MANUAL

SWM-GHG Calculator (2023) – Life Cycle Assessment approach

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TOOL FOR CALCULATING GREENHOUSE GASES (GHG) IN SOLID WASTE MANAGEMENT (SWM)

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Preliminary Note

This manual provides background information and additional explanations on the use of the SWM-GHG Calculator. However, it is not necessary to study the manual before using the Calculator. The quickest way to learn how to utilise the tool is to start it and to follow the instructions provided.

Besides some explanatory instructions, this manual provides additional background information and basic data. The main section titles in the manual refer to the different spreadsheets in the Tool.

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List of Abbreviations

BC	Black carbon
BMZ	Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung ("Federal Ministry for Economic Cooperation and Development")
BS	Biological stabilisation
C	Carbon
CCAC	Climate and Clean Air Coalition
CHP	Combined heat and power unit
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalents (characterised GHG emissions)
DOC	Degradable organic carbon
DOCf	Fraction of DOC which decomposes
GHG	Greenhouse gas
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
kg	Kilogramme
LCA	Life cycle assessment
MBS	Mechanical biological stabilisation
MBT	Mechanical biological treatment
MCF	Methane correction factor
MJ	Megajoule
MRV	Monitoring, reporting, verification
MSW	Municipal solid waste
MSWI	Municipal solid waste incineration
NAMA	Nationally appropriate mitigation action
NDC	National Determined Contribution
OC	Organic carbon
OX	Oxidation factor
PET	Polyethylene terephtalate
PO	Polyolefins
PS	Polystyrene
PVC	Polyvinyl chloride
RDF	Refuse-derived fuel
SLCP	Short-lived climate pollutants
t	Metric tonne
WtE	Waste to energy
UNFCCC	United Nations Framework Convention on Climate Change

1 Introduction

The SWM-GHG Calculator was first released in 2009. Its purpose was to support decision makers in developing countries and emerging economies by providing orientation on GHG effects of solid waste management, and to aid in understanding GHG mitigation effects of different waste management options. A further objective was to provide a user-friendly tool. Therefore, it was developed to be Excel-based in a simple manner with mostly fixed background data for the calculations. However, users could define some boundary conditions for the most relevant treatment options, landfilling and incineration.

1.1 What is new?

Since then, the background data has changed. For example, the IPCC Guidelines for National Greenhouse Gas Inventories published in 2006, which provide a globally harmonised approach for GHG accounting, were amended in 2019. In addition, treatment options, like mechanical-biological treatment or stabilisation plants, have become more relevant in developing countries and emerging economies.

The current updated SWM-GHG Calculator takes these aspects into account, essentially it includes the following adjustments and changes:

- Characterisation factors for the Global Warming Potential (GWP) are updated with the most recent values from the 6th Assessment Report of IPCC (IPCC 2021).
- Default values from IPCC 2006 were updated according to the IPCC 2019 refinement.
- Emission factors, e.g. for recycling, were updated, and default and calculation values are now more transparently displayed on a separate worksheet “Factors”.
- Previously fixed calculation values can now be defined by users:
    - Further boundary conditions for landfills regarding methane generation and final emissions to the atmosphere.
    - Options for the use of biogas and landfill gas (CHP or biomethane generation).
    - Options for different mechanical-biological treatment or stabilisation plants.

Layout and design were changed where necessary, and some optional side calculations are provided.

The changes allow for an up-to-date and to a certain extent more accurate calculation. However, the tool can still only provide orienting information and allows a rough assessment of the climate effect of different waste management options. Consequently, it cannot represent a fully-fledged Life Cycle Assessment (LCA) or replace an Environmental Impact Assessment. Additionally, it is not suitable for monitoring, reporting and verification (MRV) of national GHG inventories or programmes because these have to follow a different methodology and/or reporting systematic. Nevertheless, it is very valuable to estimate the amount of potential GHG emissions resulting from decisions on future treatment of the current waste generated.

1.2 Outlook further or other calculation methods and tools

LCA approach and MRV Systems

The general differences between the LCA approach and MRV systems are explained, for example in (Vogt et al. 2019, Chapter 10). The LCA method for waste management is a holistic sectoral approach which includes emission savings potentials and investigates a defined waste amount, calculating all potential future emission from its treatment (especially relevant for landfilling). MRV systems are typically applied to follow mitigation actions and are used for National Inventory Reports (NIR) of Annex I Parties or Biennial Update Reports (BUR) of non-Annex I Parties[1], where countries report their yearly GHG emissions (each year or biennial). MRV systems shall comply with common international UNFCCC reporting requirements to be able to track emissions and emission reductions towards internationally agreed climate mitigation objectives (GIZ 2013). They are also required for National Determined Contributions (NDC)[2] or Nationally Appropriate Mitigation Action (NAMA). Reporting of yearly emissions also applies to GHG emissions from landfills resulting from waste quantities disposed of in previous years. In addition, in this reporting system, incineration with energy generation and biogas use are not reported under the waste sector but under the energy sector, and recycling is indirectly included in the industry sector. Crediting GHG emissions potentially saved by waste management in these other sectors is not possible in MRV systems to prevent double accounting.

Thus, landfilling of waste and considering emission savings potentials are fundamental opposites in the two methods. LCA approach and MRV systems (GHG inventories) cannot be merged to a single method. However, for emissions from waste treatment other than landfilling, interfaces between the two methods can be developed and used (see Vogt et al. 2019). In case of emission savings potentials from LCA results, an own reporting template can be established where the results are documented for information only. For emissions from landfilling, no connection is possible between the two methods as the calculation basis is completely different. Nevertheless, it is possible to use tools for the different methods complementarily.

Alternative and/or complementary tools

For MRV systems, yearly emissions from waste landfilled in the past can be calculated using the **IPCC Waste Model**. The most recent version is available on the IPCC website: https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol5.html. The tool is quite complex and it is recommended to copy or print the step by step instructions and follow them while using the tool. Depending on the starting year inserted, the tool provides yearly methane emissions from landfilling for the following 80 years. For a complementary use with the LCA approach it is recommended to insert the same basic input parameters for waste composition,

[1] Annex I Parties include industrialised countries plus countries with economies in transition. Non-Annex I Parties are mostly developing countries.

[2] NDCs are part of the 2015 Paris Agreement. All countries, irrespective if Annex I or non-Annex I, have agreed to submit their plans for climate action as NDCs by 2020 and every five years thereafter.

fraction of degradable organic carbon (DOCf), methane correction factor (MCF) and so on (see Chapter 11.6).

An overview on existing tools for MSW and GHG calculation is available on the Municipal Solid Waste Knowledge Platform of the Climate & Clean Air Coalition (CCAC) (https://www.waste.ccacoalition.org/tool). The different topics of the listed tools are briefly explained there and mainly are

- data collection tools
- tools for landfill gas emissions or landfill gas projects
- LCA tools

The data collection tools are very useful. Knowledge on waste data is the basis to get reliable results from GHG accounting. The influence of different waste data on the GHG results is for example shown in Vogt et al. (2019, Chapter 9) for different treatment options. For MRV systems, reliability of results is crucial with respect to access climate finance and participate in market mechanisms, to demonstrate to donors the emission reductions and impacts, to improve trust among the parties, and to meet reporting obligations to the UNFCCC.

The listed tools for landfill gas emissions or landfill gas projects include the IPCC Waste Model. However, the links to documents are sometimes outdated[3], some tools are as complex as the IPCC Waste Model, and sometimes it is difficult to understand underlying calculation factors. Simpler tools do exist, like the “simple model (for MSW)” from a Dutch landfill specialist[4], and such tools may exist also for other countries.

Some of the tools on the CCAC website were developed on behalf of the CCAC and address especially short-lived climate pollutants (SLCP), such as the SWEET tool. Considered SLCPs include black carbon (BC) and organic carbon (OC) which both occur from incomplete combustion. For both, available emission factors as well as GWP characterisation factors are combined with very high data uncertainties and should be reported separately from other GHG emissions (Vogt 2015). This is not the case in the SWEET tool. The presented total GWP result given in CO_2 equivalents (CO2e) must therefore be considered having limited reliability. In general, it would have been recommendable to model BC and OC emissions as parameters, providing default values with guidance for users. Otherwise the SWEET tool is well structured, assumptions and calculation values are transparently documented. GHG emissions can be calculated for up to 4 scenarios, and are provided as yearly emissions over 180 years, also per source (transport, waste burning, landfills, organics management, waste handling equipment, waste combustion) and as changes compared to the business as usual (BAU) scenario. The SWEET tool does not take into account emission savings potentials.

Among the LCA tools, the original SWM-GHG Calculator from 2009 is also listed. A similar tool is the GHG Calculator for Solid Waste (Version II, 2013) by IGES. Also similar but much

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[3] E.g. the link on the IPCC Waste Model leads to the older version before the 2019 refinement.

[4] https://www.afvalzorg.com/landfill-gas/lfg-models (30.11.22)

more complex is the Emission Quantification Tool (EQT) (Version 2, 2018) which was developed based on the IGES tool on behalf of the CCAC.

The relevance of climate zones for landfill gas emissions

In general, the calculation of landfill gas emissions from a defined waste amount landfilled follows the IPCC guidelines (2019) both with the LCA approach and with MRV systems. The difference lies in the time dependency of yearly emissions with the MRV systems which are basically defined by the methane generation rate (k) values. Simplified, the k-value defines the velocity of degradation of the DOCf in the waste landfilled. It basically depends on the climate zone (temperature and humidity) and on the type of organic waste landfilled (lignin and cellulose decompose slower than carbohydrates, proteins and fats).

The IPCC guidelines (2019) define four climate zones and recommend k values for different waste types. The most rapid degradation takes place in tropical moist and wet climate zones, followed by boreal and temperate wet zones, then tropical dry zones and are slowest in boreal and temperate dry climate zones. For the example of a defined amount of bulk waste that is landfilled, the methane generation phase is nearly completely finished in the tropical moist wet climate zone after about 50 years. In the boreal and temperate wet zone 97% are degraded after 50 years, 92% in the tropical dry zone and 87% in the boreal and temperate dry zone. After the time horizon of 100 years that is usually taken into account to assess the GWP, the cumulated GHG emissions in all four climate zones are nearly identical to the overall GHG emissions calculated with the LCA approach for this bulk waste amount.

Although, this is normally not necessary, the LCA results could also be illustrated as a time series by using the IPCC k values. This may be of help for decision makers to decide on interim measurements. For example, it might be important to assess until when at the latest currently assumed landfilling should be changed or modified to reach certain goals.

1.3 Outlook alternative treatment options (not represented in the tool)

The SWM-GHG Calculator comprises relevant treatment options for residual waste and for separately collected organic waste. Organic waste is of high climate relevance in countries where waste is mainly landfilled. Diversion from landfill is the most relevant GHG mitigation measure. Actually, any alternative organic waste management is better than landfilling even if landfill gas is collected and used.

Composting in the SWM-GHG Calculator is calculated with default emission values for methane (CH_4) and nitrous oxide (N_2O) from IPCC 2006 (no refinement 2019) which are comparably high (see worksheet “Factors”). In practice, these emissions could be much lower by respecting some important boundary conditions. Most relevant is a proper surface-volume-relation, like in triangular windrows, the right carbon-nitrogen content, sufficient aeration, and sufficient water. The best practice for low GHG emission composting is described in a guideline of the German association of quality compost (BGK 2010, only available in German).

A general pre-requisition for best practice treatment of organic waste is source segregation, as this is a key to clean waste fractions, allowing quality products and high recycling rates.

Other recycling opportunities for organic waste are for example described in (Bulach et al. 2021, in German). Treatment options of organic waste, like pyrolysis or hydrothermal carbonisation (HTC), have been discussed and tested for many years, but so far they have not been relevant in terms of volume. From a climate protection point of view, the HTC process is not favourable as it is rather energy intensive, while having a low emission savings potential. Pyrolysis is more promising provided that the input material is homogenous (mainly wood waste), and that the produced biochar substitutes wood chips, activated carbon and peat substitute as assumed in Bulach et al. (2021).

Another alternative method for organic waste described in Bulach et al. (2021) is treatment with soldier fly larvae. The soldier fly larva is a tropical feeding insect that can be used to treat organic residues and waste, especially food waste. After crushing and adjusting the water content of the input material, the young larvae are placed on the biomass and, under aerobic conditions, they transform it into a special compost, so-called "larval fertiliser", within about 12 days. During this time, the larvae grow up to the pre-pupa stage. They are then separated from the rest of the substrate and can either be used directly as live food or further processed into meal and oil. The protein-rich larvae meal can replace e.g. fishmeal for feeding. The larval fertiliser can be used in agriculture because of the improved nutrient availability due to enzymatic digestion by the larvae, if necessary after a post-composting.

For their growth, the soldier fly larvae need an average temperature of at least 20°C. For German conditions, this means a relatively high heat demand which is the main reason why the treatment process is not favourable in Germany from a climate protection point of view. The GHG emissions from treatment are higher than the emission savings potentials (net debit). However, in countries with warm climate the heat demand can at least be partly covered by the ambient temperature. In Vogt et al. (in publication), a 75% coverage of the heat demand by the ambient temperature was assumed. With this assumption the specific net result is still a net debit but much lower than for German conditions. If the heat demand could be covered by the ambient temperature throughout the year, the emission savings potential would exceed the GHG emissions from treatment. Therefore, especially in countries where the temperature is about 20°C throughout the year, the treatment with soldier fly larvae may be a high-quality alternative.

2 Background and objective

Climate change is considered one of the greatest global challenges of the 21st century. The anthropogenic emissions of greenhouse gases (GHG) are responsible for the global warming. In the Paris Agreement of 2015, nations worldwide agreed to limit global warming to well below 2, preferably 1.5 degrees Celsius, compared to pre-industrial times. To reach this goal it is important to minimise the GHG emissions in each sector as fast and much as possible.

