Partnership on Transparency
in the Paris Agreement

Good Practices in GHG Inventories for the Waste Sector

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About the Partnership on Transparency in the Paris Agreement

In May 2010, Germany, South Africa and South Korea launched the Partnership on Transparency in the Paris Agreement (formerly: International Partnership on Mitigation and MRV) in the context of the Petersberg Climate Dialogue with the aim of promoting ambitious climate action through practical exchange. With the Paris Agreement entering into force in 2016, the path has now been paved for the Partnership to focus on implementing the Agreement and particularly on the Enhanced Transparency Framework. Over 100 countries, more than half of which are developing countries, have taken part in the Partnership's various activities to date. The Partnership has no formal character and is open to new countries. Currently, the secretariat of PATPA is hosted by the GIZ Support Project for the Implementation of the Paris Agreement (SPA).

Find more information on the partnership here:
www.transparency-partnership.net

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Abbreviations

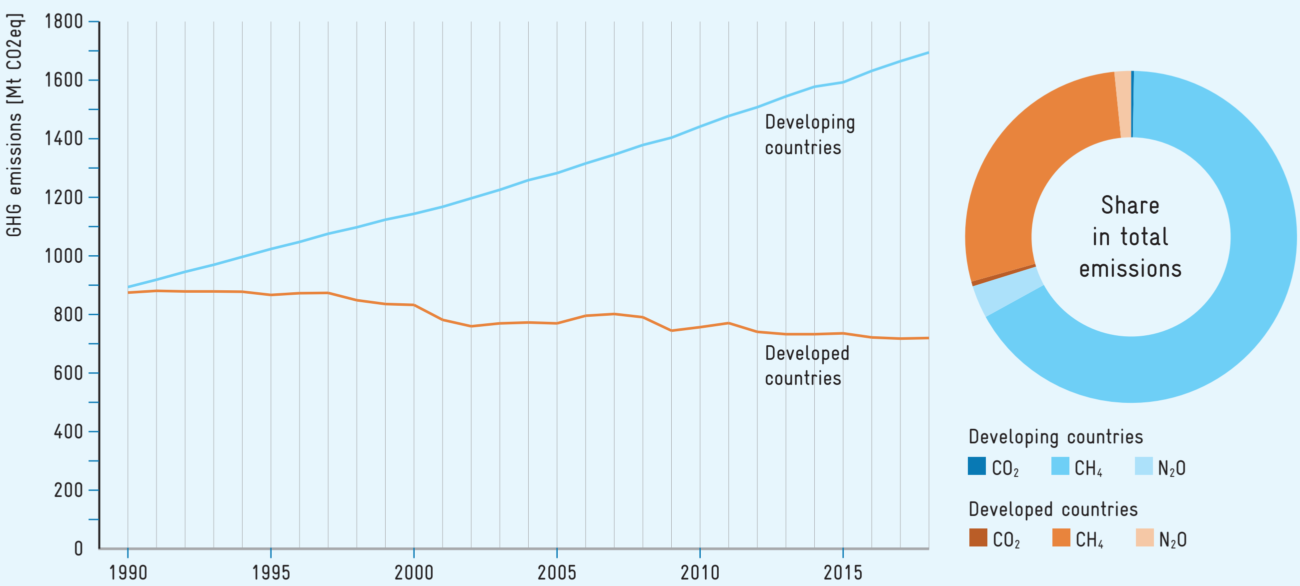
AD	Activity Data
AFOLU	Agriculture, Forestry and Other Land Use
BOD	Biochemical Oxygen Demand
BTR	Biennial Transparency Report
BUR	Biennial Update Report
CCW	Carbon Content in Waste
CDM	Clean Development Mechanism
CH_4	Methane
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
CRT	Common Reporting Tables
Dind	Industrial Degradable organic component
DOC	Degradable Organic Carbon
DOCf	Fraction of DOC which decomposes
EF	Emission Factor
ETF	Enhanced Transparency Framework
F	Fraction of CH_4 in Generated Landfill Gas
FCF	Fossil Carbon Fraction
FAO	Food and Agriculture Organization
FOD	First Order Decay
GDP	Gross Domestic Product
Gg	Gigagram, the same as 1 kt or 1000 t
GHG	Greenhouse Gas
GIZ	German Agency on International Cooperation
ifeu	Institute for Energy and Environmental Research
IGES	Institute for Global Environmental Studies
JICA	Japan International Cooperation Agency
IPCC	Intergovernmental Panel on Climate Change
k	Methane generation rate constant or half life
LULUCF	Land Use, Land-use Change and Forestry
MBT	Mechanical Biological Treatment
MCF	Methane Correction Factor
MPGs	Modalities, Procedures and Guidelines
MRV	Monitoring, Reporting and Verification
MSW	Municipal Solid Waste
NAMA	Nationally Appropriate Mitigation Action
NC	National Communication

