disposal process, consult the defined water content, which is usually given in the GeneralComment field of the inventory. If you are creating a new disposal process, you can establish an appropriate water content. But remember that water content will play a role in energy utilization in incineration and should reflect the state of the material during disposal.

Real-world waste compositions

Toxic elements like heavy metals or halogens can play a crucial role in the LCIA burden of waste disposal processes, even if they are only present as traces.[9] It is therefore important to research and include such trace amounts, especially toxic ones.

Merely theoretical compositions—e.g. inventorying poylethylene only as carbon and hydrogen—shall not be used, but they can inform choices or constitute comparisons for common matrix or bulk elements. Even in brand new materials, like plastic pellets, traces can be present, either as traces already contained in raw materials, or from processing contamination or lost catalysts. The composition of waste fractions should reflect the state a particular, homogenous material is in after it has been discarded. This can include post–production contamination from usage, grime and dust, which can be different from brand new material.

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6 In tailings impoundments, a 30% water content is assumed with reflects the water content in *stacked settled tailings*, not the water content of the pumpable *tailings slurry* produced from ore beneficiation before stacking and before water recirculation.

7 This is the reason that waste materials are deliberately defined as <u>wet</u> mass.

8 422 kg = 500 kg / (1 – 30%) · (1 – 17%).

9 For instance, in average MSW, the element zinc makes up but 0.11 % by weight of the total waste mass, but it accounts for 55% of the LCIA burden of MSWI incineration (with ReCiPe'13). Or the element barium in MSW makes up but 0.015 % by weight (150 ppm), but barium-related emissions account for 7.6% of the LCIA burden. Heeding small traces in waste can be very crucial.

Toxic elements are also present in biomass materials and other materials considered to be "natural". They need to be included for an impartial assessment. For instance 21% of the burdens in the landfilling of natural wood comes from contained toxic traces, although they make up only 0.01 w% (10 ppm) of the waste composition.[10]

Of course the major elements by weight present in a waste must be included, even if they are not toxic or not environmentally relevant. For instance oxygen in an ash composition.

You should also make sure that expected pollutants are not missing. A galvanising sludge from a chromium-plating process without any chromium content is evidently incomplete and inadmissible. A chromium content must be at least be estimated. And likely some other heavy metals might be relevant in this example. Preliminary LCIA results and LCIA characterisation factors can help to establish relevancy on different elements also in this task. Sources and procedures to obtain waste compositions must be described in a documentation report of your inventory.

You should compile as many data points as available. The more the better. At least some data is better than no data. But be sure to use *real world data* with priority, and data from pilot plants or feasibility tests, estimates or theoretical considerations only for completeness. Having more data points recorded helps to produce a typically encountered composition from the inherent variability often present in waste materials.

If you are in the desirable position that you have *several* data points for the same chemical element, employing a geometric mean is deemed most appropriate, since trace compositions often have left-skewed distributions, close to lognormal (Doka 2003-II:Fig.2.10). From experience, it is best to compile literature data for a waste fraction in spreadsheets, where you can do calculations on the literature data.[11] Advice on how to handle data points below a detection limit is given in the next section.

Please be diligent in researching waste compositions: it is the most crucial aspect of waste disposal in LCA. You may be working on a mere carbon balance and therefore might think defining a waste with only their carbon content and ignoring any toxic elements is sufficient. But once made approximations or short-cuts tend to have a long half-live in LCA. Your data or your disposal inventories might be repurposed by other authors using full LCIA indicators, and the fact that you have cut corners can be forgotten. You have then created an unfair advantage for your waste by making it appear that it is free from any toxic traces.

Measured data below detection limit

When researching elemental composition of waste materials, some data items might be encountered below a detection limit (BDL), for instance a mercury content might be given as "<0.01 mg/kg". By itself such an information is not very helpful, because it says more about the *used instrumentation* than about the waste sample itself. As a single data point, it is therefore close to meaningless regarding the sought after waste composition. However, when such information is given along with *additional data*

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[10] Don't confuse "toxic" to mean "synthetic". Chemical elements like zinc or copper are natural, not man-made. Even in anthropologically very unimpacted environments, natural tissues take up and contain heavy metals and other toxic traces.

[11] A geometric mean—the mean of the lognormal distribution—can be obtained by standard Excel function GEOMEAN(). The arguments of this function cannot contain any zero values. You therefore must exclude zero values from literature for the function. You can do this manually, or automatically by using an *Excel array function* like {=GEOMEAN(IF(C5:G5=0,"",C5:G5))} , here assuming C5:G5 is the range containing your literature data.

points for the same element, especially above a detection limit, it can be useful to heed also the information implied from data points below a detection limit. A value given as below detection limit, i.e. "<DL" can be included as an active formula "=factor*DL" in an Excel table where you compile your literature data. So "<0.01 mg/kg" could be included as "=factor*0.01" (plus heeding the appropriate unit conversions). The value for DL should obviously be adapted to the value given in the used source.

The factor parameter should ideally be a centralised cell reference in your data compilation worksheet, for instance as "=C7*0.01". Cell C7 can then subsequently be changed consistently and centrally, to test how sensitively the mean waste composition is affected by the choice of the parameter "factor". A factor of 0.71 (=1/√2) is frequently employed in literature (Turner et al. 2019:15). A different reasonable choice is 0.5, representing an uniform rectangular distribution between zero and DL; which is the information conveyed by "<DL" without any assumptions on a distribution. A factor of 0.3 would coarsely represent a distribution left-skewed towards zero.

If the waste composition is affected to a large degree by the choice of the factor in relevant elements—meaning elements which play a large role in LCIA results—then more data sources with above DL data points should be found, to make the relevant elements more reliable.

Describe your approach of how to heed "<DL" literature values in the documentation report of your inventory.

Making mass balances complete

The compiled waste composition with the unit "kg element per kg wet waste" should in theory add up to 1 kg or 100 w%. It is however very common in raw data for waste compositions that mass balances do not add up to 100% or 1 kg. Waste is almost never a well-defined material and its composition is often subject to many poorly controlled vagaries and can be quite variable—especially regarding traces, but also water content. It has to be expected that the compiled mean or median values from a literature survey of real world measurements to establish a waste composition do not add up to 100% even when a fairly complete range of elements and many data points for each element has been obtained.[12] Frequently, such raw data compilations undershoot the 100% total. It is assumed here that this gap to 100% is not occurring because important elements in the waste by mass have been ignored (cf. section 'Real-world waste compositions' on page 11 above).

To bring the waste fraction composition data up to 1 kilogram—the amount for a waste composition definition expected in the disposal model calculations—several types of corrections are imaginable. These corrections should be only applied at the very end of waste fraction composition definition, not during the compilation of literature raw data values, in order not to distort values unduly.

At the outset, the total mass gap present in the compiled raw data can be calculated, the difference to 100%, denoted here with Δm. Then the *most common element* in a composition can be sought out. That will for example be carbon in many polymers, oxygen in a combustion ash composition, or water in a wastewater or a sludge composition. The total mass gap Δm can then be compared to the mean value for this most common element, m_e. Frequently, this ratio ($\Delta m/m_e$) is small—say 1%—and well below the real world variability of the element. In order to bring the total waste fraction mass to 100%,

[12] For instance in a measuring campaign for elemental composition of mixed municipal waste, the established average values added up to only 88 w%—a 12% mass gap—although an extensive range of chemical elements and water was included, cf. Doka 2013:26)

the mean amount of the most common element m_e can be corrected by the initially found mass gap Δm.

If for some reason this first approach is undesirable—say you want the iron content in a ferrous scrap to remain exactly what is found in literature—you can also add the mass gap to the *second most abundant element* in a waste, say oxygen. Or you can add a value for a non-toxic, non-relevant element, like silicon.

A third approach would be to simply scale all values found by a certain factor to bring the sum total up to 1 kg. This is however not advised. It affects the amounts of *all* recorded elements, while the previous approaches only affect a single one.

Your chosen approach to close any mass gaps and your reasoning should be described in an accompanying documentation report of your inventory.

As mentioned previously, any inorganic carbon shall not be included with the recorded organic carbon. The mass of inorganic carbon must be recorded as a mass of something ecologically harmless like silicon, magnesium or potassium (not calcium, as it is used in the tailings impoundment models to determine the duration of the buffered carbonate phase and it shall not be changed from the actual literature value).

Heating values

Heating values are relevant in incineration processes, as they influence the amount of usable energy generated, and the amount of assistant processing energy required.

Both upper and lower heating values are required and shall refer to one kilogram of wet waste, i.e. including water content. The unit is Megajoules per (wet) kilogram MJ/kg. Often literature values of upper heating value only refer to dry mass content, and such data must be downscaled heeding the water mass in the waste. The lower heating value shall be appropriate for the given water content and compatible with the given upper heating value. Further remarks see in point 167 in the waste tool's Calculation Manual.