Waste management contributes to the anthropogenic greenhouse effect primarily through emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Under the UNFCCC reporting requirements the sector “waste” is limited to direct and non-energy GHG emissions to avoid double accounting. The resulting contribution by landfilling and waste water management is reported to about 3% globally[5].

However, this contribution does not include future GHG emissions from landfilling, nor the additional GHG reduction potentials triggered by waste management that result from material recycling and energy recovery (further explanation below). The entirety of the contribution to climate protection that is achievable this way can be demonstrated with the help of the life cycle assessment (LCA) method of waste management (e.g. shown in Dehoust et al. 2010, Vogt et al. 2015).

"Recycling and energy recovery" in GHG national inventories

The effects of material recycling or energy recovery are not credited to the "Waste" sector in the GHG inventories, but are included in the "Energy" or "Industry" sectors for methodological reasons. For instance, scrap recycling is included in the industry sector under "Metal Production: Iron and Steel Production" using an emission factor for steel production in an electric arc furnace where most of the scrap is used. The resulting emissions are lower than those from other steel production methods where primary material is used. Additionally, because scrap is used for steel production less pig iron produced from iron ore is needed. Both these effects, the saved emissions due to the recycling process and the reduced emissions from substituting the extraction of iron ore and production of pig iron, are not stated separately in the GHG inventory.

In general, the contribution from recycling in the sector “Industry” is hard to quantify. There is a data gap between recycling and the use of recyclates in national productions. On the one hand, the actual losses from recycling to a recycled content are usually not known and, on the other hand exports of recycled materials or of materials to recycling are not considered in national inventory reports.

Therefore, national inventories only partially reflect the contribution of waste management activities to GHG mitigation. Developing countries and emerging economies would not only considerably reduce their GHG emissions at comparably low costs, but would also significantly contribute to improving public health conditions and environmental protection if they were to put in place sustainable waste management systems. GHG emissions produced by the waste management sector in developing countries and emerging economies are highly relevant, in particular because of the high percentage of biodegradable components contained in the waste streams. The potential to reduce GHG emissions is significantly higher than the above mentioned 3% from UNFCCC reporting. Over and above this, stepping up recycling could further reduce emissions, although it must be pointed out that the recyclable components of waste in developing countries and emerging economies are usually lower than in industrialised countries.

A study conducted on behalf of the Federal Ministry for Economic Cooperation and Development BMZ estimates that developing countries and emerging economies could reduce their national GHG emissions by around 5% merely by adopting municipal waste management systems (ifeu 2008). The authors reckon that if other waste types, especially waste containing high levels of biodegradable organic matter, in particular the residues of

[5] See e.g. “Global GHG emissions by sector”. https://ourworldindata.org/emissions-by-sector#waste-3-2 (24.10.22)

agricultural activities and the food industry or other, similar industrial wastes are included in the waste management system, the reduction of greenhouse gas emissions in these countries could be doubled, i.e. in the order of 10%. For comparison: the German waste management activities accounted for about 20% of the overall GHG reduction achieved over the period 1990 to 2005 mainly by establishing diversion from landfill through a landfill ban (Troge 2007).

The objective of the "Tool for Calculating GHG Emissions in Solid Waste Management" (SWM-GHG Calculator) is to aid in understanding the effects of proper waste management on GHG emissions. The SWM-GHG Calculator allows quantification and comparison of GHG emissions for different waste management strategies at an early stage in the decision making process. Default values allow approximations to be made even if basic data are not (yet) available. Additionally, the SWM-GHG Calculator provides guidance information on the costs associated with different waste management strategies.

The use of the SWM-GHG Calculator does not require profound professional experience in solid waste management. It can even be used by persons having only basic knowledge in the sector, e.g. by decision makers or mayors. Nevertheless, the SWM-GHG Calculator can be better used and the results are better understood the more experience users have.

3 Methodology

Basically, the calculation method used in the SWM-GHG Calculator follows the Life Cycle Assessment (LCA) method. Different waste management strategies can be compared by calculating the GHG emissions of the different recycled (typically glass, paper and cardboard, plastics, metals, organic waste) and disposed of waste fractions over their whole life cycle – from "cradle to grave", in a manner of speaking. The tool sums up the emissions of all residual waste or recycling streams respectively and calculates the total GHG emissions of all process stages in CO_2 equivalents (“CO_2e”). The emissions calculated also include all future emissions caused by a given quantity of treated waste. This means that when waste is sent to landfill, for example, the calculated GHG emissions, given in tonne CO_2 equivalents per tonne waste, include the cumulated emissions this waste amount will generate during its degradation over decades.

Figure 3-1 shows a simplified example of an integrated waste management system. At every stage of the recycling and disposal chains GHG emissions occur for each single waste fraction. Recycling activities lead to secondary products ("secondary raw materials"), which substitute for primary raw materials or conventional energy generation (WtE, "waste-to-energy"). The benefits from the substitution of primary raw materials or energy are calculated as credits according to the emissions avoided in the corresponding processes, pursuant to the LCA method. These credits are called “emission savings potentials”. They are calculated as technical substitution potentials (100% substitution of primary material disregarding market shares of secondary materials in an economy). A quantitative attribution to the national inventory reports is not possible (Chapter 11).

The accounting procedures applied for the generation of secondary raw materials encompass every stage in the process, from the separation of waste to sorting and preparing waste, as well as transport emissions. Only the emissions from waste collection were neglected because it may be assumed that emissions generated by waste collection are more or less in the same range for each scenario, as can be seen in Figure 3-1.

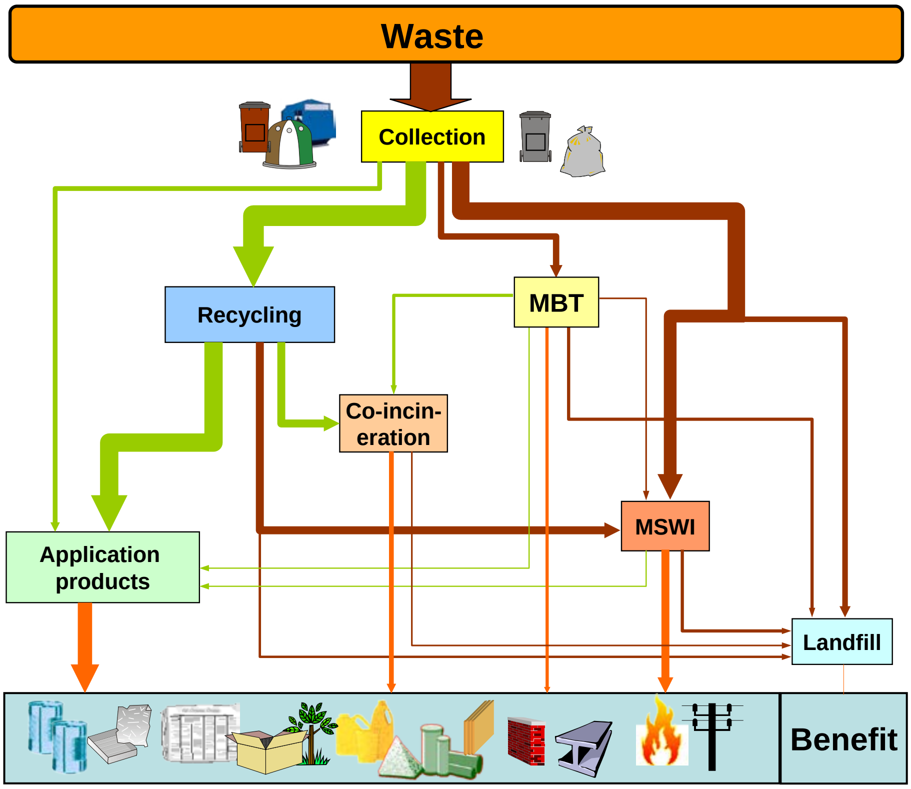

Figure 3-1 Flow diagram of an integrated solid waste management system

Source: own illustration, ifeu.

Up to four different waste management systems can be compared using the SWM-GHG Calculator; in addition to Status Quo, three user-definable scenarios can be analysed in one step. **If users want to do calculations with different waste quantities or compositions, the SWM-GHG Calculator must be copied and saved under a different name.**

For methodical and practical reasons it was necessary to design the tool by applying various simplifications. It must be emphasized that the SWM-GHG Calculator can by no means represent a fully-fledged Life Cycle Assessment (LCA). For example, most GHG calculations for the recycling chains are based on emission factors which account for specific treatment options in Germany and Europe. This is why the SWM-GHG Calculator delivers common results based on average data for recycling. Nevertheless, the variations are not serious or critical for decision making. Details of the main assumptions made are explained in this manual.

Furthermore, the SWM-GHG Calculator is not suited to calculating the anticipated quantity of Certified Emission Reductions (CER) in the framework of the Clean Development Mechanism (CDM)[6] or of Emission Reduction Units (ERU) in the framework of the Joint Implementation (JI). Firstly, the CDM and JI refer to individual projects which need to be

[6] Basic information according to the CDM procedure can be found e.g. in (UBA 2009)

calculated accurately compared to a baseline. Secondly, CDM projects often refer to landfill gas projects which address waste disposed of in the past. The SWM-GHG Calculator, on the other hand, compares different solid waste management systems or strategies based on the current waste generation. The total waste amount and its composition needs to be equal for all systems compared.

The simplifications discussed above were necessary and had to be accepted for the benefit of better manageability of the SWM-GHG Calculator. Against the background of the tool's objective – to aid in understanding the consequences of waste management activities with respect to the related GHG emissions – it serves as a valuable orientation aid. The results deliver a sufficiently accurate quantitative approximation of the GHG impacts of different strategies as an important contribution to decision making.

Even if users have no access to complete data for the situation in their region or country they can use the proposed default values to achieve a best guess. Certainly, the better the databases – especially in terms of waste quantities and composition – the better and more reliable are the results. Nevertheless, in practice waste treatment options must be thoroughly assessed in any case before realising a new project. The results of the SWM-GHG Calculator can and should provide additional information for the decision making process only.

4 Recommendations for defining scenarios

Some recommendations for defining scenarios are given, together with an example describing a possible Status Quo scenario and three waste management strategy scenarios. The exemplary scenarios are described briefly in Table 4-1.

1. All scenarios have to refer to the same region, waste quantity and waste composition.
2. Describe the Status Quo as realistically as possible. Initially collect only easily accessible or available basic input data (population figures, waste quantities and compositions, present waste disposal practice). Don’t waste time on ambitious data research. If data are not easily available, use the default values provided.
3. Define Scenario 1 as the probable future business-as-usual development scenario, e.g. solutions in neighbouring regions, solutions discussed on political and professional levels. Try to estimate the quantities of waste already being recycled, in particular by the informal sector, as accurately as possible, but do not overestimate them! Keep in mind that even comprehensive informal recycling schemes do not recover more than about 50% of the generated recyclable waste components (paper, cardboard, plastics etc.).
4. Define Scenario 2 as a more advanced solid waste management system. For example, extension of waste collection services to as yet unconnected municipalities or city quarters; optimisation of recycling activities, e.g. by cooperation with the informal sector or supportive measures; introduction of composting for selected waste streams (garden, park, market waste); possible pre-treatment/biological stabilisation of residual waste before sending to landfill.

5. Define Scenario 3 as a modern solid waste management system according to the advanced standards and strategies in some western European countries, e.g. source segregation and subsequent recycling systems, waste-to-energy strategies, etc.; stay realistic with achievable recovery rates. Figures of more than 80% - 90% material recycling are not achievable even with source segregation and very advanced strategies and technologies (see Table 7-1).

Last but not least and most important: **Play with the tool**! Try to identify what can be achieved in GHG mitigation by applying different visions for the organisation of solid waste management in your city, in your region or even in your country!

Table 4-1 Example of a Status Quo and definition of alternative scenarios

Status Quo	The Status Quo describes a typical situation in an emerging or developing country where no appropriate sanitary waste management currently takes place. Waste is partly recycled by the informal sector under difficult health conditions. Some neighbouring municipalities or districts are not yet covered by regular waste collection services. The majority of the waste is dumped on unmanaged disposal sites under anaerobic conditions producing methane; other parts are disposed of in low heaps (“scattered disposal”) under aerobic conditions, producing mainly carbon dioxide. Half of the waste is burned in open fires producing extreme air pollution.
Scenario 1: Improved recycling; disposal of residual waste to sanitary landfill	In this scenario it is assumed that a higher recycling rate can be realised and that garden and park waste is partly collected separately and composted. The remaining residual waste is mainly disposed of to sanitary landfill with a high-efficiency gas collection system (50%). The collected gas is used for electricity generation. 10% of the remaining residual waste is still scattered but no longer burned, assuming rural areas cannot be connected to the central landfill.
Scenario 2: Recycling as for Scenario 1; biological stabilisation of remaining residual waste	This scenario is similar to Scenario 1 with one important difference: it is assumed that the remaining residual waste is no longer sent to landfill directly, but is pre-treated in a stabilisation process before being discarded, thus significantly minimising the resulting methane emissions from landfill. Gas collection is therefore no longer needed. Recycling rates and connection rates to central facilities are identical to Scenario 1. In accordance with Scenario 1, 10% of the remaining residual waste is still scattered but not burned.
Scenario 3: Advanced solid waste management system	This scenario represents the most advanced solid waste management strategy. High recycling rates for dry recyclables are assumed as well as additional separate collection of food waste, which is anaerobically digested. The remaining residual waste is separated via mechanical-biological stabilisation mainly producing a refuse-derived fuel (RDF) fraction that is half each used in a cement kiln and a WtE-plant. Dry recyclables are separated in a pre-treatment step (here only metals). Additionally, an inert fraction is separated for disposal and impurities for incineration in a MSWI plant. Rural areas are connected to the system – waste scattering no longer occurs.

The percentages for recycling rates, type of biological treatment, whereabouts of the remaining residual waste and data on disposal technologies for the above described scenarios in the example used in this manual are shown in Table 4-2 to Table 4-5. These tables correlate with the input boxes in the SWM-GHG Calculator where users should insert their own data for their Status Quo and the scenarios they would like to compare. Depending on the treatment options chosen white cells in the tool will become green to indicate where further data input is needed.