Share of biogenic carbon

The recorded organic carbon must be distinguished into fossil and non-fossil carbon, which will be used to distinguish fossil vs. biogenic CO_2 etc. For this a ratio of the share of biogenic carbon in the waste must be given in the waste fraction definition as a number between 0% to 100%. Usually, in homogenous waste fractions, the ratio is either 100% (e.g. wood) or 0% (e.g. polyethylene). But for maximum flexibility any number between 0 and 1 can be entered. For instance, average sewage sludge contains some fossil carbon due to the use of synthetic polymer flocculants.

Inorganic carbon shall not be considered in the amount of organic carbon, as outlined previously on page 11. [13]

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[13] Inorganic carbon is commonly present as carbonate minerals (R-CO_3), for instance in calcium carbonate $CaCO_3$. The term "Inorganic" shall not be confounded to be synonymous with "non-biogenic". Inorganic carbon is often present as fossil compounds, like carbonate minerals in marble, limestone or chalk. But inorganic carbon can also be *biogenic* and a part of living biomass, for instance in shells of bird's eggs, snail shells, or pearls from mussels. *Organic* carbon means the carbon atoms are in compounds containing chemical bonds between carbon and carbon (C-C) and/or between carbon and hydrogen (C-H), giving Organic Chemistry its name. Organic carbon can be contained in biogenic materials, like wood, but also in

Degradability in a landfill

The degradability of the homogenous waste fraction in a municipal waste landfill must be specified for proper use of a fraction in a sanitary, unsanitary landfill or open dump model. This is the degradability within 100 years and for a temperate climate.[14] Measured numbers are surprisingly low with most fractions being below 30 w% (see Tab. 8.1 on page 35 in the Excel tool's Calculation Manual). For tissue paper it is 39%. Degradability for common polymers is especially low. More details on degradability are in Doka 2003-III, chapter 6.1.1 "Waste-specific degradability in sanitary landfills" page 43ff.

As outlined before (see page 9), materials with different degradability should be entered as *separate fractions* to obtain accurate emission behaviour in the model.

Burnability of a waste fraction

Burnability of a waste fraction is included in the model as binary choice, 1 or 0 for yes or no. A burnable waste is one that can be incinerated ("burned") and will contribute to the raw flue gas in an incineration process. By contrast, an unburnable or inert waste fraction will not incinerate, will not enter the flue gas, and remain as solid bottom ash. Whether or not a waste fractions burns *by itself* does not enter into the consideration here. For instance, a very wet biomass sludge is "burnable" in the model, even if it does not ignite well or at all by itself. In the incineration process mixed with other wastes it will be dried and ultimately incinerate.

As outlined before (see page 9), burnable materials should be entered as *separate fractions* from unburnable, inert wastes in order to obtain accurate emission behaviour in the incineration models.

Solidification in residual material landfill

This is a special provision only for wastes going directly into a *residual material landfill* (VVEA type C). Solidification with cement prior to landfilling in a residual material landfill can be entered as 1 or 0 for yes or no. This will only be used for separate inventories of direct disposal of a waste in residual material landfill. The parameter is indicated per waste fraction. Some highly polluted wastes or wet sludges need to be solidified before being able to be landfilled legally in a residual material landfill. Examples are green liquor dregs from pulp production, sludge from steelrolling, or brine filtration sludge from NaCl electrolysis.

Share of recyclable metals

For the elements iron, aluminium and copper the share in the waste fraction that is recyclable can be specified as a characteristic of a particular waste, as a ratio between 0% and 100%. As recyclable are considered the metallic, non-oxidised, and bulky parts of the element in the waste. 100% signifies all

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fossil materials like oil or coal. A material characterised as "biomass", might therefore contain both inorganic carbon and organic carbon.

14 The municipal waste landfill models are regionalised since 2017 and will use this temperate degradability as a starting point. Degradability will be adapted depending on precipitation and temperature, which changes results especially in cold climates and very dry climates.

of the element in the waste is recyclable. Very small or thin parts will likely oxidise and not be in recyclable form after incineration.

Please, make sure you do not confound the terms "recyclable" and "recycled". A recyclable material is not the same as a recycled material. The term "recycl*able*" denotes only a material's limit to a *possibility* of recycling and is not the same as the term "recycl*ed*". In the Excel waste tools recyclability is a characteristic of a *waste fraction*, while the actually used recycling rates are a parameter of the applied *disposal technology*. See Fig 8.1, page 37, in the tool's Calculation Manual.

3.1.2 List of waste fractions already included in the Excel waste tools

Over the years many waste fractions could be recorded in various projects and utilised in the Excel waste tools. The following is a compilation of the waste fractions contains in the tools in March 2023 along with their project origin. Details on the compiled fractions are explained in the indicated reports.

Ecoinvent 2000 project, see (Doka 2003-I:chapter 4)

average residual materials from MSWI
PE
PP
PS
PVC
PET
PU
Mixed various plastics
rubber
Plastics from electronic consumer goods
Plastics from electronic industrial goods
PVF
tin sheet inert
tin volatile
MSWI iron scrap
Alu in MSW
Glass
inert material (as cement)
newspaper
packaging paper
average paper
cardboard
soiled textiles
chrome-preserved wood electricity pole
chrome-preserved building wood
natural wood
cement hydrated
Gypsum natural
organics in plastic plaster
Emulsion paint (remains)
paint (remains)
PVC for sealing sheet
EPS insulation
PE for sealing sheet
PE for vapour barrier, flame-retarded
Filler (limestone)
plastiziser
inert material
bitumen
wiring copper
wiring plastic
bilge oil
separator sludge
refinery sludge
hazardous waste avg.
waste oil
Anti-Freeze liquid
waste solvents mixture
cooling tower residue
AT hard coal ash
BE hard coal ash
CZ hard coal ash
DE hard coal ash
ES hard coal ash
FR hard coal ash
HR hard coal ash
IT hard coal ash
NL hard coal ash
PL hard coal ash
PT hard coal ash
SK hard coal ash
hard coal ash small scale
lignite ash small scale
drilling waste
inorganic Waste Si wafer production
wood ash pure
sludge from pulp and paper production
composition of paper sludge ash
Green liquor dregs from pulp production, to landfill
Ash, from Incineration of Deinking Sludge, to landfill
Nickel smelting slag
dust from unalloyed electric steel production to landfill
slag from electric steel production to landfill
BOF waste mix
sludge from pig iron production to landfill
dust from electric chromium steel production to landfill
Sludge from Steelrolling
redmud from bauxite digestion
spent pot liner, carbon fraction
spent pot liner, refractory fraction
filter dust, aluminium electrolysis
dross, aluminium electrolysis
reduced residues dichromate prod
residue from TiO2 production (sulfate process)
residue from TiO2 production (chloride process)
salt tailings potash mining
Brine filtration sludge without mercury cells
Brine filtration sludge with mercury cells
residue from H3PO4 purification
decarbonising waste
cation exchange resin f. water

anion exchange resin f. water
EDC Oxychlor catalyst
Formox catalyst carrier
Ethylene oxide catalyst carrier
polluted rail ballast residue
Al in ASR burnable
Al in ASR inert
Fe in ASR burnable
Fe in ASR inert
Zn in ASR burnable
Zn in ASR inert
Cu in ASR burnable
Cu in ASR inert
Pb in ASR burnable
Pb in ASR inert
sulfidic tailings nickel mine

Ecoinvent Bioenergy 2007, see (Jungbluth et al. 2007)

biomass, 65% water
biomass, 60% water
biomass, 80% water
raw WWTP sludge
digester sludge WWTP
sewage grass refinery (wastewater)
sewage whey digestion (wastewater)

Ecoinvent Electronics, see (Hischier 2007-V)

Capacitor (w/o plastics rubber paper)
CRT coating
liquid crystals
ITO coating
silver

Old Swiss MSWI fractions, see (Hellweg 2000)

paper
Mixed cardboard
plastics
laminated materials
laminated packaging, e.g. drinks cartons
combined goods e.g. diapers
glass
textiles
minerals
natural products
compostable material
inert metals
electronic goods
volatile metals
batteries
electronic goods

Ecoinvent v3+ New Swiss MSWI composition, see (Doka 2013)

average municipal solid waste, burnable part
average municipal solid waste, unburnable (inert) part

Ecoinvent v3+ Tailings from various metal ore beneficiations, (Turner et al. 2019)

Several tailings composition for different geographies are provided per mined metal

generic tailings from sulfidic metal mine operation
generic tailings from sulfidic nickel ore mine operation
generic tailings from sulfidic copper ore mine operation
generic tailings from sulfidic zinc-lead ore mine operation
generic tailings from sulfidic gold ore mine operation
generic tailings from sulfidic silver ore mine operation

Construction and excavation wastes, see (Doka 2020-IM)

Concrete
mineral building waste
lime residue from paper production
cast iron
cement (Doka 2020)
slag from MG silicon production
waste zeolite
sand
excavation material, clean