Entries on worksheet "Start":

Before entering the data to define the different treatment options in the scenarios you have to insert some basic information on the Worksheet "Start" (see Chapter 6).

Entries on worksheet "Recycling":

Table 4-2 Recycling rates – Example of a Status Quo and alternative scenarios

	Status Quo	Scenario 1	Scenario 2	Scenario 3
Paper, cardboard	30%	50%	50%	70%
Plastics	30%	50%	50%	70%
Glass	10%	30%	30%	50%
Ferrous metals	40%	60%	60%	70%
Aluminium	40%	60%	60%	70%
Food waste				20%
Garden and park waste		20%	20%	20%

Table 4-3 Organic waste to recycling: composting or anaerobic digestion of separately collected organic waste – Example of a Status Quo and alternative scenarios

	Status Quo	Scenario 1	Scenario 2	Scenario 3
Composted		100%	100%	50%
Anaerobically digested				50%
Total (must be 100%)		100%	100%	100%
Biogas				
Biogas yield (m^3/t waste)				100
Methane content (Vol%)				60%
Biogas use				in %
Electricity, heat generation (CHP)				100%
Biomethane generation				
Total (must be 100%)				100%

Entries on worksheet "Treatment & Disposal":

Table 4-4 Waste treatment and disposal of residual waste – Example of a Status Quo and alternative scenarios

	Status Quo	Scenario 1	Scenario 2	Scenario 3
Scattered waste not burned	10%	10%	10%	
Open burning of waste (incl. landfill fires)	10%			
Wild dumps/unmanaged disposal site	80%			
Controlled dump/landfill without gas collection				
Sanitary landfill with gas collection		90%		
BS + landfill			90%	
MBT aerobic + further treatment				
MBT anaerobic + further treatment				
MBS + further treatment				100%
Incineration				
Total (must be 100%)	100%	100%	100%	100%

Table 4-5 Data on disposal technologies – Example of a Status Quo and alternative scenarios

	Status Quo	Scenario 1	Scenario 2	Scenario 3
Methane correction factor (MCF)				
Wild dumps/unmanaged disposal site	0.7			
controlled dump/landfill without gas collection				
Sanitary landfill with gas collection		1		
Oxidation factor (OX)		10%		
Efficiency of gas collection		50%		
Landfill gas use				
No treatment, ventilation only				
Flare				
Electricity, heat generation (CHP)		100%		
Biomethane generation				
Total (must be 100%)		100%		

Mechanical-biological treatment plants				
Output fractions MBS				
Ferrous metals				2%
Non-ferrous metals				1%
Plastics				
Glass				
Impurities to incineration plant				2%
RDF for thermal treatment				30%
RDF for co-incineration (cement kiln)				30%
Losses				30%
Compost-like output (CLO)				
Output to landfill				5%
Total (must be 100%)				100%

RDF from MBS				
Fossil carbon content (% wet waste)				9%
Net calorific value (MJ/kg waste)				10

5 Overview (Intro)

The current version of the SWM-GHG Calculator was updated and extended by ifeu Heidelberg on behalf of GIZ in cooperation with KfW based on the jointly developed version of 2009, with funds provided by the German Federal Ministry for Economic Cooperation and Developement (BMZ).

The tool is based on Excel as a very common spreadsheet application and implemented in a rather simple manner in order to allow users to quickly understand how the tool works. The tool contains brief instructions on what to do. Principally, the ambition is to retain the Excel character as far as possible because most users are familiar with this software. In addition to the instructions, further information can be found in the tool, e.g. in the reading text or in the Excel comments. Additionally, intermediate results are shown at a number of places; the respective areas in the tool can be recognised by boxes marked yellow.

The SWM-GHG Calculator comprises the following sheets (marked in green), where user input is required:

Start: Specification of basic information, waste amount, composition and characteristics and country-specific electricity grid.

Recycling: Specifications for recycling of separately collected waste, up to 4 scenarios can be compared.

Treatment & Disposal: Specifications for waste treatment and disposal, up to 4 scenarios can be compared.

Costs: Specification of costs for recycling of separately collected dry and organic waste, and waste treatment and disposal.

The results are presented on the following worksheets:

LCA SQ: Results of the Status Quo scenario

LCA Sc1: Results of Scenario 1

LCA Sc2: Results of Scenario 2

LCA Sc3: Results of Scenario 3

LCA results all: Summary comparison of the results of up to four scenarios.

Costs results all: Summary comparison of the absolute costs of up to four scenarios and mitigation costs per tonne of GHG of the scenarios 1 to 3 compared to the Status Quo

The sheets are explained in more detail in the following sections.

Basically, to work with the tool, data must be entered into the green cells.

Further (read only) worksheets provide basic information (“Intro”), calculation data (“Calculation”, “Factors”) and literature references (“Bibliography”). The worksheet “Notes” enables users to make notes or side calculation entries.

6 "Start"

Some basic data must be entered to start calculations.

On the first worksheet, "Start", these are:

- Country selection (from a dropdown list)
- Total waste amount
- Waste composition in percentages of wet weight
- Waste characteristics (classification of water content)
- Country-specific GHG electricity emission factor

6.1 Country selection

With the country selection default data for the total waste amount (grey box for optional side calculation), the waste composition and the country-specific GHG electricity emission factor are provided.

6.2 Total waste amount

The total waste amount needs to be entered in the green cell in tonnes/yr.

You can do a side calculation which is based on the country-specific waste quantity (in kg/cap/yr) combined with the number of inhabitants. Country-specific values are provided with the country selection done in step 1. The values refer to data from the IPCC guidelines 2019. In the tool, the data can be found on the worksheet "Factors". The data are either country values or regional values depending on information available from IPCC. The information is given with the default values (see screenshot), and on the worksheet "Factors" regional values (used if no country values are available) are marked in red.

Optional side calculation: total waste amount
To obtain the total waste generation in the country or region, insert the annual per capita waste generation and population in the green cells.
Note: for many developing countries IPCC recommends to multiply the per capita waste generation rates by the urban population only (see countries in italics on the worksheet "Factors", or manual, Annex)

		Default value			
MSW generation rate		440	kg/cap/yr	Country value	Source: IPCC 2019, see worksheet "Factors"
Inhabitants		45,100,000			Source: DSW 2021, see worksheet "Factors"
Result:		0	tonnes/yr		

The number of inhabitants is provided per country from the "DSW-Datenreport 2021" (DSW 2021). If the IPCC 2019 MSW generation rate is used it must be considered that "for developing countries in italics in the table, the waste generation rates should be multiplied by the urban population only." (IPCC 2019, Annex 2A.1, Table 2A.1, Footnote 2).

In case a region within a country or a city is investigated, it is recommended to enter the respective number of inhabitants in the side calculation (see screenshot above).

With the entry of the number of inhabitants and the entry of the total waste amount intermediate results are provided for information in the yellow box.

View before data entry

Intermediate result / information
Your input results in a total waste amount of
Result - total waste amount

tonnes/yr	0
kg/cap/yr	insert inhabitants in the green cell
kg/cap/day	insert inhabitants in the green cell

View after data entry

Intermediate result / information
Your input results in a total waste amount of
Result - total waste amount

tonnes/yr	2,000,000
kg/cap/yr	133.333
kg/cap/day	0.365

Please note that **1 kg/cap/day = 365 kg/cap/yr** is generally used as a conversion factor.

6.3 Waste composition

Waste composition is one of the main factors influencing GHG emissions from solid waste treatment, because different waste fractions contain different amounts of regenerative and/or degradable organic carbon (DOC) and fossil carbon. DOC is crucial for landfill gas generation, while only fossil carbon contributes to climate change in case of incineration. CO_2 from organic carbon is considered neutral to the climate because it originates from plants that bonded atmospheric CO_2. Another important aspect is the calorific value, which varies as a function of waste composition. For example, usually, the higher the organic waste content in municipal solid waste (MSW); the lower the calorific value is caused by the typically higher water content of the waste.

The calculations in the SWM-GHG Calculator are based on the total waste amount. This is necessary to assess possible waste management scenarios properly. The total waste amount is defined as the sum of waste for disposal and waste for recycling. Recycling includes activities from the informal sector.

The waste composition must be entered in percentages of wet weight. The relation to weight is more reliable than a relation to volume. It is recommended to carry out a sorting analysis whenever possible to acquire the necessary data. If no data can be provided, the default values from the IPCC 2019 guidelines can be used, which are provided with the country selection done in step 1. Here again, the data are either country or regional values as indicated (see screenshot below), and on the worksheet “Factors” regional values are marked in red.

The total of the composition must be 100%. However, the default values from IPCC 2019 often do not sum up exactly to 100%, and can be used nevertheless.

The IPCC guidelines do not provide separate values for ferrous and non-ferrous metals. Typically, the share of ferrous metals and non-ferrous metals is about 85:15. This split is used to additionally provide differentiated values (see screenshot).

Components	Default value Regional values		in % wet waste
Food waste	50.4%		
Garden and park waste	0.0%		
Paper, cardboard	12.1%		
Plastics	13.8%		
Glass	3.3%		
Ferrous Metals	4.4%	3.74%	
Aluminium		0.66%	
Textiles	5.8%		
Rubber, leather	0.0%		
Nappies (disposable diapers)	0.0%		
Wood	0.0%		
Other, inert waste	10.5%		
Total (must be 100%)	100.3%		

Default value in the example are regional values of Southern Asia

Explanations and recommendations:

- Food waste is waste from kitchens before (waste from preparation) and after (scraps, leftovers) consumption; this includes smaller quantities of animal waste.

- If no information is available to distinguish between food waste and garden & park waste it is recommended to allocate the known percentage of organic waste as 50% food waste and 50% garden and park waste.

- If information is available on quantities of cardboard composites or cardboard packaging it may be added to the waste fraction "Paper, cardboard".

- Plastics include polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), polystyrene (PS) and polyvinyl chloride (PVC).

- Aluminium is the only non-ferrous metal regarded separately here; other non-ferrous metals are of minor importance and should be included in "Other, inert waste".

- "Other, inert waste" consists mainly of mineral waste, ashes, and all other waste fractions that are not mentioned, like "fine fraction", "miscellaneous", etc. This fraction has a low carbon content (about 3%, IPCC 2019), and the calorific value is set to 0 in the calculations.

6.4 Waste characteristics – water content

The water content of waste, and consequently the calorific value, can differ significantly, having an important impact on the results when waste is incinerated. The SWM-GHG Calculator respects this dependency and users must distinguish between waste with low or high water content.

Insert "1" for either low or high water content into the green cells.

Even though "high" and "low" water content is a rather arbitrary distinction, it aids more precise calculations such that it can be assumed that the deviation due to simplification is probably no greater than the general uncertainty of the results. On the other hand, the effort required to determine the water content is relatively high and may not be possible in many developing countries.

Table 6-1 shows some indices to help judge if the waste in question has a low or high water content.

As a very rough rule of thumb a water content below 40% can be considered as low and a water content above 40% as high.

Table 6-1 Indices for low and high water content

Low water content	High water content
- The waste looks dry	- The waste is sludgy, water is oozing out
- The waste has a high ash content, e.g. in regions where people heat and cook on coal-burning stoves	- The waste has a high level of food waste caused by regional eating habits and lack of livestock to feed scraps to
- The waste has a low level of garden waste or waste from plants, e.g. in arid regions	- The waste has a high level of wet/non-ligneous garden waste or waste from plants, e.g. in humid areas
- The waste is stored under dry conditions	- The waste is stored openly, precipitation adds to the water content

6.5 Calculation of waste parameters – intermediate result

Based on the defined waste composition and the indication of low or high water content the regenerative carbon content, fossil carbon content and calorific value parameters are calculated by taking the respective carbon content and calorific value of each waste fraction and multiplying with the percentage of each waste fraction. The low and high water content are considered for the organic waste fractions, because these fractions usually vary most in water content. Other waste fractions such as paper/cardboard, plastics, glass, metals and textiles usually have a fairly stable water content and can be specified with fixed calorific value.

All calculation processes are shown transparently on the "Calculation" worksheet in the SWM-GHG Calculator.

Table 6-2 Carbon content waste fractions - Total and fossil carbon

Fraction	C total	C fossil
	% wet waste	% of total C
Food waste	15.2%	0%
Garden and park waste	19.6%	0%
Paper, cardboard	41.4%	1%
Plastics	75.0%	100%
Glass	0%	0%
Ferrous metals	0%	0%
Aluminium	0%	0%
Textiles	40.0%	20%
Rubber, leather	56.3%	20%
Nappies (diapers)	28.0%	10%
Wood	42.5%	0%
Other, inert waste	2.7%	100%

Source: IPCC 2006, no refinement in IPCC 2019

Table 6-2 shows the percentages used for total and fossil carbon content of the waste fractions according to (IPCC 2006). Table 6-3 shows the calorific values of the waste fractions used in the calculations. The table also shows the estimated water content of organic waste in case of a low or high water content.

Table 6-3 Calorific value waste fractions

Fraction	Calorific value	
Organic waste low water content	4	MJ/kg wet waste
Organic waste high water content	2	MJ/kg wet waste
Paper	11.5	MJ/kg wet waste
Plastics	31.5	MJ/kg wet waste
Glass	0	MJ/kg wet waste
Metals	0	MJ/kg wet waste
Textiles, rubber, leather	14.6	MJ/kg wet waste
Wood	15	MJ/kg wet waste
Other, inert waste	0	MJ/kg wet waste

Source: (AEA 2001); wood and other, inert waste ifeu estimate

The results of the calculations for calorific values and regenerative and fossil carbon content are shown in the tool for information. They are shown in the yellow box.

Intermediate result / information

The defined waste composition and water content
lead to following physical properties of the total waste:

Result - calorific value and carbon content of total waste

Calorific value	in MJ/kg	8.6
Total carbon content	in % wet waste	25.6%
Fossil carbon content	in % wet waste	11.1%
Regenerative carbon content	in % wet waste	14.5%

If the cell for the calorific value indicates "wrong", please check that the question on water content was answered correctly. “1” needs to be inserted in one of the cells.