Old wastewaters, see (Doka 2003-I:chapter 4)

wastewater, unpolluted
glass production effluent
black chrome coating effluent
condensate from light oil boiler
tube collector production effluent
rainwater mineral oil storage
maize starch production effluent
potato starch production effluent
pig iron production effluent
concrete production effluent

lorry production effluent
ceramic production effluent

New/corrected wastewaters, see (Doka 2021-WW)

sewage sludge, average, CH 2016
wastewater, average, CH 2016
heat carrier liquid, 40% C3H8O2
LCD module production effluent
plywood production effluent 2003
wastewater from hard fibreboard production 2014
wastewater from medium density fibreboard production 2014
wastewater from particle board production 2014

Ecoinvent photovoltaics wastewater, see (Jungbluth et al. 2009)

PV cell production effluent

Ecoinvent electronics components wastewater (Hischier & Lehmann 2007-I)

wafer fabrication effluent

Ecoinvent electronic devices wastewater (Lehmann & Hischier 2007-III)

CRT tube production effluent
LCD backlight production effluent
liquid crystal production effluent

3.1.3 Creating a waste material

After having found or defined one or several waste fractions pertinent to your waste, you can now use those fractions to build waste materials. Many times, a waste material will be consisting of just one single fraction. But it can be convenient to be able to combing dissimilar, heterogeneous fractions into one single waste material (and therefore later in one single disposal inventory) instead of several.

A waste consisting of more than one fraction is called a **complex waste**. See for instance the example of a glass bottle with a paper label in footnote 4 on page 9. Another example are sealing sheets from construction which consist mainly of a polymer like polyethylene or PVC (burnable, 1% degradability) but also contain 11-14% filler (unburnable limestone, 5% degradability) and glass fibre reinforcement (unburnable, 1% degradability). With the definition of a complex waste you can have fractions with are so dissimilar in their behaviour in incineration and/or landfill combined into one single waste material, and still having accurate emissions from this waste in the disposal models.

Since the waste fractions have been compiled to sum up to 1 kg, the definition of a waste material is either the selection of a single waste fraction unchanged, or the weighted combination of several waste fractions, with the condition that the weights sum up to 1 (or 100%). For instance the waste polyethylene sealing sheet consist of 85.3% PE, 13.5% limestone, and 1.2% glass fibres, summing up to 100%. Defining new complex wastes for the Excel waste tools is described in the Calculation Manual in point 133 ff. (Doka 2023:35).

What does "inert waste" mean?

"Inert" is an attribute that is often ambiguous in the realm of LCA of waste disposal. The meaning of term "inert" can be informed by different backgrounds and lead to misunderstandings.

"Inert" in chemistry: In chemistry—probably the seminal origin—an inert material is one that does not take part in a chemical reaction in a significant way, it is inactive. It is unaffected by the chemical reactions taking place. For instance glassware in a chemistry lab is inert, not affected by most reactions taking place in them.

"Inert" in waste management: In waste management the term "inert" is used to delineate from *reactive* wastes with acute hazards of self-ignition, explosion, evaporation, corrosion, or toxicity. For safe storage and transport of a waste such distinctions are important. In a broader sense, "inert" can also mean waste materials which will not start to degrade and rot and create decomposition gasses. Inert waste can be stockpiled in less demanding waste than a reactive or quickly decomposing waste. The Swiss waste legislation of 1990 knew "inert material landfills", which basically were for excavation material and mineral building waste, which were *comparatively* less polluting and less reactive than mixed municipal solid waste or hazardous waste and had therefore less restrictions on handling and disposal.

"Inert" in pharmacology: In pharmacology an "inert ingredient" or excipient is a substance added to a medication, but is not the intended active ingredient and can help handling, dosage, preservation etc. Starch, sucrose, salts of fatty acids, or polyethylene glycol are examples of such "inert ingredients".

"Inert" in the Excel waste tools by Doka LCA: In the Excel waste tools the term "inert" was used to denote unburnable waste fractions, e.g. glass, bulk metals, stones etc. which are modelled to go into incinerator bottom ash, i.e. in contrast to "burnable" wastes.

Sometimes the term "inert" is misunderstood to mean "harmless" or "unpolluted". But this is not correct. Just because a waste is relatively *less harmful or less polluting* than another waste, we should not assume in LCA that it is *not* polluting. If a material is inert in the sense that it does not explode immediately or that its transport logistics are relatively easy, this does not mean it does not contain significant pollutant potential. In LCA we should *quantify and record* occurring emissions of pollutants and let the LCIA results inform our judgements, not *a priori* classifications. For this reason, in 2020 the inert landfill models were extended to contain the direct pollutant emissions in these types of landfills (Doka 2020-IM), while before those emissions were neglected based on an a priori judgement of a relative harmlessness. In LCA landfill models, also inert wastes lead to pollutant emissions, even if to a relatively lower degree than other wastes. And in LCA large amounts of low-emitting materials can add up to considerable burden signals. Which is why it is important to reveal also the emissions of waste deemed "inert". Inert wastes should not be thought of as "harmless", but a better way is to think of them as "slowly reacting".

The term "inert" will sometimes also be used as a greenwashing label. When for instance a cobalt mine operator declares it produces only "inert wastes" akin to rocks, but means the tailings from cobalt ore beneficiation by this, they are transgressing the boundaries of greenwashing. Tailings wastes are finely ground and therefore highly reactive, come from metal-bearing veins and have therefore elevated contents of heavy metals and other pollutants, and due to frequent sulfide content can create sulfuric acid and a low, acidic pH leachate, which mobilises those metals, leading to large acute and long-term burdens. Such a waste shall be not assessed misleadingly as "inert waste rocks", but properly with its pollutant content and the tailings impoundment models elaborated in 2018 (Doka 2018-4).

In LCA work, even if wastes were to be classified with some justification as "inert wastes" they must also be assessed waste-specifically with their pollutant content and appropriate disposal type. They cannot simply be dismissed as having no emissions.

3.2 Circumstances of waste disposal

As outlined in chapter 2.2 on page 7, the waste disposal fate depends on a range of circumstances (local possibilities, operator behaviour, waste associations).

In addition to the examples and descriptions in that chapter the following text contains more information on choosing a correct disposal process for a waste material.

3.2.1 Geography

Waste management

The geographic differences in waste management on the planet are very large. The *location* where a particular waste-producing process occurs in can therefore have a large influence on the available disposal channels. This means that a waste fate can be very different from one location to another, even if the waste material itself were identical. This is a reiteration of the statement made in chapter 2.2, that the disposal path of waste material is not decided based on material characteristics alone.[15]

Ideally for inventory work, information would be available on how wastes are disposed. This is however information often difficult to come by and associated phrases like "wastes were disposed in agreement to local legislation" inform us that apparently no illegal corruption took place, but does not really pinpoint the actual nature of the disposal technology employed, and are therefore not really useful for LCA purposes.

You should gather some impressions on the waste management practices in the geographic location where your inventoried process occurs. A web or literature search on waste disposal practices in a country will help to sharpen the understanding on the level of technology in a country. For instance hazardous wastes, which in richer countries will be usually disposed separately might well end up in municipal waste streams in poorer countries, or even be disposed of in an uncontrolled manner with open burning or dumping. Also a report like (UNEP 2015) contains information and impressions on different waste management practices around the world.

15 By contrast, in the ecoinvent v1-2.2 methodology (2003-2010) an abridged guidance was given for the disposal path of different waste materials (Frischknecht et al. 2003, Tab. 4.8). For instance all burnable wastes were sent to MSWI, or used oils to hazardous waste incineration, or all bulk metals recycled. This was based on the project's goal of creating inventories which were focussed on Switzerland and Europe, and in that framework trying to pick an appropriate, likely, and streamlined single-channel disposal per waste, when in reality probably *several* pathways would apply in different ratios. In other regions also entirely different disposal paths for those same materials can be appropriate.

Statistical data

In (Doka 2018) and (Doka 2021) the worldwide disposal practices of municipal solid waste (MSW) and wastewater have been researched for many countries, based on available statistics, estimates, or extrapolations. This compiled data can be used to estimate waste fates in those countries. Furthermore, several trends can be observed based on these data compilations. Trend analyses can be used to derive estimates for missing statistical waste management data.

Data gap estimates and predictions

While there is considerable variability between countries, generally only economically richer countries will tend to have advanced waste treatments technologies like municipal waste incineration, sanitary landfills with landfill gas capture, or three-stage wastewater treatment plants. For instance, municipal waste incineration is practically only realised in countries with Gross National Income (GNI) above 10'000 $/capita.year (Doka 2018:33). Or wastewater treatment in three stage treatment plants[16] tends to become the most frequent wastewater treatment type only in countries with GNI above 10'000 $/capita.year (Doka 2021:Fig.4.10). Sewering of wastewater—with or without subsequent treatment—is rare in countries with GNI below 10'000 $/capita.year, but plateaus on a high rate of 92% in countries with GNI above 40'000 $/capita.year (Doka 2021:Fig.4.6). Open burning, as an uncontrolled way to disposal of municipal waste, occurs almost everywhere, but tends to be more frequent in economically less rich countries (Doka 2018:Eq.3.6). Also the frequency of fires even in *controlled* landfills is higher in economically less rich countries (Doka 2018:Eq.3.12).

GNI was used in (Doka 2018, 2021) as a *predictor variable* to estimate missing statistical data that is hard to establish, from a parameter readily obtainable for many countries. For instance a missing rate of open burning of municipal waste in Congo DR can be estimated from an available GNI of 410 $/capita.year. It is important however to understand that *no causality* is implied by this estimation approach. No statement is made nor implied along the lines that "A country has first to do well economically, for it to manage waste in an advanced manner". Also the reverse statement is not made or implied like "Because this country has decided to advance waste management, it has reduced the human health damages and as a consequence prospered economically." GNI is strictly used as a predictor, which has good discerning qualities for countries and is routinely measured.

Not every waste material is in the mixed municipal solid waste bin

The waste fates mentioned in the previous section refer to municipal solid waste or wastewater. Not every waste material is in these bins. It is well possible that a particular waste material is not disposed via these bins. Some industries can also maintain their own disposal sites, for instance tailings impoundments from ore refining in the metal mining industry. The figures and charts from (Doka 2018, 2021) can give an impression of the state of the waste management in a particular country and for materials in municipal waste streams these pathways are applicable. In countries with little wastewater treatment it is probably unlikely to assume that any external treatment of industrial wastewater takes place.

[16] The three stages are mechanical (sieving, sedimentation of solids), biological (accelerated microbial degradation), chemical (precipitation).

Further refinement: rural vs. urban territories

Waste management progress is frequently more advanced in urban settings than in rural settings. This can play a role in determining the waste disposal fate for your process.

For example, waste collection is important for good waste management in a territory. Uncollected waste is likely to be disposed in an uncontrolled manner like open burning or open dumping. Waste collection is commonly more frequent in urban than in rural settings[17] and this is prominent in economically less rich countries, as shown in Fig. 3.1.

It is possible for a waste material to be not dependent on *municipal* collection. A waste material might be transported directly to a disposal site without the use of a municipal waste collection truck. But if collection rates are low and uncontrolled disposal is abundant in a country, it becomes less likely that advanced waste management is performed in direct industrial waste disposal.

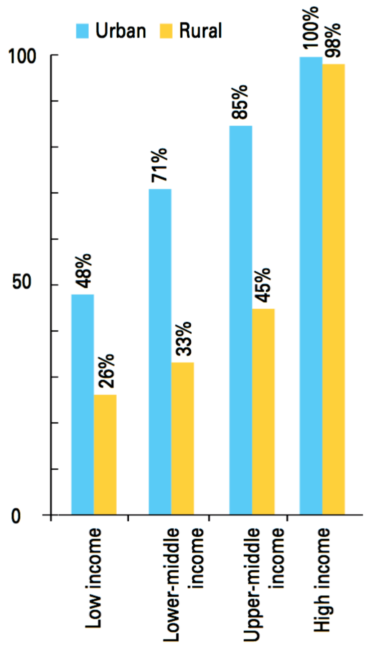

Fig. 3.1 Typical waste collections rates in urban and rural settings by income level (adapted, data from Kaza et al. 2018:33)

In another example, Maxson (2009:Tab. 17) found that open burning is three times more frequent in rural than in urban settings (Doka 2018:10ff.)

Also the rate of sewering of wastewater is larger in urban territories than in rural territories (see Fig. 3.2 with data from Doka 2021). Also treatment of wastewater is more frequent in urban territories than in rural territories (see Fig. 3.3). The ratio of the rates of sewering in urban territories over the sewering rate in rural territories shown in Fig. 3.4 denotes how much more frequent sewering is in urban vs. rural settings. This ratio can become very high especially for countries with GNI below 20'000 $/capita.year (the chart for the ratio of wastewater treatment is very similar, not shown). This means that in such countries the situation of wastewater sewering and/or treatment in an urban setting can be vastly different from the situation in a rural setting. For instance in a country with a GNI of

17 Major reasons of more frequent waste collection in urban territories is the larger urgency of avoidance of unsanitary, uncontrolled disposal in densely populated territories, but also an advantage in logistics over dispersed rural settlements.

10'000 $/capita.year it is a *factor 2 to 8 more likely* that wastewater sewered in an urban setting compared to a rural setting (middle 50% quantile).

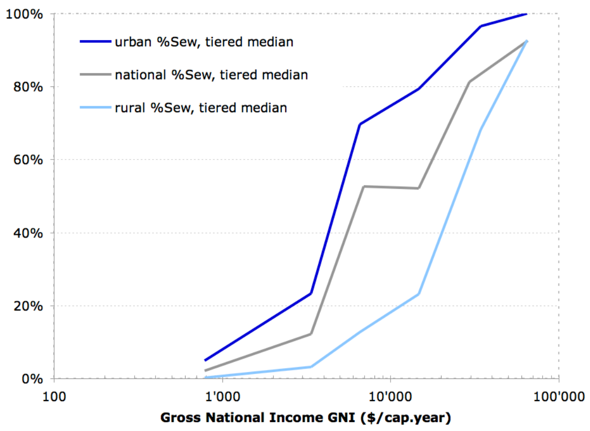

Fig. 3.2 **Typical wastewater sewering rates in urban and rural settings and national average by income level. Tiered median of classes of GNI.**

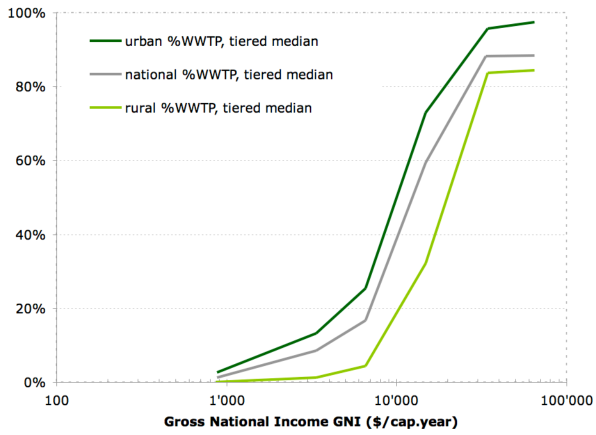

Fig. 3.3 **Typical wastewater treatment rates in urban and rural settings and national average by income level. Tiered median of classes of GNI.**

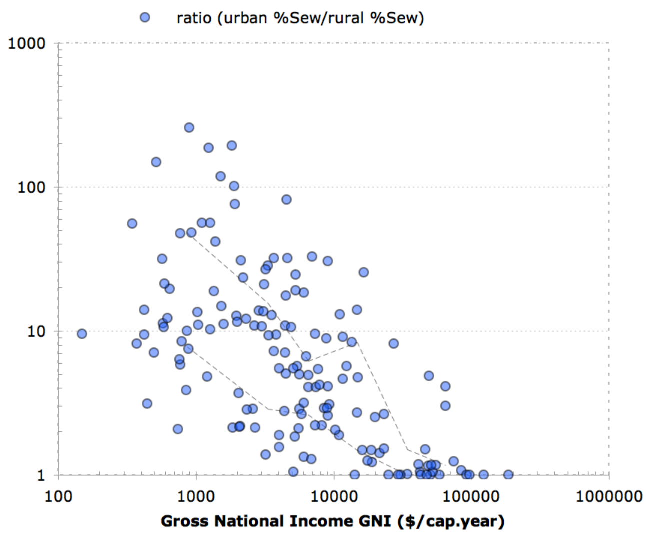

Fig. 3.4 **Ratio of wastewater sewering rates in urban vs. rural territories by income level. Lines indicate the 25% and 75% tiered quantile, respectively.**

So not only the *country* your process is located in plays a role in determining a waste management, but also whether it is in a *rural or urban territory*, or in cases where your process takes place in multiple facilities in the country, the geographic distribution of them in urban and rural settings.

The compiled data on municipal solid waste is contained in the accompanying Excel table to (Doka 2018). Data on wastewater treatment (divided into national, urban, and rural territories) is in the appendix B of (Doka 2021) as well as in sheet "GNIWWT" of the workbook "Central Repository" of the Excel waste tools.

3.2.2 Influence of local climate conditions

Since 2017 the models for landfills have been continuously regionalised. This means that leachate generation in landfills and thus weathering speed of the landfill and emissions from landfills also depend on the *rainwater infiltration at the site*. The modelling parameters require the definition of a precipitation rate and an actual evaporation rate to calculate the infiltration of water into the landfill body. So even identical waste materials in identical treatment types, say a residual material landfill, can have different emissions *depending on the local climate*. This means that for LCA work not only the waste management practices of a country play a role—as outlined in the previous section—but climate can significantly modify the results of a particular landfill type.[18] Almost all modelled treatment types have a dependence on climate/infiltration, either directly via landfill leachate, or via the disposal of higher order wastes.