Carbon content and calorific value are important parameters in many ways. As explained in Section 6.3, the organic and fossil carbon content influence the GHG emissions results. The calorific value is an important indicator for the combustibility of the waste. However, the results calculated and shown in the SWM-GHG Calculator are never reliable or representative enough to decide whether waste is appropriate for incineration or for waste management strategy decisions. More precise information acquired by detailed analysis of the waste is needed for decision making. The most important parameters that must be known are combustible matter, ash and water content. Based on these three parameters the calorific value can be assessed with the help of what is called the fuel triangle (Figure 6-1). The triangle combines the three parameters in a graph that shows whether a waste is capable of self-sustaining incineration (red area) and indicates the respective calorific value.

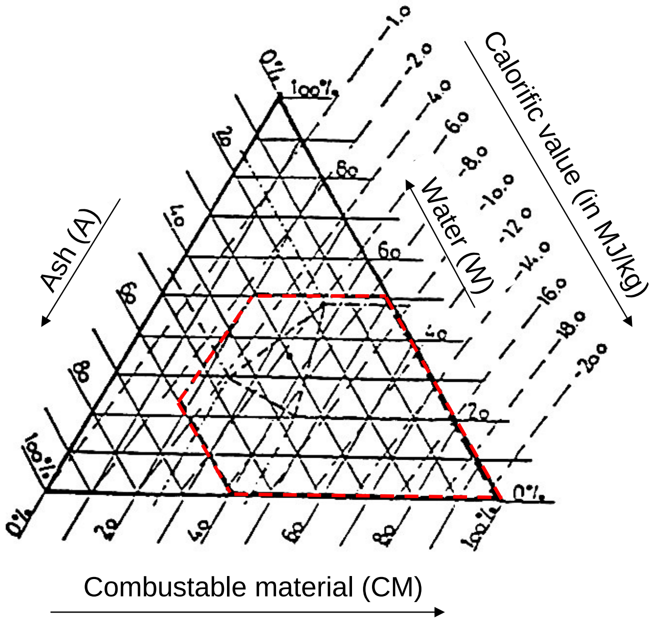

Figure 6-1 Fuel triangle

As a rough rule of thumb it can be assumed that self-sustaining incineration is difficult or no longer possible if the calorific value of a waste is < 6 MJ/kg. As discussed above, in practice waste should be thoroughly tested for incineration suitability.

Furthermore, the heavy metal, sulphur and halogen contents in particular have a considerable impact on flue gas cleaning requirements and incineration costs. Determination of these parameters requires in-depth surveys of waste composition, and physical and chemical analyses.

6.6 Country-specific GHG emission factor for generation of electricity

Electricity generation produces GHG emissions. Usually, these are direct emissions from fuel combustion (mainly CO_2 from oxidation of the fossil carbon in the fuel) and indirect emissions from the supply of fuels, e.g. methane emissions from the mine during hard coal mining. Overall, the specific quantity of GHG emissions per kilowatt hour electricity depends on the energy carriers or mix of energy carriers used for electricity generation. The highest GHG emissions result from coal and oil as they have the highest fossil carbon content relative to energy content. The lowest GHG emissions from fossil fuels result from natural gas because natural gas has a low carbon content relative to energy content. Almost no GHG emissions at all result from such renewable energy sources as wind or water and from nuclear power plants, as in these cases no fossil carbon is burned.

The tool provides default values for country-specific GHG electricity emission factors according to the IFI Methodology (IFI 2022) with the country selection in step 1. **However, these values should be considered with caution as they do not represent the current electricity grid mix in a country.** The IFI methodology/approach accounts for project emissions associated with grid electricity consumption and takes into account future developments. The values provided in the tool are factors for "electricity consumption" which refer to the combined margin grid emission factor consisting of an operating margin (33%) and a build margin (67%):

- The operating margin represents the cohort of existing power plants whose operation will be most affected (reduced) by the project.
- The build margin represents the cohort of the prospective/future power plants whose construction and operation could be affected by the renewable energy project, based on an assessment of planned and expected new generation capacity.

In some cases the combined margin grid emission factor is even 0 (e.g. Albania, worksheet “Factors”).

Nevertheless, these data source is provided in the tool (worksheet “Factors”) as it is the only publicly available harmonized data set for a longlist of countries and offers at least an orientation in case users do not know and cannot identify the specific GHG electricity emission factor in the country under investigation. **If you are not sure what to choose please do not hesitate to make a best guess or try two different values to see the difference in the results.**

In addition, further data sources may be consulted which provide GHG electricity factors for some countries:

1. carbon footprint 2019, country specific electricity factors in kg CO2e per kWh for countries and territories, https://www.carbonfootprint.com/docs/2019_06_emissions_factors_sources_for_2019_electricity.pdf

2. IGES 2022, List of Grid Emission Factors, excelfile for download with operating, build and combined margin (similar to the IFI methodology) for CDM countries in t CO2/MWh, https://www.iges.or.jp/en/pub/list-grid-emission-factor/en (21.11.22)

3. AIB 2021, European Residual Mixes, and production mix and supplier mix for European Countries in g CO2/kWh (e.g. Figure 4), https://www.aib-net.org/sites/default/files/assets/facts/residual-mix/2021/AIB_2021_Residual_Mix_Results_1_1.pdf

A profound source for GHG emission factors for World countries from electricity and heat generation is the International Energy Agency (IEA)[7]. However, these data are not publicly available but must be purchased.

The CO_2 emission factors for electricity production are not only used to calculate the GHG emissions from electricity demand, but also to calculate the benefit from electricity generated by a waste treatment technology (e.g. incineration).

[7] https://www.iea.org/data-and-statistics/data-product/emissions-factors-2022 (21.11.22)

7 "Recycling"

On the "Recycling" worksheet you are asked for the recycling rates of different waste fractions, which have been separately collected (e.g. from households, by informal sector from different places)[8] and additionally for the type of treatment in the case of organic waste:

- Recycling rates for dry materials
- Recycling rates for organic waste (food waste, garden and park waste)
- Share of composting and anaerobic digestion of recycled organic waste
- Biogas generation and use in case of anaerobic digestion

7.1 Dry materials

Dry waste fractions that are considered in the SWM-GHG Calculator are

- Paper, cardboard
- Plastics
- Glass
- Ferrous metals
- Aluminium

The share to recycling asked for in the SWM-GHG Calculator corresponds to the amount per waste fraction (Figure 7-1).

Example – share to recycling for paper, cardboard:

The total waste in a region is 1,000,000 tonnes per year The share of paper and cardboard in the total waste quantity is 10% = 100,000 tonnes per year The share to recycling defines how much of these 100,000 tonnes of paper and cardboard in the total waste is collected separately for recycling. ➔ If 30,000 tonnes of paper, cardboard are recycled per year, then the share to recycling is 30,000/100,000 = 30% and this value must be entered into the green cells.

The share to recycling should include the activities of the informal sector. Therefore, the waste quantity that is already separated by the informal sector must be included in the calculation.

[8] Recyclable material that is sorted out from residual waste through treatment in mechanical-biological treatment plants are addressed on the worksheet “Treatment & Disposal”.

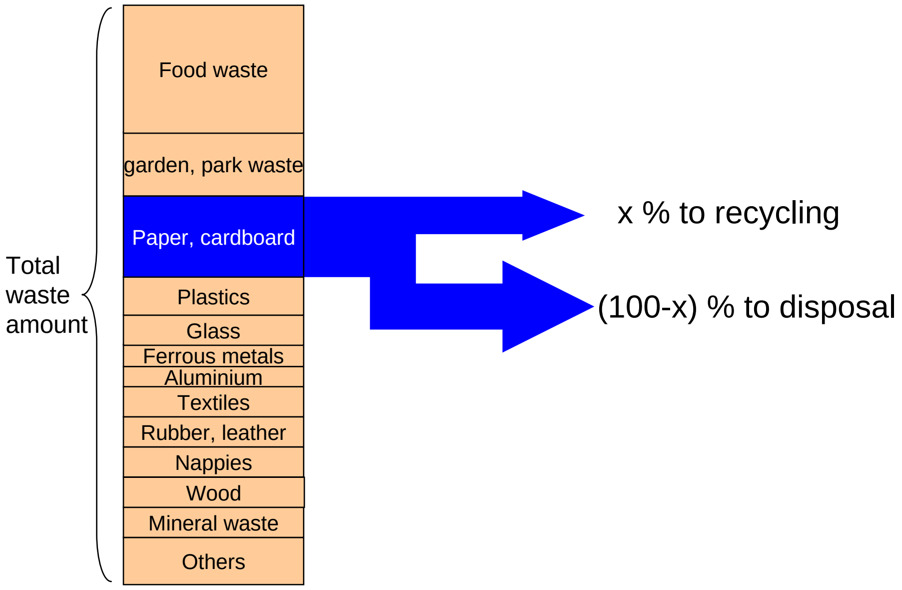

Figure 7-1 Example recycling rate for paper, cardboard

In contrast to the "*share to recycling*" the "*recycling rate*" refers to the amount finally recycled, i.e. the secondary raw material and/or product which is generated through recycling and used in production processes. This differentiation is especially relevant for plastics where treatment residues from recycling can be about 30% or even more, depending on the collection system and the recyclability of plastic products.

Shares to recycling and recycling rates vary from country to country and it is not possible to provide default values. Usually, countries with integrated waste management systems have high recycling rates. Table 7-1 shows the recycling rates for waste fractions in the EU27 (Prognos, CE Delft 2022), for Germany (ARGUS, Öko-Institut, HTP 2019) and one older source for Mexico in 2004 (SEMARNAT/INE 2006). The recycling rates for the EU27 and for Germany correspond to the explanation given above and refer to the amount of secondary raw materials produced from separately collected material.

Table 7-1 Recycling rates in the EU27, in Germany, and in Mexico

	EU27	**Germany**	**Mexico**
	Prognos/CE Delft 2022	ARGUS/Öko-Institut/HTP 2019	SEMARNAT/INE 2006
Glass	67%	92%	13%
Paper, cardboard	57%	94%	16%
Plastics	15%	42%	8%
Ferrous metals	83%	93%	80%
Aluminium	75%		
Wood	35%	15%	
Textiles	15%	89%	
Organic waste	24%	71%	3%

7.2 Organic waste composting and/or digestion

Organic waste considered in the SWM-GHG Calculator is:

- Food waste
- Garden and park waste

The recycling rate for organic waste must be entered analogous to dry material. The SWM-GHG Calculator calculates two treatment options for organic waste: composting and digestion. The next step therefore asks how much of the recycled organic waste is either composted or anaerobically digested; as a simplification the two organic waste fractions are not distinguished further.

Example – recycling rate and type of treatment organic waste

The total waste amount in a region is 1,000,000 tonnes per year
The share of food waste in the total waste is 40% = 400,000 tonnes per year
The share of garden and park waste in the total waste is 15% = 150,000 tonnes per year
The share to recycling for food waste is 20% = 80,000 tonnes per year
The share to recycling for garden and park waste is 50% = 75,000 tonnes per year
➔ In total 155,000 tonnes of organic waste are collected for recycling per year
The next step asks how much of the 155,000 tonnes of organic waste is either composted or anaerobically digested
➔ If 15,500 tonnes of the organic waste are digested and the rest is composted, then 15,500/155,000 = 10% must be entered into the green cells for anaerobic digestion and 90% for composting.

If organic waste is recycled the sum of organic waste anaerobically digested and/or composted must be 100% in any case. In case of anaerobic digestion further information are needed with regard to the biogas generation and use (white cells will become green). The default values provided refer to a mix of food waste and garden & park waste resulting from separate collection from households. The biogas yield is higher with organic waste rich of fats and oils. The range of the methane content is typically between 50 and 70 Vol%, the former for carbohydrates, the latter for proteins and fats.

7.3 Intermediate results – waste parameters of remaining residual waste

The shares to recycling defined change the composition of the remaining residual waste and consequently the waste characteristics. For your information, the corresponding calorific values and regenerative and fossil carbon content of the remaining residual waste are now presented as intermediate results, which are shown in the yellow box. Further calculations for treatment & disposal are in terms of this elementary composition of the remaining residual waste. In addition, the result for the overall share to recycling in relation to the total waste generated is shown in the upper part.

	Status Quo	Scenario 1	Scenario 2	Scenario 3
Result: the recycled share of the total waste generated in %	10%	17%	17%	33%

Intermediate result / information

Separate collection changes the original waste composition, the recycling rates you inserted lead to the following physical properties for the remaining residual waste:

Result - carbon content of total waste		Status Quo	Scenario 1	Scenario 2	Scenario 3
Calorific value	in MJ/kg	7.6	6.9	6.9	6.2
Total carbon content	in % wet waste	23%	21.5%	21.5%	19.9%
Fossil carbon content	in % wet waste	9%	7.1%	7.1%	5.8%
Regenerative carbon content	in % wet waste	14%	14.4%	14.4%	14.1%

7.4 Recycling – treatment processes and GHG emission factors

GHG emissions for the recycled waste fractions defined in this step are mainly calculated based on the mass of waste recycled and a GHG emission factor. The GHG emission factors used are shown in the annex (Chapter 14.1). They correspond to the European level, and are described briefly in the annex.

An exception are GHG emissions from anaerobic digestion. These are calculated per scenario as the biogas generation and use are user defined parameters. Further background data for the process and the calculation are also described in the annex.

8 "Treatment & Disposal"

On the worksheet "Treatment & Disposal" you are asked for the type of disposal of the remaining residual waste, and some data on disposal technology.

- Options for waste treatment and disposal
- Data on disposal technologies – landfill
- Data on disposal technologies – Incineration
- Data on disposal technologies – Mechanical-biological treatment

The remaining residual waste is the waste that remains after recycling material has been extracted from the total waste either by the informal sector or by separate collection (see Figure 7-1 "(100-x)% to disposal").