- sanitary landfill
- unsanitary landfill
- open dump
- residual material landfill
- construction waste landfill
- excavation landfill
- tailings impoundments
- municipal incineration via slag compartment and residual material landfill
- wastewater treatment via sludge disposal to incineration or sanitary landfill

In wastewater treatment also water evaporation from treatment pools is calculated in a climate-dependent manner. So the only treatments where model results are *not* dependent on climate are open burning, deep underground deposits (salt mines), wastewater disposal with 0% treatment, and hazardous waste incineration, which still is based on the model of 2003.

Ideally the local climate of the pertinent country or territory is used. Doing this for every country in the world can lead to a very large number of very similar treatment datasets in a database. To avoid this, as a means of data reduction five coarse *infiltration classes* were introduced in (Doka 2018:chapter 4). With those classes the realistic range of real world infiltrations can be depicted, instead of some 200+ datasets for all of the worlds countries. It is however not compulsory to use these infiltration classes.

In landfills of mixed municipal waste (sanitary landfill, unsanitary landfill, open dump) climate data is also used to adjust a *waste fraction's degradability*. So here climate not only affects leachate volume and landfill weathering, but by influences also decay speed of the waste, which can change the model results in a different way. In locations with precipitation below 200 mm/year degradability can be significantly be reduced. In cold climates with mean annual air temperatures below –2 °C, freezing and permafrost can reduce decay speed. Both climate aspects—precipitation and temperature—can affect the modelled degradability of a waste fraction.

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[18] Of course other aspects of a technology might be not identical in different countries. For instance the gross efficiencies of energy utilization in municipal waste incineration can be variable, or the technology mix of DeNOx-stages. In sanitary landfills the capture rate of landfill gas can be variable and the subsequent utilisation/flaring.

3.2.3 Choosing the correct disposal process

Choosing a correct waste disposal for your inventory consists not only in choosing a waste material, but also make sure that the disposal pathway is realistic and appropriate for your case. When compiling an inventory you need to be aware of the disposal pathway(s) a waste material takes in the background database. In ecoinvent v1.0-2.2 datasets this is much easier than in ecoinvent v3+ datasets.

Ecoinvent v1.0-2.2 and its disposal dataset names

In ecoinvent v1.0-2.2 inventories (or more generally in EcoSpold1 datasets) a waste material and the disposal path are both declared in a disposal inventory's name. By choosing a disposal inventory one automatically also chooses the waste's disposal. A waste material can have more than one disposal path with several disposal datasets. An inventory entry like "5 kg disposal, polypropylene, 15.9% water, to municipal incineration" defines the waste material (polypropylene) and simultaneously its disposal fate, here incineration.

In EcoSpold1:	A disposal entry defines a waste material and its disposal activity e.g. ***5 kg disposal, polypropylene, 15.9% water, to municipal incineration***

This makes it very clear what kind of disposal is implied with the choice of a particular disposal inventory. In EcoSpold1 the disposal entries answer directly both important questions: of *what* is the waste material and *where* is it going to. Whether the range of waste materials and their available disposal methods available in a background database are also *appropriate* for your specific waste-generating activity is up to you or a waste disposal expert to decide.

Ecoinvent v3+ and its waste material exchanges

By contrast, in ecoinvent v3+ inventories (or in EcoSpold2 datasets) the waste output is chosen by the material's name alone. An ecoinvent v3+ inventory might have an entry like "5 kg waste polypropylene" in what is called the "undefined System Model". So the inventory entry only gives information of *what* waste material is meant, but not (yet) *where* it will be disposed.

But after a processing step by the Database Service Layer[19] this entry might be linked up to the technology mix of the disposal of that particular waste material (a.k.a. the market dataset) and that can invoke one or several disposal activities like incineration or landfilling.[20]

In EcoSpold2:	A disposal/waste output entry defines only a waste material e.g. ***5 kg waste polypropylene*** The employed disposal activity/ies will later be linked up via market datasets

So, in EcoSpold2 a waste material and its disposal activity are not automatically associated like in EcoSpold1. To make matters even more complicated, certain waste material names are only used for

[19] See https://ecoinvent.org/glossary-terms/#database-service-layer (accessed 8 May 2023)

[20] It is possible to "hardwire" a waste output to a particular disposal activity also in EcoSpold2, with so called ActivityLinks. Along with the waste output exchange, one can define the treatment activity this waste shall be treated by. But ActivityLinks are rarely used in EcoSpold2 in the "undefined System Model".

certain specific disposal paths in ecoinvent v3+. For instance, the distinction of "waste packaging paper" and "waste paper, unsorted" is not really evident from the names alone. The material "waste packaging paper" is part of the common *mixed municipal solid waste* and usually goes to incineration or landfilling. But the name "waste paper, unsorted" is actually for paper from the paper recycling bin (i.e. not the mixed municipal waste bin) and is destined for waste paper sorting and recycling (the sorting process will produce an output called "waste paper, sorted"). So with choosing either "waste packaging paper" or "waste paper, unsorted" the inventory author will pre-decide on this waste paper going either to final disposal as mixed municipal waste without any paper recycling or to a specific paper recycling activity. Only this decision is not really noticeable from the waste names alone.

Another example of waste names deciding on subsequent disposal in EcoSpold2 is "waste cement, hydrated" and "waste cement in concrete and mortar". The exchange "waste cement, hydrated" is cement used to solidify wastes in residual material landfills and will go wholly and *exclusively* to residual material landfills. The exchange "waste cement in concrete and mortar" is part of a range of building materials, and in this case includes the *demolition energy expenditure* to obtain this material from an old building and also some particulate emissions to air from demolition (cf. Doka 2003-V:Tab 3.20). That the entry "waste cement in concrete and mortar" implies inclusion of demolition energies and emissions is not noticeable from the name alone.[21] A similar example are the exchanges "iron scrap, unsorted" and "waste reinforcement steel". The exchange "iron scrap, unsorted" comes from the iron recycling bin, so largely already separated out metal wastes. The exchange "waste reinforcement steel" is a pre-demolition building waste. It represents for reinforcement steel in concrete, and its treatment will include the demolition energy expenditure to obtain this material from an old building (actually the *surplus* of energy input that reinforced concrete requires over un-reinforced concrete). These are two waste materials at very different stages. The "waste reinforcement steel" is still in the concrete within the building, and after the demolition and a sorting process could also become "iron scrap", while "iron scrap, unsorted" can come from a wide range of different processes, not only building demolition—and assigning a demolition energy to all those materials is likely misplaced, as most of them were not embedded in concrete.

So, picking the correct waste material exchange name in EcoSpold2 can decide on subsequent disposal fates and can thus be an difficult choice. You need to study the exact names of the waste materials and the activities treating those exact waste materials to make an informed choice on an appropriate waste exchange name to put in your waste-producing EcoSpold2 inventory.

Available treatment activities

A background database will usually contain a range of waste treatment activities, maybe even for the exact waste you are looking for. But just because a disposal of the material is *available* does not necessarily mean that it is the *appropriate* treatment in your case, because not only waste material identity determines treatment, but also the circumstances of its production, as outlined previously on page 7ff. You need to make sure, not only that a waste material is depicted accurately, but also that its disposal pathway is realistic. That can mean that you cannot choose certain disposal activities in the background database, even if they are available and seem to match your waste material.

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21 The EcoSpold2 waste name was derived from the preceding EcoSpold1 activities "disposal, building, cement (in concrete) and mortar, to sorting plant" which told you immediately that this is from *building disposal*. And in this case the material would go (as part of mixed demolition rubble) to a sorting plant. Another EcoSpold1 activity for the same material was "disposal, building, cement (in concrete) and mortar, <u>to final disposal</u>" which was for mixed inorganic building rubble going to landfill unsorted. Both these two disposal fates remain also in EcoSpold2/ecoinvent v3+ activities.

A misconception related to this issue occurred in the draft version of ecoinvent v1.0 in 2002 in the inventory of wind power plants. The author diligently inventoried end-of-life materials—carbon-reinforced polymers, steel, concrete etc.—and linked them up with available waste disposals. Some copper wire from the power plant's generator needed disposal too, but the only available disposal for copper was copper into *waste incineration*. Linking up the generator copper with that disposal resulted in a large LCIA burden signal for wind power—but was based on a entirely unrealistic scenario of large masses of used copper wire going into a waste incinerator. In the real world, the incinerator operator would probably not even accept such a waste, and the copper wire will more realistically going to recycling—maybe even sold. In the ecoinvent v1 methodology that meant the recycled copper could be cut off in the inventory, which was ultimately inventoried that way. Here the mere *availability* of a disposal dataset in the database misled an inventory author to use a very unrealistic disposal pathway for the waste. This is an example why circumstances of waste generation are also important to consider by inventory authors, not only waste composition.

The question might arise here, why the dataset for "copper metal in incineration" even existed in the database. The answer is that it was created for some minor amounts of copper wire, carried along with other wastes like in burnable building waste, or from electronic appliances illegally disposed in incinerators. In disposal datasets from the Excel Waste Tools, the GeneralComment of the datasets contain a text on the waste origin and recommended use of the dataset since 2013. In case of copper metal into incinerator it reads:

> *Recommended use of this dataset: For disposal of bulky, non-dust copper, which goes to incineration as part of a larger item or in small amounts only. Pure, isolated copper fractions will not be disposed in incinerators, but rather go to recycling.*

You are advised to consult these texts in the disposal datasets to inform you better on the appropriateness of a particular dataset for your application. The texts are always preceded by the phrase "Recommended use of this dataset" so you can more easily locate it.

4 Situations of activities' waste output information

Since LCA is a very flexible procedure, inventory work can pertain to a vast range of very different activities: from agricultural production or forestry, to ore mining and smelting, building activities, mere processing steps like wire drawing or plastic extrusion, energy technologies like fuel combustion or nuclear power plants, production of pesticides or pharmaceuticals, service activities like transport or Information Technology and many more. Since these are very different processes, it is also clear that any waste materials produced in those activities can be very different. Waste materials might encompass wastewaters, smelter slags, air filter ashes, demolition waste, spent packaging, or discarded products and many more. There might be inventories where waste materials are the paramount contribution to an activity's burden and there might be inventories where they are of medium or minor importance. Due to this wide range of possibilities no fixed rules can be devised, which wastes one shall focus on.[22] But some general remarks regarding inclusion of waste materials in waste-producing activities can be made.

1. In inventory work for LCA, we should strive to be completists: we should want to capture processes as detailed and as complete as possible in order to show the complete range of ecological burdens of the inventoried process—big and small. This also pertains to waste materials, where we should gather information on quantity and composition of produced waste materials in an as detailed manner as possible. Level of detail also includes elemental composition i.e. content of chemical elements, cf. section 'Composition data' on page 10. If all the information you have is that a waste output is a "sludge" or an "industrial waste" this is not sufficient for LCI. It is by comparison equivalent to someone saying that the input to a process is "a metal". Also here you would task yourself as an inventory author to find out: What metal? Copper? Aluminium? Steel? Something else? Any alloying elements? Also with waste, coarse material categories are not sufficient.

2. Data gaps are a frequent problem in LCI work. If we can't find good process data, we should strive to fill those gaps with at least some estimates or approximations, derived from similar processes or from theoretical considerations. In this, we should for mostly focus on the *environmentally relevant contributions*. There is little sense making large work efforts to fill an irrelevant data gap with some estimate, and then having no project work time left to fill a much more relevant data gap. Work efforts should be spent on the relevant contributions—not only, but to a large degree. This general advice also applies to inventorying waste materials. Any proxies used should be distinctly reported, cf. chapter 4.2.1 'Reporting proxies' on page 33.

3. Relevancy of contributions are based on their *ecological* relevance, i.e. the process' preliminary LCIA results. This relevancy depends not only on the characteristics of waste material and its treatment technology, but also on their generated amount, as well as all other burden contributions in the waste-producing process taken together. Due to this, no general advice on how to proceed can be given. When 100% is the total calculated LCIA burdens from the all direct and indirect, grey process chain contributions of your investigated process, then a contribution, say, below 1% can very probably be considered less important.

[22] This is nothing new for inventory work. Similarly, there are also no fixed rules on which *input materials* to heed for process inventories. An input material that is totally negligible in one process might be the majorly relevant contribution in another.

4. Different LCIA methods have different emphasis on environmental effects. A mere Climate Change indicator will miss out on any toxic effects or resource aspects. In waste disposal, the "classical" air pollutants like fossil CO_2, NO_x, SO_2, PM play frequently an important role, but often more important are toxic emissions to water of heavy metals and other elements, like for example Arsenic or Phosphorus. So to properly judge ecological relevance of waste disposal, you should be looking at LCIA methods that actually value this large range of different pollutants. Climate Change burdens alone are not appropriate to judge burdens from disposal. Circumspect and fully aggregating LCIA methods like ReCiPe are currently probably the best to avoid any assessment gaps.[23]

5. Generated waste *mass* alone does not decide on ecological relevance. A minute amount of a hazardous waste material might be much more relevant than the many orders of magnitude larger mass of a less polluting waste. It is up to your responsibility to know the activity you are inventorying well enough in its environmental effects to recognize and quantify such contributions.

6. Also the *type of waste material* alone does not decide on ecological relevance. Naturally waste materials with high pollutant contents should certainly be considered. But it is well possible that in a process with a small amount of some highly polluted waste output and a large amount of a, say, packaging waste the latter turns out to be the more relevant one. In a process with only packaging waste in the real world, that packaging waste automatically becomes the most relevant waste and maybe even an overall relevant process contribution. So, it cannot be said that some types of waste are always less relevant.[24]

7. Relevancy of contributions are highly situational. If a process has overshadowing direct emissions, for instance from a fuel combustion, it might well be that the contribution from waste disposal is very small. If the direct emissions of a process are small or benign, discarded waste might become a relevant contribution, even if it is the same amount, composition and treatment.

8. Just because a contribution is small does not mean its contribution shall be left out of the inventory. As LCI completists we are not removing contributions from inventories, only adding or updating with better data. If you can include a waste accurately with its composition and treatment, there is no reason to exclude it, even if the contribution is minor. You maybe had to make some estimates or approximations to establish relevancy also of small contributions. For instance you inventoried a waste PET plastic flow to incineration to stand in for a specific waste polymer output, say POM (polyoxymethylene), not available in the database. Also here it is better to *keep* those estimates in the inventory—along with a commentary—rather than retain a data gap. Such estimates serve several valuable purposes. They are evidence that you have actually considered and not forgotten the respective real world wastes. They record and show the accurate amount of this waste, which a data gap would not. The estimates can *show* in LCIA results that their relevance is actually low, which a data gap could not. They constitute a record of the way in which you have evaluated the low

23 The Swiss Ecoscarcity method (a.k.a. UBP, MOeK, MES) has intentionally no valuation of most landfill emissions and is therefore not suitable to assess disposal burdens.

24 Again, if you think about the *input side* of an inventory that same observation is very familiar. For instance, production of inorganic building materials (bricks, concrete, cement) might have less of an impact per kilogram than steel or other metals. Nevertheless in common building styles not metals will be the dominant contribution, but the inorganic building materials, because although they are less impacting *per kilogram*, their *mass per building* is very much larger than the mass of metals.

relevancy for this waste. The estimate entries will alert future readers to the fact that there is something here, which mere data gaps could not. The estimates also act as a *placeholder* for a future situation, where better data on this waste becomes available for an update. See section 2 regarding finding proxies on page 28.

Several different typical situations can occur when compiling an inventory of an activity. This is coarsely outlined below.

4.1 No waste output

Firstly, it is perfectly possible, that an activity has **no waste output** in the real world. For instance, a hydrogen combustion process might—aside from air emissions—not have any solid or liquid waste outputs, if the fuel is rather pure. But there will be waste flows from the used furnace infrastructure materials, which is commonly in a separate infrastructure activity. Or a transformation process like wire drawing could have no waste, or maybe only little waste, like lubricants.

So, no waste output in an inventory is not necessarily a mistake. But it is up to you, the inventory author, to know whether this is reasonable and appropriate.

4.2 One or several waste outputs

Secondly, waste flows can commonly occur from main product material losses, or from used auxiliary materials.

Main product material losses

If for example a chip etching process produces 60% of discard, it will have two effects:

1. a larger input flow, compared to a process without any discard
2. a non-zero waste output flow

So, in this example, for one unit of etched chip product output, an input of 2.5 units of unetched chip are required (=1/(1 – 0.6)). And 1.5 units of waste chips output are produced (= 2.5 – 1).

The applied loss rate of the main product determines the waste output. It is also possible that loss rates at various stages of an activity are reported in your raw data source.

It is imaginable that losses are recycled internally and it is the task of the inventory author to create consistent model of the process, heeding conservation of mass. It might be for instance that a real world input feed consists of 15% of internal (closed-loop) recyclate, but that does not mean that you can produce one unit from only 0.85 units of input; also the 0.15 units had at one point come from an external input, and represent only a "looped factory stock".

Used auxiliary materials

Even if you have a process with 0% loss rate of the main product, it does not mean that there are no waste outputs at all. The process might require some auxiliary material input which can be used up, like lubricating oil, solvents, catalysts, used-up machining parts etc. Auxiliary materials might have different life times and it depends on the real-world life time how frequently they are replaced. This information is required to properly calculate the required inputs of auxiliary material per product unit.