Example – remaining residual waste

> The total waste amount in a region is 1,000,000 tonnes per year
>
> The total waste recycled is 300,000 tonnes per year (sum of paper, cardboard, plastics, glass, ferrous metals, aluminium, food waste, garden and park waste to recycling)
>
> ➔ The resulting remaining residual waste is 1,000,000 - 300,000 = 700,000 tonnes per year.

You must indicate the type of treatment for this amount of remaining residual waste on the worksheet "treatment & disposal".

8.1 Options for waste treatment and disposal

Manifold treatment types and technologies exist. Some should be avoided at all costs as they pose health hazards to the population and damage the environment, some are very simple but at least less hazardous, and finally there are sophisticated or advanced treatment technologies. The treatment technologies represented in the SWM-GHG Calculator are listed below.

The first group includes common present practices that should be avoided at all costs. They affect waste which is not regularly collected but usually scattered or delivered to a wild dump site. Additionally, scattered waste is sometimes burned in the open (including directly at households), producing huge amounts of extremely toxic substances (in particular dioxins, furanes, aromatic hydrocarbons ...).

1) Scattered waste not burned
2) Open burning of waste (incl. landfill fires)
3) Wild dumps/unmanaged disposal site

The second group is that of simple treatment and disposal technologies. Apart from disposal to controlled landfills this includes simple biological stabilisation (BS) before disposal whereby methane emissions are reduced.

4) Controlled dump/landfill without gas collection
5) Sanitary landfill with gas collection
6) BS + landfill

The third group includes advanced technologies. Apart from waste incineration this includes treatment options with the purpose of separating recyclable fractions out of the residual waste before stabilising the remaining waste biologically prior to sending to landfill or to produce a refuse-derived fuel that may be co-incinerated, e.g. in cement kilns.

7) MBT[9] aerobic + further treatment
8) MBT anaerobic + further treatment
9) MBS[10] + further treatment
10) Incineration

The total of the percentages of waste treatment and disposal options entered must equal 100%.

All treatment types and technologies mentioned are described briefly in the Annex (14.2).

---

[9] Mechanical-biological treatment

[10] Mechanical-biological stabilisation

8.2 Data on treatment & disposal technologies

The tool requires some important parameters to be defined:

a) related to landfill:

- Methane correction factor (MCF)
- Oxidation factor (OX)
- Efficiency of gas collection
- Landfill gas use

b) related to incineration plants

- Net efficiency of energy utilisation

c) related to mechanical-biological treatment plants

- Output fractions from treatment
- Characteristics for produced refuse derived fuels (RDF)

The methane correction factor (MCF) determines the share of methane generated depending on the conditions of the landfill. In case of different type of landfill sites it is recommended to assess a weighted average. For this an optional side calculation is provided in the tool, and default values from the IPCC (2019) guidelines are given (see screenshot).

Optional side calculation: MCF specification

Insert the shares	Default values	Type of site
	1	Managed - anaerobic
	0.5	Managed well - semi-aerobic
	0.7	Managed poorly - semi-aerobic
	0.4	Managed well - active aeration
	0.7	Managed poorly - active-aeration
	0.8	Unmanaged - deep (>5m waste) and/or high water table
	0.4	Unmanaged - shallow (<5m waste)
	0.6	Uncategorized SWDS
	Total (must be 100%)	
Result:	**0**	**weighted MCF**

The MCF has to be defined for all landfill options. The following parameters are only relevant for sanitary landfills which are well-managed or which have gas collection systems. Further explanations on the parameters can be found in the Annex (14.2.5).

The oxidation factor (OX) determines the share of methane generated which is oxidised in case of sanitary, well-managed landfills which are covered with oxidising material (e.g. soil, compost).

Efficiency of gas collection in this context means the share of all potential methane generated from a given quantity of waste that can be captured, or in other words the ratio of collected landfill gas to the total generated landfill gas from a given quantity of waste.

Treatment options for collected landfill gas are: no treatment or ventilation only, flaring, electricity and heat generation (CHP) and biomethane generation. The total of the percentages of gas treatment you entered must equal 100%. In addition, it is asked for the efficiency of flaring.

As mechanical-biological treatment (MBT) plants three types are differentiated: an aerobic MBT, an anaerobic MBT and a MBS. The MBT mainly aim at stabilising separated organic material through composting (MBT aerobic) or anaerobic digestion (MBT anaerobic), the MBS mainly aims at producing a RDF fraction. To specify the process for further calculation the share of output fractions must be inserted in the green cells as well as the fossil carbon content and the net calorific value of the produced RDF fraction (cells will become green if the respective treatment option is chosen). The default values provided refer to the average output of German plants in operation. Some other example values and further information on the treatment technologies are provided in the Annex (14.2.7 to 14.2.9).

For the net efficiency of energy utilisation through waste incineration default values are provided in the tool. Further information on the process and the default values are given in the Annex (14.2.10).

9 "Costs"

Typical default cost figures for the different activities have been deduced here from literature, data and empiricism. You can use the given default values, but if specific local data are available, these should be used preferably. The default values represent a rough orientation about average total costs ranges (dynamic prime costs). They can vary strongly depending on the size of plants, selected operator models, local prices and salaries and GDP of the country.

The costs of establishing collection systems are also assumed to be required in each scenario and are not taken into account.

Costs for recycling are the effective net costs already including revenues from sales of materials or energy. Collection costs are not included here and have to be covered through other means, for example municipal waste fees, national subsidies or contributions from extended producer responsibility (EPR) systems. Municipalities have to take care that costs for public relations, the provision of bins and/or bags for the collection of recyclables, administration costs, etc. are sufficiently covered.

Table 9-1 shows a range of minimum and maximum costs per tonne of waste for the different treatment options included in the SWM-GHG Calculator. The values can also be found in the SWM-GHG Calculator. They following publications have been used to determine common cost ranges:

- World Bank 2018: What a Waste 2.0, What a Waste 2.0 : A Global Snapshot of Solid Waste Management to 2050 (worldbank.org)
- Pfaff-Simoneit, W. 2012: Entwicklung eines sektoralen Ansatzes zum Aufbau von nachhaltigen Abfallwirtschaftssystemen in Entwicklungsländern vor dem Hintergrund von Klimawandel und Ressourcenverknappung, Sektoraler Ansatz Abfallwirtschaft Entwicklungsländer (uni-rostock.de)

- UNEP/ ISWA 2015: Global Waste Management Outlook, Global Waste Management Outlook | UNEP - UN Environment Programme

Table 9-1 Dynamic prime costs (DPC) – Default values for treatment options

Costs in Euros/t waste	Min	Max
Controlled dump/landfill without gas collection	3	20
Sanitary landfill with gas collection	10	40
BS + landfill	15	35
MBT aerobic + further treatment	25	65
MBT anaerobic + further treatment	35	70
MBS + further treatment	50	80
Incineration	70	150
Recycling of dry waste	0	30
Composting[1)]	5	50
Anaerobic digestion	30	100

Explanation of dynamic prime costs

Dynamic prime costs are the discrete total annual costs (capital costs, operating costs, additional costs, replacement investments, etc.) accumulated over the calculated lifetime of the investment, discounted to year 1 of the investment, divided by the cumulated annual discounted total quantity of waste being treated over this period. The dynamic prime costs correspond to the theoretical gate fee which an operator needs to charge to cover the total emerging costs including interest for treatment/disposal of the waste in the plant in order to balance surpluses and shortfalls over the total operating period.

10 "Results"

The results from the data entered and from the calculations as explained above are shown on different worksheets in the SWM-GHG Calculator:

Results for one scenario:
- "LCA SQ": results of GHG emission balance for the Status Quo
- "LCA Sc1": results of GHG emission balance for Scenario 1
- "LCA Sc2": results of GHG emission balance for Scenario 2
- "LCA Sc3": results of GHG emission balance for Scenario 3

"LCA results all": GHG emission balance scenario comparison – waste quantities, GHG emissions.

"Costs results all": Scenario comparison – annual costs and specific GHG mitigation costs.

10.1 Results for each scenario

First of all, all results referring to one scenario are shown on a separate worksheet. The worksheet is structured as follows:

- Waste treated in t/yr
- Results for GHG emissions recycling and disposal in t CO_2-eq/yr
- Results for absolute costs for the calculated scenario
- Results for specific costs per t CO_2-eq for the calculated scenario

Waste treated in tonnes per year are shown in a table, a bar chart and as a mass balance diagram.

Results for GHG emissions recycling and disposal are shown in a table and a bar chart (Figure 10-1). This figure shows the results for a theoretical Status Quo scenario as described in section 4. The bar chart shows the results separately for recycling and for disposal activities and also as the sum of both components ("Total MSW"). The first bar in the figure indicates the GHG emissions caused by recycling (Debits). The second bar represents the emission savings potential by recycling (Credits, negative values). The third bar shows the net effect, i.e. the difference between debits and credits (Net).

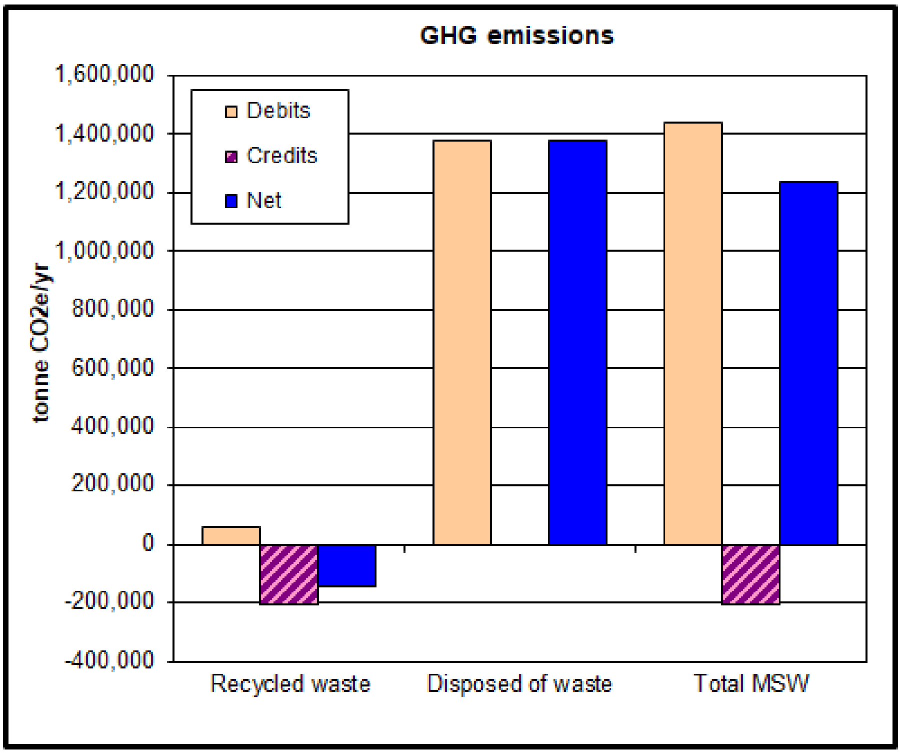

Figure 10-1 GHG emissions in a theoretical Status Quo scenario

Additionally, the results for GHG emissions are shown in more detail both for recycling (Figure 10-2) and for disposal (Figure 10-3).

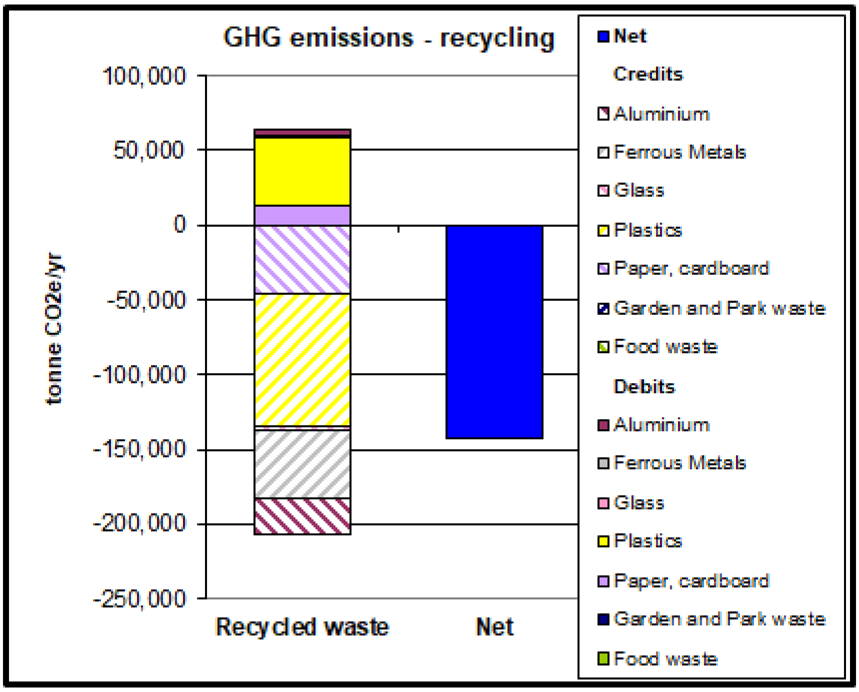

Figure 10-2 GHG emissions by waste fraction - recycling

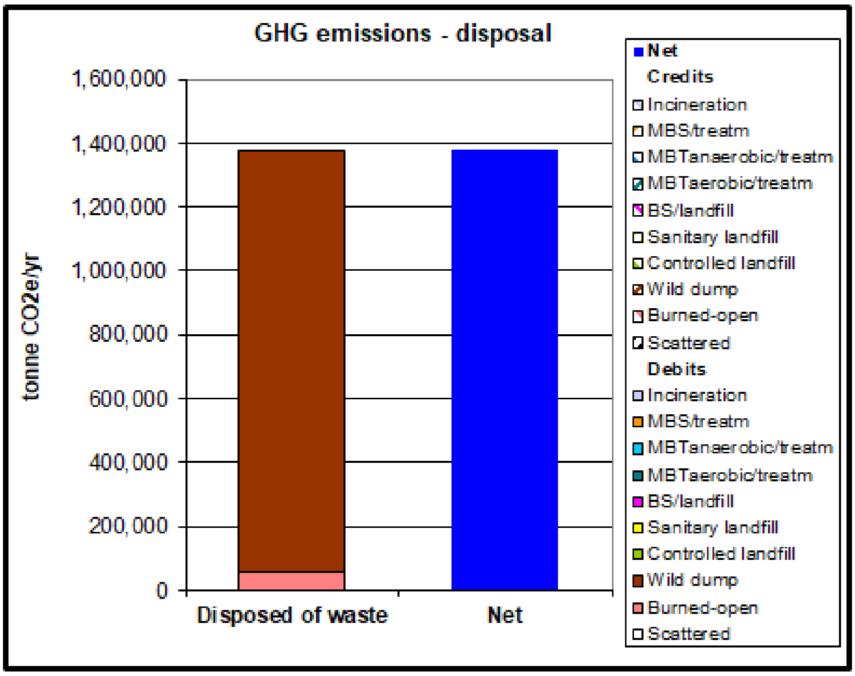

Figure 10-3 GHG emissions by treatment option - disposal

In the recycling figure (Figure 10-2) the bars with "Debits" and "Credits" are itemised into results for each recycled waste fraction. Thus the positive values in the first bar ("recycled waste") show the debits (GHG emissions from recycling of plastics, paper and aluminium, the contribution of the other fractions is too small to be visible) and the negative values in the first bar show the credits (with the highest contribution made by plastics and paper, followed by ferrous metals and aluminium recycling). The second bar ("net") again represents the net result, the difference between positive (debits) and negative (credits) values, and is identical to the net result for "recycled waste" in Figure 10-1.