Depending on the nature of the auxiliary material, it might leave the process unchanged and therefore output mass is equal to the input mass. It is also possible that an auxiliary material changes composition as it takes up matter from the main product stream, or partly disintegrates and gives off matter into the produced good, or as emissions.

Packaging can be thought of as auxiliary material of transport and distribution.

Mass balancing principles

The descriptions above are meant to motivate you to think about the real-world sources of waste materials in your process. Basically wherever there are losses or worn-out materials replaced over time it is worthwhile for you as the inventory author to consider and know where those materials or their parts end up. Of course, not all material outputs are automatically waste materials per se. Direct emissions to air, water or soil are not considered to be wastes, but emissions.[25] Lost or worn material might also be carried off within the main product stream.[26]

The distinction of "main product material losses" or "used auxiliary material" as such is not really relevant for the consideration of the treatment of wastes. Relevant is the physical reality of a process and the actually created output materials and for you to identify them. There can be cases which are hard to separate into those two categories (are for instance slag-forming agents added to a metal smelter carrying of e.g. 1% of the target metal from ore producing a product loss waste or a auxiliary material waste?).

Thinking along mass flow networks with inputs and outputs and heeding conservation of mass will give you a clear understanding of the real world process and with help you to establish waste flows.

Waste from nothing?

Sometimes waste mass is not created from inventoried input materials but from "invisible" (meaning not inventoried) inputs: for instance ash from a combustion process can contain oxides formed from oxygen contained in the combustion air input. This oxygen input is commonly not recorded in a process inventory, but it adds very real mass to the ash waste output. If you are calculating waste outputs, such a mass increase from oxidation needs to be heeded.

Waste or by-product?

With any output materials one can ask if they represent a *waste* or a *tradable by-product*. That question depends on local circumstances and choices; see remarks on "bins available" and "binning behaviour" on page 7. A rather straightforward answer is to look at *market prices* for that material. If somebody *pays you* money to get a material from you, it is a tradable by-product. If *you have to pay*

[25] Such a misunderstanding occurred in the creation of ecoinvent v3+ activities of "treatment of brake wear emissions, lorry", which were falsely categorised as an industrial activity of "Treatment and disposal of non-hazardous waste " (ISIC number 3821) and also have their activity names structured like a technosphere waste treatment. But they do not contain any technosphere waste treatment at all, but only *direct emissions to air*. So this "activity" is merely a separate dataset containing some untreated, direct emissions of the road vehicle operation phase, and therefore firmly belongs to the industrial category of "Freight transport by road" (ISIC number 4923), and not that of a waste treatment. Also other datasets in ecoinvent v3+ have that same mistake, i.e. various "tyre wear" and "road wear" datasets of lorries or passenger cars.

[26] For instance in cement kilns the flue gas filter ashes can be added to the final product.

somebody else for them to accept the material, it is a waste material. In the latter case the material is said to have a "negative value" or a "negative price". On the boundary case of a zero price, you have a "no value" good, and it is frequently close to a waste (for instance municipal wastewater sewage sludge used in agriculture).

If a material is a *waste*, then its treatment will be part of the downstream process chain of the waste-producing activity. But if a material is a *by-product*, then your process is a **multi-output process** and you will have to consider how to deal with this situation in a manner that is compatible with the methodology of the LCA database you are working for. In the UVEK database, minor by-products are frequently simply cut off, i.e. receive no burden of the producing process chain and all those burdens are attributed to the main product. If a cut-off is used, it is helpful to document your cut-off flows, cf. chapter 4.2.2 'Reporting flows into cut-off' on page 34. Other approaches are allocation by revenue, or substitution, i.e. subtraction of credited burdens. The latter has frequently problems of lack of substitution process (there is for instance no alternative source of titanomagnetite smelting slag other than titanomagnetite smelters themselves) and violation of the 100%-rule that recombined mono-functional processes must result in the original multi-functional process. In the ecoinvent database v3+ (since 2011) the inventory authors must not decide on any allocation or multi-functionality issues; various allocation methods are applied in different SystemModels by the Database Service Layer.

Just because something is recyclable, or contains recyclable content, the material is not necessarily a tradable by-product. Many recycling operations *receive a fee* for accepting their input materials, which gives that material a "negative value" and therefore it counts as a waste. Such recycling operations are then multi-functional processes since they provide the service of waste disposal (taking up waste for a fee) as one function and they supply a tradable good (the produced recyclate material) as a second function.

Information sources on waste masses

When compiling process inventories, you should of course check your sources on any information given on waste materials. A factory's environmental report might contain for instance annual output figures. As with other inventory items, you should check their plausibility.

In process descriptions, information on waste outputs and qualities often receive less attention than information on process inputs like energy or raw materials. Maybe waste issues—at least for the main product—are implied by reporting on process yield. Waste from auxiliaries is often completely disregarded in reports from engineers, researchers and inventors.

Even when waste mass information can be found, sometimes unhelpful aggregated, or unspecific general classifications are used, like:

- Bulk waste
- Chemical waste
- Controlled waste
- Composite waste
- Commercial waste
- Degradable waste
- Fly ash
- Hazardous waste
- Industrial waste
- Inert waste
- Inorganic waste
- Municipal solid waste (MSW)
- Non-hazardous waste
- Recyclable waste
- Residual waste
- Sludge
- Slag
- Special waste

All these terms and similar ones are unhelpful as they can apply to *range of very different materials*. Since the first and foremost goal in including waste in LCA is waste-specifity (cf. chapter 2.1 on page 6), generic waste classifications like the ones listed above are unhelpful, and should not be used without further refinement into more granular and process-specific waste materials.

Also looking at existing life cycle inventories made previously by others does not guarantee that waste materials are properly included. A missing waste flow does not necessarily mean it is not there in the real world, but maybe that the author simply has not heeded it—either deliberately, or by mistake. Also an inventoried waste flow in an existing LCI had to rely on the available disposal processes of a background database and might have used a proxy at the time, but now can be replaced with more accurate data. Or a specific waste flow might have been poorly inventoried with an unsuitable generic, average one. For instance a process-specific wastewater output might just have been inventoried with an average municipal wastewater composition. Using coarse generic average waste materials is almost always not appropriate in inventory work.[27] See chapter 5.1 'Using inappropriate, average waste compositions' on page 36 .

When it comes to finding information on waste compositions and other characteristics, you can try to get information from the process operators, but likely this won't yield sufficient information. You should make a web search in trying to find elemental composition data for your waste, especially the relevant ones. Cf. remark on relevant pollutants in section 'Composition data' on page 10. Many wastes and by-products are attempted to be used as recyclates and studies might exist that detail specific process waste stream compositions. For example a metal smelting slag might be tested as an additive in cement production, and a study on this could feature a chemical analysis of the used slag.

4.2.1 Reporting proxies

If you have approximated wastes of minor importance with an similar material and disposal, it is very helpful to document those choices transparently. You might for example have real world *waste straw* output to incineration which you approximate with the available *paper* to incineration. That this "paper" represents actually "straw" should be clearly documented somewhere. Otherwise over time

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[27] The only place where generic averages—like average municipal solid waste or average municipal wastewater—are appropriate is in inventories of entire households or municipalities. Or as a mere proxy of a waste flow with demonstrated insignificant relevance.

this information is easily lost and can leave future users confused. Ideally you note the information on the real world material in the *comment to the proxy exchange* in the inventory and simultaneously also in a *report* that documents your inventory work. A possible exchange comment text can read:

> *This waste is an approximation (proxy) for a real world output of waste straw. No mass adaptations were made.*

It is good for future maintenance of this dataset to include both terms "approximation" and "proxy" to make sure this text is easily detectable with a software search. In case an adaptation of the mass was performed, e.g. to reflect a split or other adaptations, this should be noted as well, e.g.

> *... Waste mass is increased by 18% to reflect a higher water content.*

It is also advised to repeat any introduction of proxies in a text report on your inventory.

4.2.2 Reporting flows into cut-off

In EcoSpold1 any valuable by-products or minor materials going to recycling can optionally be left out of the process inventory generating them.[28] This methodological choice is called "sending a material into the cut-off".[29] The downstream fate of that material will then not be part of a processes inventory, nor will there be a multi-functionality from sold by-products (cf. section 'Waste or by-product?' on page 31). The result of the cut-off approach is that a process generating a recycled waste will not be burdened by any disposal of that waste and therefore have a comparative advantage to a process generating a non-recycled waste. In recycling processes converting the recyclable materials into actually usable recyclates the input flow comes *from* the cut-off into the process and the comparative advantage over a production process using primary materials is then that no upstream burdens from primary resource procurement and refining is required.

Even if a cut-off material is not a formal part of the compiled inventory, it is a good idea to report on the cut-off flows. There is currently no established or standardised way or location to report on cut-off flows. For the upcoming new version of the data quality guidelines for the UVEK database a proposal has been accepted (as of May 2023) that information on flows going into cut-off shall be listed in detail with amount and specific material name in the EcoSpold1 field "GeneralComment" (ID 492) (or alternatively in "IncludedProcesses" ID 402). Additionally also any cut-off flows should be mentioned in the documentation report to your inventory. No standard phrasing is defined yet but obviously the verb "cut off" or the adjective "cut-off" should occur in the text. Also cut-off outputs should be distinguished from cut-off inputs.

An example text might read like this:

> *Following output flows are cut off from this process inventory and are not associated with any indirect burdens: 0.025 kg iron scrap to recycling, 0.00123 kg zinc concentrate to zinc smelters, 2.1 MJ net heat to district heating.*

Such a comment has various functions: It informs the reader and gives a more complete process description beyond the process flows that are in the inventory. It can help to make sense of mass

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[28] The cut-off choice only applies to EcoSpold1 files and LCIs using the methodology used in ecoinvent v1-2.2. But also other allocation choices are possible in EcoSpold1/ecoinvent v1-2.2 methodology. In EcoSpold2 (ecoinvent v3+) the author must not make such allocation choices themselves directly in the inventory (in the undefined System model), but fitting allocation choices will be later applied in various SystemModel "worlds" by the Database Service Layer.

[29] It is equivalent to allocating 0% of a processes burden to the by-product(s) and 100% of the burden to the main product.

balance results. It might help future updates and adaptations of that process, if different allocation choices than cut-off are made.[30]

30 In ecoinvent v3+ many process inventories were based on the previous ecoinvent v2.2 of 2011 where cut-offs were allowed, but still many processes are not completed (status May 2023), because those previously un-inventoried cut-off flows falsely remain absent from the inventory.

5 Examples of inventory errors in waste-producing activities

5.1 Using inappropriate, average waste compositions

Since the specific waste composition is the most crucial aspect of disposal burdens, using an inappropriate waste composition for your waste material can be an important error.[31] A simple rule of what not to do is this:

"Don't use *average* waste disposal activities to depict the disposal of any *specific* waste material"

In the following, the datasets representing disposals of mere average waste into the respective treatment type are listed. Do not use these datasets as your first choice for inventory work. Choose (or create) more waste-specific treatment inventories. The datasets listed are part of the UVEK 2021 database.

(This chapter is mainly based on a internal document written in February 2023 titled "Waste disposals to avoid in LCI work".)

[31] It might be that the waste disposal is of little importance in your waste-producing process, and so the exact choice of the correct waste material has little importance either way, which—although being an error—is then not a *serious* error. But this judgement depends on the chosen LCIA method. And choosing wrong waste materials can be an important error in another process.

Treatment	Datasets	Average waste material and remarks
Municipal solid waste incineration (MSWI)	• disposal, municipal solid waste, 22.9% water, to municipal incineration	Average mixed municipal solid waste (MSW) as incinerated in Switzerland. Largely from households and small businesses. Contains some 30% kitchen and biowaste and is therefore hardly ever appropriate for industrial process waste outputs.
Sanitary landfill (SLF, VVEA Type E)	• disposal, municipal solid waste, 22.9% water, to sanitary landfill	Same as above (average mixed municipal solid waste MSW) but landfilled in sanitary landfill (reactive household waste landfill, VVEA Type E)
Residual material landfill (SLF, VVEA Type C)	• disposal, average incineration residue, 0% water, to residual material landfill	Average solid waste in residual material landfill in Switzerland (VVEA Type C). Taken from average incineration residues from MSWI incinerating average Swiss municipal solid waste (MSW), therefore not representing specific process residues.
Hazardous waste incineration (HWI)	• disposal, hazardous waste, 25% water, to hazardous waste incineration	Average mixture of hazardous waste being incinerated in HWI in Switzerland
Construction waste landfill (VVEA Type B)	• disposal, inert waste, 5% water, to construction waste landfill	Average mixture of solid waste in construction waste landfill in Switzerland (VVEA Type B). Consists of polluted soil and excavation material, mixed inorganic non-recycled building materials and other. Not suitable for "average building waste" since sans burnables (burnables are not considered "inert" in Swiss legislation).
Excavation material landfill (VVEA Type A)	• disposal, excavation material, clean, 20% water, to excavation landfill	Average mixture of solid waste in excavation material landfill in Switzerland (VVEA Type A). Mostly consists of clean excavation material.
Tailings impoundment	• disposal, non-sulfidic tailings, off-site	Tailings from metal ore beneficiation (not specific to any metal ore). Contains no emissions (2022). Replace with *specific* waste going to construction waste landfill as a proxy.
Tailings impoundment	• disposal, sulfidic tailings, off-site	Tailings from metal ore beneficiation (not specific to any metal ore). World average. Replace with specific waste of particular metal ore tailings going to tailings impoundment (Cf. work of David Turner in Turner et al. 2019).

Wastewater treatment	• treatment, sewage, from residence, to wastewater treatment, class 2 • treatment, sewage, to wastewater treatment, class 1 • treatment, sewage, to wastewater treatment, class 2 • treatment, sewage, to wastewater treatment, class 3 • treatment, sewage, to wastewater treatment, class 4 • treatment, sewage, to wastewater treatment, class 5 New datasets of 2021: • treatment, wastewater, average • treatment, wastewater, average, rural • treatment, wastewater, average, urban	Average mixed wastewater as generated in Switzerland. Largely from households and small businesses. Pollutant load dominated by human faeces and is therefore hardly ever appropriate for industrial process waste outputs. classes 1-5 refer to capacity classes of the plant: 1 = large plant, 5 = small plant. Superseded in 2021 with distinction of rural (= small size), urban (= large size), or else national (= average size)
Underground deposits	• disposal, hazardous waste, 0% water, to underground deposit	No waste-specific emissions in model (yet). Just packaging and storage expenditures. With advantage new distinct datasets for specific wastes are generated.
Landfarming	NA	No average waste to landfarming exists

5.2 Using unrealistic disposal paths

Even when the waste material is known and available, not every disposal path is realistic. Errors can be made if the dependence of disposal paths on circumstances (geography, behaviour, aggregations) outlined in chapter 2.2 on page 7, are not heeded properly.

Using municipal waste incineration for a country with little economical wealth is very likely incorrect. Municipal waste incineration is usually not available in countries with a Gross National Income below 10'000 $/capita.year.

In section 'Available treatment activities' on page 26 the error from assuming large copper masses of a wind turbine generator go to municipal incineration, instead of the recycling cut-off.

Assuming glass from a glass-reinforced polymer can be disposed in the same way as (bottle) glass recycling is unrealistic. More likely the plastic-glass aggregate is not separated and goes to incineration or landfilling—or to open burning or open dumping in economically less wealthy countries.

5.3 Using incomplete waste compositions

As mentioned in section 'Real-world waste compositions' on page 11, the waste compositions you use should contain the major and the most relevant chemical elements of your waste. Expected pollutants should not be missing. For instance, a galvanising sludge from a chromium-plating process without any chromium content is inadmissible.

5.4 Not knowing your process and nomenclature

In order to identify a waste stream you need to know how it is produced and what it is called or its synonyms. One practitioner had the task of inventorying the composition of tailings from an ore beneficiation process. Ore beneficiation takes up raw ore—i.e. metal-bearing minerals—as an input and has the goal of concentrating the target ore mineral(s) and remove unwanted, non-target minerals. Tailings are the removed non-target minerals after the raw ore has been ground into a powder and separated, usually using floatation tanks. The practitioner researched a *raw ore composition* and wanted to use it as the composition of the separated tailings waste. This was denied in a review. So the author confounded input and waste output of the assessed process, which admittedly is a very extreme misapprehension for an inventory author .

5.5 Closing remarks

The previous chapters only give some examples of errors that can occur when inventorying waste outputs. It is by no means meant to be a complete list.

6 Glossary

ASR	Automotive Shredder Residue. From End-of-Life road vehicles.
BAFU	German abbreviation of the Swiss Federal Office for the Environment (FOEN) (German: Bundesamt für Umwelt)
GNI	Gross National Income. The annual per capita income of all residents of a country. In contrast to the GDP (Gross Domestic Product) the GNI also includes income by the country's residents made abroad, but excludes domestic income claimed by foreign residents abroad.
MSW	Municipal solid waste. A mixture of waste generated in households, small businesses and commerce. Usually excludes waste from industrial operations, but definitions in countries might vary.
UVEK	German abbreviation for the Swiss Federal Department of the Environment, Transport, Energy and Communications (DETEC), standing for Eidgenössisches Departement für Umwelt, Verkehr, Energie und Kommunikation (UVEK). The UVEK maintains an LCI database for several purposes. This database is called "UVEK database" in this report.
VVEA	Swiss waste ordnance of 2016 (German: Verordnung über die Vermeidung und die Entsorgung von Abfällen).

7 References

Web addresses indicate the source of electronic documents. The subsequent (date in brackets) refers to the date of retrieval.

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