In the disposal figure (Figure 10-3) the bars with "Debits" and "Credits" are itemised into results for each type of treatment. Similar to the example for a Status Quo scenario MSW is scattered and open-burned to each 10% and 80% is disposed of to wild dumps. Only open burning and wild dumping contribute to the result causing positive values (debits) in the first bar ("disposed of waste"). No benefits are derived from these treatment options, therefore no credits or negative values are seen. The second bar ("net") again represents the net result, the difference between positive (debits) and negative (credits) values, and is identical to the net result for "disposed of waste" in Figure 10-1.

Results for absolute costs and specific costs per t CO_2e are shown in tables.

10.2 "LCA results all"

This worksheet shows the results for the waste mass flows and the GHG emissions for all calculated scenarios. The upper part shows a table and a bar chart comparing the waste quantities treated in each scenario. The results for the GHG emissions are also shown in a table below and additionally in two bar charts. From the total net results in tables also the GHG mitigation relative to the Status Quo scenario is given.

The examples shown below correspond to the results for the scenarios as defined in section 4. The first diagram (Figure 10-4) compares the four scenarios and shows the results in the same manner as in Figure 10-1. The first bar (Debits) shows the total GHG emissions in the Status Quo scenario, the second bar the credits, and the third bar the net result.

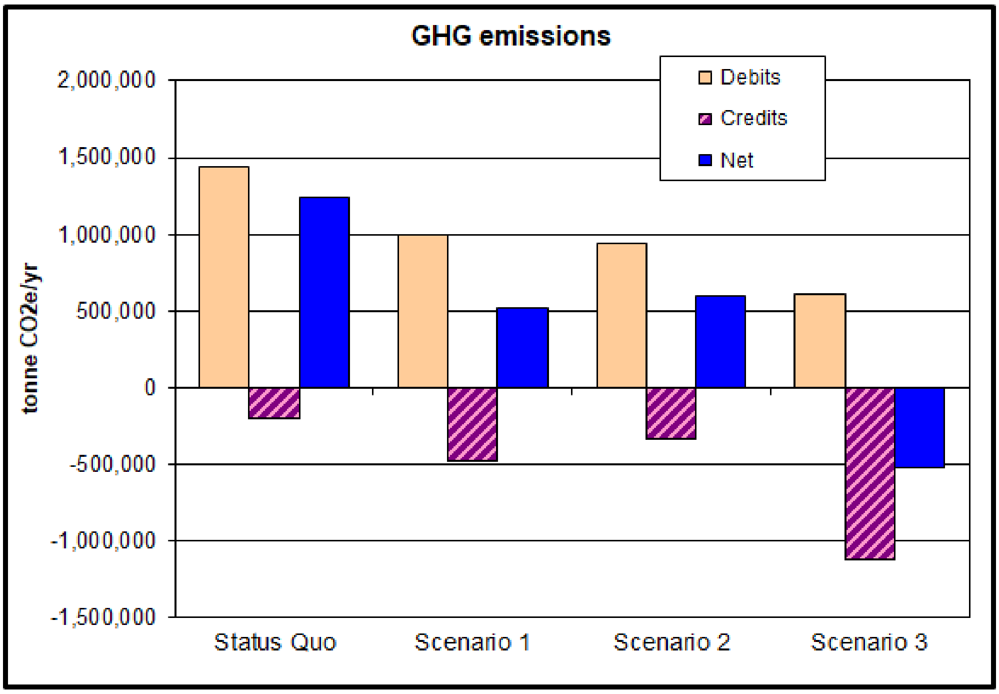

Figure 10-4 Overview of GHG emissions for all scenarios

Figure 10-5 also shows the results for the comparison of the four scenarios, but using a different structure and in more detail. The first section refers to the results for recycling. The first four bars show the debits from recycling in the four scenarios and the second four bars the credits from recycling in the four scenarios. The next section shows the same for disposed of waste. In the final section debits and credits and net results are shown for the total MSW treatment in each case for the four scenarios.

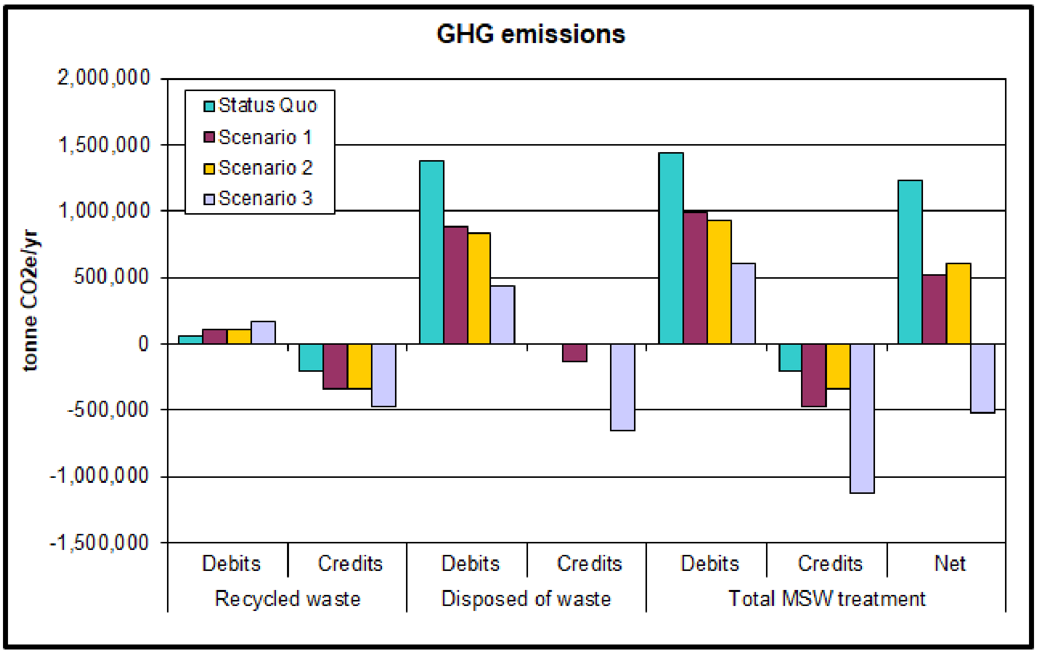

Figure 10-5 Overview of GHG emissions for all scenarios

10.3 "Costs results all"

This worksheet shows the results for the absolute costs for all calculated scenarios in one table. Additionally, the mitigation costs are shown in a separate table below. The mitigation costs are calculated as a comparison to the Status Quo scenario and per tonne of waste treated in each case. Depending on the results it may not be reasonable to indicate mitigation costs. For example, when a scenario causes more GHG emissions as the Status Quo scenario, no mitigation costs can be accounted as no GHG emissions are reduced. Nor can mitigation costs can be accounted if the total costs of a scenario that minimises GHG emissions are lower than the total costs in the Status Quo scenario. Although this case is not very likely or is more probably the effect of an incorrect entry, the resulting "costs" would not be mitigation costs but represent a profit.

11 "Factors"

The worksheet “Factors” contains emission factors and values used for the calculations (yellow cells). The factors are listed in this separate worksheet to (1) enable users to transparently understand background data and (2) to simplify updating and adaption of the tool in the future. The worksheet is password protected to avoid accidental changes.

The worksheet comprises the following data

- Global Warming Potential (GWP) factors
- Default emission factors, Stationary Combustion
- Emission values recycling
- Emission values composting, anaerobic digestion
- Emission values incineration
- Default values solid waste disposal
- Country-specific default values

11.1 GWP factors

The global warming potential (GWP) is calculated with the most recent characterisation factors according to IPCC (2021) for the 100-year horizon (GWP100). Previous factors from IPCC are listed for information.

11.2 Default emission factors, Stationary Combustion

The heat demand and demand for fossil fuels are calculated using the default emission factors for stationary combustion in the energy industries from IPCC (2006) (no refinement in IPCC 2019). The values for the individual GHG emissions are converted into CO_2 equivalents (CO2e) using the GWP100 factors.

The GHG emission values for heat and fossil fuels are also used to calculate the benefit from heat and biomethane generated by a waste treatment technology (e.g. incineration, anaerobic digestion).

11.3 Emission values recycling

Emission values for recycling are aggregated values for GHG emissions caused from recycling (debits) and emission savings potentials from produced secondary materials and energy (credits). Further explanation see Annex (14.1).

11.4 Emission values composting, anaerobic digestion, and mechanical-biological treatment or stabilisation

Default emission factors for methane (CH_4) and nitrous oxide (N_2O) according to IPCC 2006 (no refinement in 2019) are used to calculate the respective emissions from composting and anaerobic digestion of separately collected organic waste. For comparison values for

Germany are also listed. Further explanation on the recycling processes are given in the Annex (14.1.1 and 14.1.2).

IPCC 2006 (or 2019) does not provide emission factors for mechanical-biological treatment. According to IPCC "Emission from MB treatment can be estimated using the default values […] for the biological treatment. Emissions during mechanical operations can be assumed negligible." Therefore, the emission factors for composting are also used for the biological treatment in an aerobic MBT. For anaerobic digestion the IPCC default values are outdated (sources from 2005 and earlier) and do not consider post-composting of digestate. Therefore, GHG emissions for the MBT anaerobic are roughly estimated based on the IPCC default values as GHG emissions from anaerobic digestion plus GHG emissions from post-composting of digestate (0.5 kg digestate/t input). Mechanical-biological stabilisation (MBS) differs from MBT aerobic as it typically is a closed system with shorter retention time and therefore generates less CH_4 emissions. Here GHG emissions are roughly estimated as half of the IPCC default emission values for open composting. Further explanation on the treatment processes are given in the Annex (14.2.7 to 14.2.9).

11.5 Emission values incineration

IPCC 2019 provides examples of CH_4 and N_2O emissions for incineration as a function of the type of technology. For the calculation emissions from continuous incineration and stoker are considered. In accordance with IPCC 2019 CH_4 emissions are neglected due to low concentrations and high uncertainties. From the range of N_2O emissions from different countries and studies an average value is used for the calculation. For comparison recent measurement results for one plant in Germany are also listed in the tool. Further explanation for the incineration process is given in the Annex (14.2.10).

11.6 Default values solid waste disposal

Default values for solid waste disposal according to IPCC 2019 or IPCC 2006 (in case of no refinement in 2019) are provided as information and/or are used for the calculation. For the fraction of degradable organic carbon (DOCf) which decomposes the recommended default value for bulk waste is used for the calculation as average value for MSW which cannot be further defined. Default values for MCF, OX, fraction of methane in generated landfill gas (FCH4) and methane recovery (R) are provided for information. Default values for the total and fossil carbon content in waste fractions are used to calculate the carbon content in the total waste generated and in the remaining residual waste.

11.7 Country-specific default values

Country-specific default values comprise GHG emission factors for electricity (Chapter 6.6), for waste generation, waste composition (IPCC 2019) and population (DSW 2021). (see Chapter 6.2, 6.3).

12 "Calculation"

The worksheet “Calculation” in the SWM-GHG Calculator contains all the calculations as described in the previous sections. In general, factors (worksheet “Factors”) and linkages are used that should place users in a position to understand the calculations as well as possible. Additionally, further explanations are given in the Excel comments. The worksheet is password protected to avoid accidental changes.

In the first sector of the worksheet some physical parameters are given and the values for carbon content and net calorific values per waste fraction can be seen. Furthermore, the total waste amount (as inserted on the worksheet “Start”) and its calculated carbon content and net calorific value are depicted (linked to intermediate result on the worksheet “Start”). Then the shares of recycling and remaining residual waste is shown and the calculated carbon content and net calorific value for the remaining residual waste (linked to intermediate result on the worksheet “Recycling”).

The total waste amounts recycled and disposed of are shown in the next section as inserted on the worksheets “Recycling” and ”Treatment & Disposal”.

The GHG calculation of specific results per tonne waste for recycling and treatment & disposal is done in the following sector. This is followed by the calculation and impact assessment of the total GHG emissions (first for recycling and then below for treatment & disposal of the remaining residual waste) that are transferred to the result worksheets.

The final sector shows the results for the total costs that are transferred to the result worksheets.

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14 Annex

14.1 "Recycling" – description of treatment processes

GHG emissions for the recycled waste fractions are calculated based on the mass of waste recycled and a GHG emission factor. The GHG emission factors used are shown in Table 14-1. These GHG emission factors are derived from European level studies (Vogt et al., in publication), (Prognos/IFEU/INFU 2008 for glass, value unchanged from previous version). The corresponding treatment processes therefore refer to the European level. They are described below.

Table 14-1 GHG emission factors for recycling

kg CO_2e/t waste	Organic waste		Paper	Glass[1]	Fe-metals	Aluminium	Plastics
	Digestion	Composting	Deinking	Melting			
Emissions	*calculated depending on the scenario (CHP, biomethane)*	186	180	20	22	850	550
Avoided emissions		96	630	500	1,500	4,600	1,070
Net result		**90**	**-450**	**-480**	**-2,025**	**-3,750**	**-520**

Source: (Vogt et al., in publication), (Prognos, IFEU, INFU 2008)

14.1.1 Composting of organic waste

For the composting of organic waste a ratio of 50% open and 50% encapsulated composting plants is assumed. The average electricity demand of the latter is calculated as 30 kWh/t organic waste. Open composting is managed with diesel-engined machinery and the diesel demand was calculated as 1.5 l/t organic waste. The GHG emissions from composting are dominated by the methane and nitrous oxide (N_2O) emissions from the composting process (default values IPCC 2006, no refinement in 2019). CO_2 emissions from electricity and diesel demand are of minor importance.

Products were considered to be one third immature compost, which is used mainly in agricultural applications. For matured compost it is assumed that about 30% are used in agriculture, 3% becomes substrate material for recultivation purposes. The rest is used for gardening purposes in professional and leisure applications or as a substrate. The application pattern determines the substituted primary material. The agricultural application substitutes for mineral fertilizer, depending on the nutrient content in the compost. If the compost is used as a substrate or as humus supply then peat and/or bark humus is substituted for, depending on the content of organic matter in the compost. When compost is used for recultivation no primary material is substituted for, because usually only waste material is used for these purposes.

14.1.2 Digestion of organic waste

Instead of composting organic waste, the material can also be treated in an anaerobic digestion facility. The outputs (products) of digestion are biogas (energy) and digestate. It is assumed that the digestate is dewatered, 50% are used directly in agriculture and 50% is post-composted. The energy demand is covered by using the biogas produced. Biogas can be either used directly in a combined heat and power plant (CHP) or further processed to biomethane. This as well as the biogas yield and methane content are user-defined parameters (worksheet “Recycling”). The CHP net efficiency for electricity is set to 35% (typical range is between 30% and 40% depending on the electrical power). In the SWM-GHG Calculator only the net electricity produced is credited. Heat production is neglected because it is usually difficult to find an external customer. Main GHG emissions are methane emissions from the digestion process and nitrous oxide emissions from agricultural applications. In case biogas is further processed to biomethane further electricity is needed to separate the CO_2 from the CH_4 in the biogas, and additional methane losses to the atmosphere occur. The latter can vary between 0.1% and about 12% of the methane input depending on the technology. Higher values occur primarily in pressurized processes. For the calculation a methane loss of 5% is assumed as average value.

Application of the matured digestion compost is similar to application of matured compost from composting and the benefits were calculated in the same way. The electricity replaced is compared to electricity generation as indicated by the user (country-specific electricity mix). Biomethane generated is substituting natural gas (credit).

14.1.3 Paper, cardboard

The GHG emission factor for paper and cardboard recycling includes sorting and production of deinking pulp (DIP). An overall sorting loss of 1% during the sorting process and 15% rejects from deinking are subtracted from existing data. Rejects are incinerated in thermal waste treatment plants (WtE plants), and co-incinerated in cement kilns and coal power plants.

The assumption for primary production was made to take the equivalent pulp production into consideration. The recycled fibres are assumed to be nearly functionally equivalent to primary fibres which is accounted for by a technical substitution factor of 0.95. It was assumed that the primary fibre consists of 33% thermo-mechanical pulp (e.g. for newspapers) and 67% of Kraft pulp (sulphate pulp). The benefits of energy generation from incineration of the residues are included.

14.1.4 Plastics

The GHG emission factor for plastics recycling includes sorting and production of recyclate (regranulate). The GHG emissions are dominated by the comparably high electricity demand for plastics recycling, which is assumed to be 680 kWh/t plastic waste (based on Dehoust et al. 2016). The loss from processing is estimated to 24% residues and 6% humidity. Residues are typically co-incinerated in cement kilns. The benefit from the substitution of coal is considered. The recyclate produced from post-consumer plastic waste is of different quality. From data for Germany (Conversio 2018) it is assumed that 47% substitutes virgin plastic material, and the rest is used as substitute for materials such as concrete and wood. In average secondary granulates have a lower performance than virgin material. To respect this a functional equivalence was established using a substitution factor of 0.8.

Data for the primary production of virgin plastic granulates were taken from PlasticsEurope[11]. The GHG emission factor for plastics represents a mixture of about 65% polyolefins (PO), 20% PVC, 10% PET and 5% PS, as typical market mix in the EU. The GHG emissions saved from the substitution of wood or concrete applications are calculated based on ifeu data for the primary production taking into account the different density and lifespan of the different materials.

14.1.5 Glass

The approach for glass and its system boundaries is different to other materials. This is due to the fact that glass factories normally operate with a mixture of primary material and glass from the waste stream. As data sets exist only for different shares of waste glass input, a specific model for glass production is used. An additional sorting step to eliminate caps and labels is considered, the fate of the about 3% sorting residues is neglectable. The waste glass is introduced into smelting devices. The saved effort of using secondary glass is calculated from glass factory data. This is a non-linear relationship and is valid for a range between 50% and 90% of secondary glass (100% secondary glass input is technically not feasible). The GHG emission factor was calculated with a share of 75%.

14.1.6 Ferrous metals

Ferrous metals are sorted and pressed and usually introduced into an electric arc furnace (100% secondary steel production). Partly iron scrap is also used in oxygen steel furnaces together with pig iron (so-called primary steel production). For the GHG assessment it is assumed that steel production is the same regardless of whether pig iron or scrap is introduced into the furnace. Therefore, recycling ferrous metals substitutes for the production of pig iron. Both processing of iron scrap and primary production of pig iron is calculated with datasets from the ecoinvent data base (v3.6). In addition, the yield from processing of post-consumer iron scrap is set to 90%.

14.1.7 Aluminium

Secondary aluminium is produced by separate smelting facilities. The data used for treatment of aluminium scrap and for the substituted primary aluminium production (primary

[11] https://plasticseurope.org/sustainability/circularity/life-cycle-thinking/eco-profiles-set/

ingot) are taken from the ecoinvent data base (v3.6). The yield from processing of post-consumer aluminium is set to 70%.

14.2 "Treatment & Disposal" – description of waste treatment and disposal processes

14.2.1 Scattered waste not burned

Scattered waste is waste randomly thrown into the landscape. It decomposes under aerobic conditions. In this way no methane emissions occur from waste degradation. Although this is favourable in terms of climate change, this practice should be avoided at all costs as it poses massive health hazards to the population and damages the environment.

14.2.2 Open burning of waste (incl. landfill fires)

In some cases waste is burned openly. This can take place either directly e.g. at households or by landfill fires. The uncontrolled combustion of waste is extremely dangerous to health due to the emissions of toxic substances. These toxic substances have no influence on climate change. However, climate change is affected by open burning because fossil carbon in the waste is oxidised to CO_2. In the SWM-GHG Calculator open burning is calculated as complete oxidation of the fossil carbon contained in the waste. Considering the uncertainty of the quantities burned in the open and because the incompletely burned remains will decompose over time this is an insignificant simplification.

14.2.3 Wild dumps/unmanaged disposal site

Wild dumps are uncontrolled and/or unmanaged landfills. In contrast to scattering, the waste is not disposed of over a wide area but is piled up at one location. Under these conditions the waste decomposes anaerobically. The extend of methane generation depends on the depth of the site and/or if the waste is deposited in water such as a pond, river or wetland. The SWM-GHG Calculator allows users to define the methane correction factor (MCF) and provides a side calculation with default values from IPCC (2019). In case no specific information is available, IPCC (2019) recommends the default value for poorly managed sites of 0.7.

14.2.4 Controlled dump/landfill without gas collection

From definition according to IPCC (2019) controlled or managed landfill sites “must have controlled placement of waste (i.e. waste directed to specific deposition areas, a degree of control of scavenging and a degree of control of fires) and will include at least one of the following: (i) cover material; (ii) mechanical compacting; or (iii) levelling of the waste."

From a GHG point of view, controlled dumps without gas collection do not differ from wild dumps/unmanaged disposal sites. In both cases methane emissions occur depending on the depth of the site and/or in case of a high water table. Like for wild dumps users must specify the methane correction factor and can use the side calculation to assess a weighted average in case of different sites.

14.2.5 Sanitary landfill with gas collection

A sanitary landfill with gas collection is a managed or well-managed landfill which has – in contrast to the above described controlled landfill – installations for landfill gas collection. In general, anaerobic conditions are given at sanitary landfills and the methane correction factor is 1. Exceptions are landfills which are actively aerated and/or which are operated under semi-aerobic conditions. Here again users can use the side calculation to assess a weighted MCF using the IPCC default values.

Apart from the MCF, methane emissions from a sanitary landfill depend on (1) the oxidation rate of methane in case of covered landfill bodies, (2) the efficiency of gas collection and (3) the type of landfill gas treatment. The SWM-GHG Calculator allows users to define these boundary conditions.

According to IPCC (2019), the oxidation rate (OX) for managed landfills is 0 if they are not covered with aerated material. The default value for managed landfills that are covered with methane oxidising material like soil or compost is 0.1. This means maximum 10% of the overall methane generated can be oxidised to CO_2 by passing through the cover layer (due to cracks/fissures or lateral diffusion where gas escapes without being oxidised). Also according to IPCC (2019) "The use of an oxidation value higher than 0.1, should be clearly documented, referenced, and supported by data relevant to national circumstances."

To define the efficiency of gas collection users are asked to enter a respective percentage in the SWM-GHG Calculator. Gas collection efficiency in this context means the share of all potentially generated methane from a given quantity of waste that can be captured, or in other words, the ratio of collected landfill gas relative to the total generated landfill gas from a given quantity of waste. The default values recommended in the SWM-GHG Calculator for this average net efficiency are 20% and 50%. The minimum value is the default value form IPCC 2019: "When CH_4 recovery is estimated on the basis of the number of SWDS with landfill gas recovery a default estimate of recovery efficiency would be 20 percent." The maximum value corresponds to the technical feasible efficiency of gas collection over the lifetime of a landfill based on expert knowledge. For example, in Germany, where the landfill ban for MSW came into effect in 2005, and where all landfills are sanitary and include a gas collection system, the gas efficiency rate was reported to be 60% in 2007. This means that although no more MSW was disposed of in comparison to 2005 and all landfills are closed and covered, still only 60% of the methane generated was captured in 2007 for technical reasons.

The average net efficiency of gas collection is time dependent. In the early stages of waste disposal to landfill, the waste is not generally covered. Only a small quantity of generated methane can therefore be captured in this phase. Later, when the waste body is covered, more of the methane generated can be captured although 100% is still not achieved due to technical limitations.

Example:

1 tonne of waste generates 200 m³ of landfill gas over a time period of 50 years. It is assumed that 60% of the landfill gas is generated during the first 10 years when the landfill is active and not covered. In this period it is assumed that 30% of the landfill gas generated can be captured. After 10 years the waste body is covered and more of the generated landfill gas can be captured in the remaining 40 years. Efficiency is estimated at 80%. The resulting average net efficiency then is: 200*(0.6*0.3 + 0.4*0.8)/200 = 0.5.

In compliance with IPCC (2019) the amount of CH_4 that is recovered (defined by user-entry) is subtracted in the calculation from the amount generated before applying an oxidation factor.

In addition to the efficiency of gas collection in the SWM-GHG Calculator you are also asked what happens to collected landfill gas. The gas may remain untreated but vented, e.g. with a simple chimney to prevent self-incineration of the waste body. Methane emissions are not reduced in this case. Alternatively, the gas can be flared, and methane is oxidised to CO_2, which is climate-neutral because it comes from regenerative carbon. Further treatment options for selection are the use of landfill gas in a CHP or processing to biomethane (CO_2 separation). The calculation for these two options is done in the same way as the calculation for biogas from anaerobic digestion (Chapter 14.1.2). The CHP net efficiency for electricity is set to 35%, and the replaced electricity is credited with GHG emissions from electricity generation as indicated by the user (country-specific GHG electricity emission factor). Heat production is neglected. For processing landfill gas to biomethane further energy is needed and the methane loss to the atmosphere is 5%.

In case of flaring users are additionally asked to insert the efficiency of the flare. Given default values are 50% for open flares and 90% for enclosed flares. Definitions for the flare types are provided in the Excel comment.

14.2.6 BS + landfill

BS + landfill is defined as simple biological stabilisation (BS) of MSW and disposal of the residue with lower methane emissions than without stabilisation. The biological stabilisation takes place by building up the MSW in compost heaps which are aerated according to the chimney principle. No, or only simple, mechanical pre-treatment (e.g. homogenisation, shredding, modulation of water content) takes place. Biological treatment occurs over a period of at least 8 weeks. The output produced is less biologically active and is disposed of with lower resulting methane emissions. The diesel demand for biological treatment and for disposal of the output is estimated to 1.5 l diesel/t waste following the energy demand for simple composting. The electricity demand is estimated at 2 kWh/t waste and is the same as for sanitary landfill.

14.2.7 MBT aerobic + further treatment

MBT + further treatment is an advanced technology concept of MSW treatment. In a mechanical-biological treatment (MBT) plant MSW is initially mechanically treated to separate metals, impurities and a waste fraction that can be used for energy generation. This refuse-derived fuel (RDF) fraction can either be used in a WtE-plant or for co-incineration for example in cement kilns. The remaining waste consists to a high extent of organic waste. In case of an aerobic MBT this material is biologically stabilised through composting. CH_4 and N_2O emissions are calculated in accordance with IPCC (2019) using the default emission factors for composting (Chapter 11.4).

The aim of this treatment option is to separate recyclables from MSW and to produce a biologically inactive material that can be deposited with negligible negative impacts in terms of climate change. The electricity demand of the aerobic MBT plant is calculated at 45.6 kWh/t waste and the diesel demand at 8 kWh/t. The fractions separated by the MBT plant which are provided as default values in the SWM-GHG Calculator are shown in Figure 14-1. The values for energy demand and mass balance represent the average situation in Germany (Ketelsen & Becker, in publication).

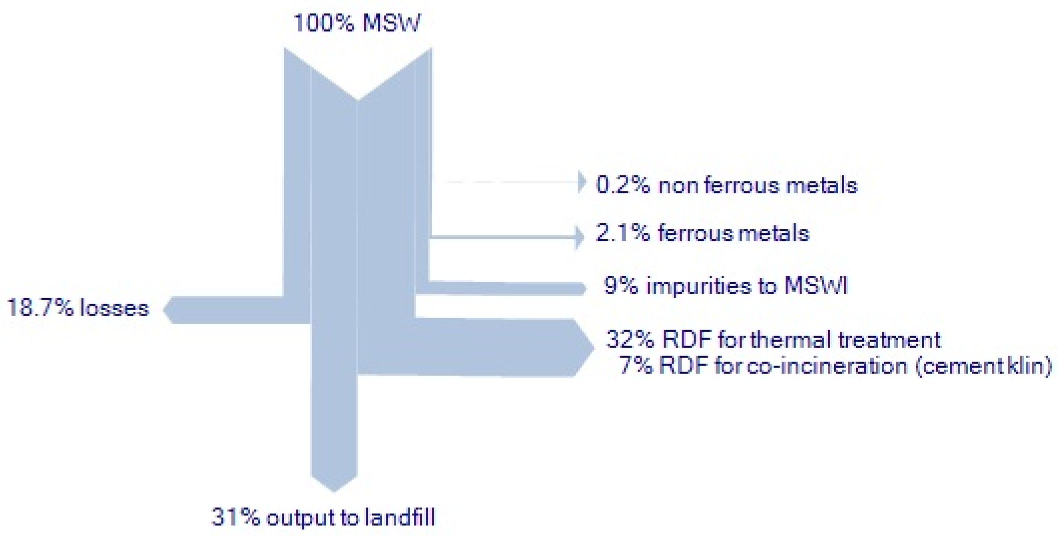

Figure 14-1 Mass flow diagram of an average aerobic MBT plant in Germany

Source: own illustration, ifeu.

The average values for Germany do not include the separation of dry recyclables other than metals as this is not typical for automatic sorting devices in MBTs (would need high tech sorting to derive marketable plastic, glass, paper fractions). Therefore, no default values can be provided for the potential separation of plastics and glass. The same accounts for compost-like output. In Germany the output from biological stabilisation has to be disposed of to landfill. Use e.g. in agriculture or on degraded soils is not allowed due to pollutants contained in mixed waste compost. However, in emerging and developing countries the law on use of the compost-like output may be different. In the calculation compost-like output is considered to cause no further methane emissions with application, due to aerobic conditions, but also no substitution effect.

The separated RDF fraction needs to be further specified in the SWM-GHG Calculator with regard to the fossil carbon content and the net calorific value. The given default values refer to the average German situation and may not be suitable for other countries. For orientation it is recommended to check on the interim results for the remaining residual waste on the worksheet “Recycling” as this is the waste input to the MBT. The fossil carbon content and net calorific value of an RDF fraction produced from it are usually both somewhat higher. Typically, net calorific value and fossil carbon content correlate, and numbers are similar (see e.g. below values for impurities). For example, estimated values for Indian cities are 12.5 MJ/kg and 12.5% fossil carbon for high quality RDF and 11 MJ/kg and 11% fossil carbon for RDF with mean quality (Vogt et al. 2019, Table 10).

The benefit from thermal treatment in a WtE-plant is the substitution of electricity and heat. The average net electrical efficiency is calculated with 10%, and the thermal efficiency with 30% (see Chapter 14.2.10). In case of co-incineration in a cement kiln or a coal power plant the regular fuel coal is substituted on an energy equivalent basis.

Separated impurities are assumed to be treated in a MSWI plant. They are defined as typical MSW in Germany with a calorific value of 9.2 MJ/kg and a fossil carbon content of approx. 9%. The average net electrical efficiency and thermal efficiency are the same as for the WtE-plant mentioned above. Electricity and heat produced are credited.

14.2.8 MBT anaerobic + further treatment

In contrast to the aerobic MBT in an anaerobic MBT the biological stabilisation is done by anaerobic digestion. The CH_4 and N_2O emissions are calculated based on IPCC (2019) default emission factors as described in Chapter 11.4.

The aim of this treatment option is the same as for an aerobic MBT. The output fractions differ slightly, and in addition biogas is produced from digestion. The electricity demand of the anaerobic MBT plant is calculated at 55.7 kWh/t waste and the diesel demand at 8 kWh/t. The fractions separated by the MBT plant which are provided as default values in the SWM-GHG Calculator are shown in Figure 14-2. The values for energy demand and mass balance represent the average situation in Germany (Ketelsen & Becker, in publication).

The calculation for output to landfill and/or compost-like output, dry recyclables, impurities to MSWI and the RDF fraction are the same as for the aerobic MBT. The biogas use needs to be defined by users, and can be either use in a CHP or processing to biomethane. The calculation for the biogas use is the same as described in Chapter 14.1.2 for biogas from digestion of organic waste or in Chapter 14.2.5 for collected landfill gas.

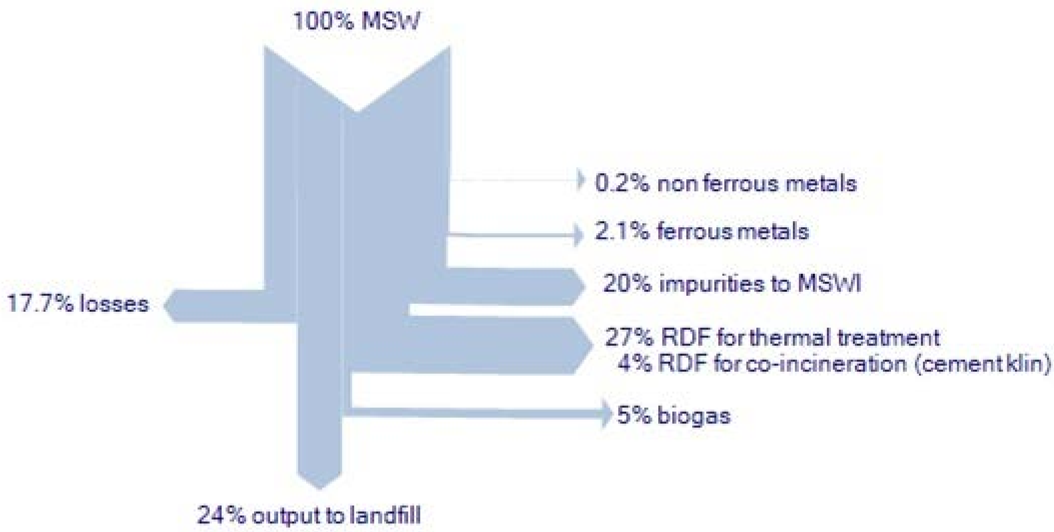

Figure 14-2 Mass flow diagram of an average anaerobic MBT plant in Germany

Source: own illustration, ifeu.

14.2.9 MBS + further treatment

Mechanical biological stabilisation (MBS) is an advanced technology concept of MSW treatment similar to MBT. Also similar to MBT, MSW is initially mechanically treated to separate metals and impurities. But in contrast to MBT the complete remaining fraction is stabilised biologically to produce RDF. Thus, no biologically stabilised and/or compost-like output is generated. Only a separated inert fraction is landfilled.

The aim of this treatment option is to produce RDF and to separate metals. The electricity demand of the MBS plant is calculated at 60.9 kWh/t waste, the diesel demand at 8 kWh/t. The fractions separated by the MBT plant which are provided as default values in the SWM-GHG Calculator are shown in Figure 14-3. The values for energy demand and mass balance represent the average situation in Germany (Ketelsen & Becker, in publication).

Like for MBT the average values for Germany do not include the separation of dry recyclables other than metals as this is not typical for automatic sorting devices (would need high tech sorting to derive marketable plastic, glass, paper fractions). Therefore, no default values can be provided for the potential separation of plastics and glass.

To stabilise the remaining, mainly organic fraction after mechanical treatment, it is introduced into a reactor where it starts to decompose and is systematically aerated. Biological heating and aeration lead to drying of the waste material to less than approx. 15% water content. With a water content as low as this the biological activity of the organic waste is brought to a halt.

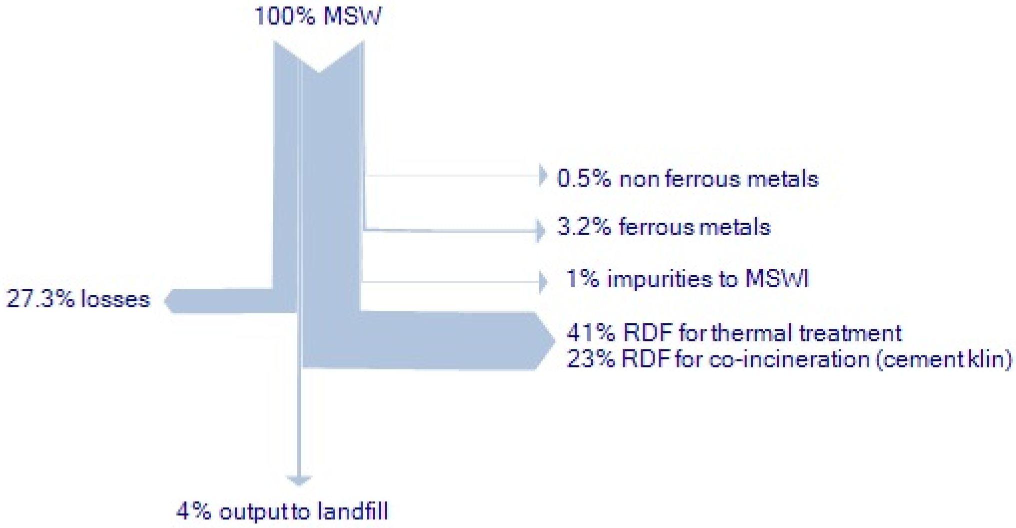

Figure 14-3 Mass flow diagram of an average anaerobic MBT plant in Germany

Source: own illustration, ifeu.

The calculation for dry recyclables, impurities to MSWI and the RDF fraction is the same as for the aerobic or anaerobic MBT. The benefits from thermal treatment or co-incineration of RDF and incineration of impurities are also calculated as described for MBT.

14.2.10 Incineration

Different incineration plant technologies exist. The most common models are stokers and fluidised bed combustion, with the first dominating in Germany. In terms of environmental concerns, the most important aspect of incineration and/or thermal treatment technologies is the type of flue gas treatment. In general, thermal waste treatment plants (MSWI or WtE-plants) should be in compliance with German and/or EU27 emission standards, for example. Emissions hazardous to health needn't therefore be feared.

Additionally, the waste should be thoroughly tested for its suitability for incineration. The most important aspects in terms of waste characteristics and quality are explained in Chapter 6.5. As a rough rule of thumb, it can be assumed that self-sustaining incineration usually requires a minimum net calorific value of about 6 MJ/kg wet waste. In addition to waste combustibility data, information on the level of heavy metals is also important, because this has considerable influence on flue gas cleaning requirements and incineration costs. Determination of these parameters requires in-depth surveys of the waste composition and physical and chemical analyses.

The main relevant emissions in terms of climate change are fossil CO_2 emissions resulting from incineration of fossil carbon contained in waste. As a conservative simplification in the SWM-GHG Calculator, complete combustion is assumed for technologically advanced incineration plants. In addition, N_2O emissions are calculated in accordance with IPCC (2019) (see Chapter 11.5). The fate of the ash and slag output products is not considered in the tool.

Modern thermal waste treatment plants usually produce energy. In a further step in the SWM-GHG Calculator users are asked to enter the net energy efficiency. If thermal waste treatment plants have a steam turbine then they produce electricity and in some cases heat. If only electricity is produced the maximum electrical efficiency is about 20% for thermodynamic reasons. If heat is also produced the electrical efficiency is lower. The degree of heat production depends on whether it is possible to sell the heat.

The default values given in the SWM-GHG Calculator for net electrical efficiency and thermal efficiency are 15% and 0% respectively. These values were chosen because it is assumed that it is barely possible to find a customer for heat in developing countries and that therefore only electricity is produced.

The emission savings potential by the substitution of electricity and heat production are considered in the SWM-GHG Calculator. For electricity generation these are the CO_2 emissions as defined by the user (country-specific electricity mix); an average value is used for heat (50% oil, 50% natural gas).

Thermal waste treatment plants in Germany are historically differentiated to MSWI plants for MSW and WtE-plants for RDF. However, both basically are of the same technology, both have to comply with the same emission standards and nowadays both treat more or less the same waste types. As MSWI plants are typically older on average, their average net energy efficiency is a little lower than that of WtE-plants. The net electrical efficiency is 11.1% and the thermal efficiency 33.5%, while WtE-plants on average have a net electrical efficiency of 14.7% and a thermal efficiency of 45.4% (Flamme et al. 2018). In total, the efficiency has increased. As of 2009 as the first version of the SWM-GHG Calculator was released the net electrical efficiency was 10% and the thermal efficiency 30% (Öko-Institut 2002), and the values were also applicable on a European level (CEWEP 2006). In the current version of the SWM-GHG Calculator, the older values are continued to be used for the calculation of the outputs to incineration and/or energy use from MBT or MBS.