N_2O	Nitrous oxide
NE	Not Estimated
NID	National Inventory Document
NIR	National Inventory Report
NO	Not Occurring
OX	Oxidation factor
QA/QC	Quality Assurance, Quality Control
R	Recovery
PATPA	Partnership on Transparency in the Paris Agreement
SWDS	Solid Waste Disposal Sites
SWM	Solid Waste Management
TOW	Total Organically Degradable Carbon in Wastewater
UN	United Nations
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
WARM	Waste Reduction Model
WWTPs	Wastewater Treatment Plants

Non-technical summary

National greenhouse gas inventories have been compiled and reported under the United Nations Framework Convention on Climate Change (UNFCCC) for many years. Under the Paris Agreement, they gain in importance as one of the pillars of the agreement's Enhanced Transparency Framework (ETF). Emissions arising from the treatment and disposal of liquid and solid waste are relatively low, but they have risen continuously in many developing countries due to changing production and consumption patterns (Figure 1), and they are expected to continue to increase in the absence of mitigation actions.

Figure 1: Greenhouse gas emissions in the waste sector



Source: Öko-Institut based on Gütschow et al. (2021).

Note: Under "developed countries", those countries listed in Annex I to the UNFCCC are summarised; under "developing countries", those not listed in this annex are summarised. Emissions were converted into CO_2 equivalents using global warming potentials from the IPCC's Fifth Assessment Report (IPCC 2013).

The experience gathered with mitigation actions in a multitude of countries have shown that significant emission reductions at relatively low costs are possible in this sector. The sector also has a great potential to achieve sustainable development co-benefits, which is a critical factor in the decision-making of countries. As a first step towards implementing mitigation actions, it is necessary to adequately quantify greenhouse gas emissions, understand in which sub-sectors they originate and what the main reasons for these emissions are.

A high-quality greenhouse gas (GHG) inventory can help to answer these questions, but compilers need to overcome some obstacles during GHG inventory preparation: for example, decisions and knowledge about waste generation and treatment are often situated at a local level with limited aggregation of data at the national level. In addition to waste generation data, it is necessary to obtain information on waste composition and treatment for inventory compilation. In many countries, these data problems are exacerbated because of an only partially formalised sector;

relevant shares of waste are disposed at dumps, are burnt on site, or are recycled by the informal recycling sector. Thus, information may mostly be available from the formal waste management sector while data on a significant portion of waste that is unofficially managed by the informal sector, among others in recycling, may be unknown.

The purpose of this study is to support the preparation of GHG inventories in the waste sector through good practice examples which can be adopted in other countries. This report complements the existing reporting guidance under the UNFCCC with real life examples in the waste sector from different countries. It is directed at persons involved in the compilation of GHG inventories in the waste sector, especially in developing countries. In addition, the study analyses the interlinkages between GHG emission inventories and mitigation actions in the sector and provides an overview of different models and data sources for waste inventories. All analysed countries in this report are applying guidelines developed by the Intergovernmental Panel on Climate Change (IPCC) and need to collect and determine the same data and parameters. While national circumstances differ, the problems can be similar, and an approach chosen in one country may be adapted and may help to overcome obstacles in another.

The IPCC has developed Guidelines for GHG inventory compilation. The guidelines currently in use include the 1996 IPCC Guidelines, the 2000 IPCC Good Practice Guidance, and the 2006 IPCC Guidelines. Under the Paris Agreement, all Parties are required to use the 2006 Guidelines for inventory preparation. The IPCC also adopted a refinement of the 2006 Guidelines in 2019, but this refinement has not yet been mandated for inventory compilation under the UNFCCC or the Paris Agreement. Countries may still decide to make use of the methods or emission factors contained in the refinement if they are appropriate for their national circumstances.

Besides detailed methodologies, explanations, and default values, the 2006 IPCC Guidelines also provide input on how to set up a national inventory system that helps to utilize available resources effectively. The task of preparing a complete GHG inventory may seem daunting initially, but even with very limited resources, it is possible to undertake initial estimates. Preparing estimates using the simplest IPCC methodology for each source category and default parameters is relatively straight-forward. In subsequent submissions, methodologies, data, and parameters can then be refined and improved. Starting small can also be advantageous if the inventory agency does not have adequate resources for the task: once an inventory has been published and been used on the national level (e.g. for policy development), it might be easier to dedicate more funding to updates and improvements. In addition to the IPCC Guidelines, many other guiding documents exist and various multilateral, national and private institutions offer capacity building programmes.

This study discusses and provides recommendations for general GHG inventory development and specific issues related to the preparation of GHG inventories in the waste sector, including:

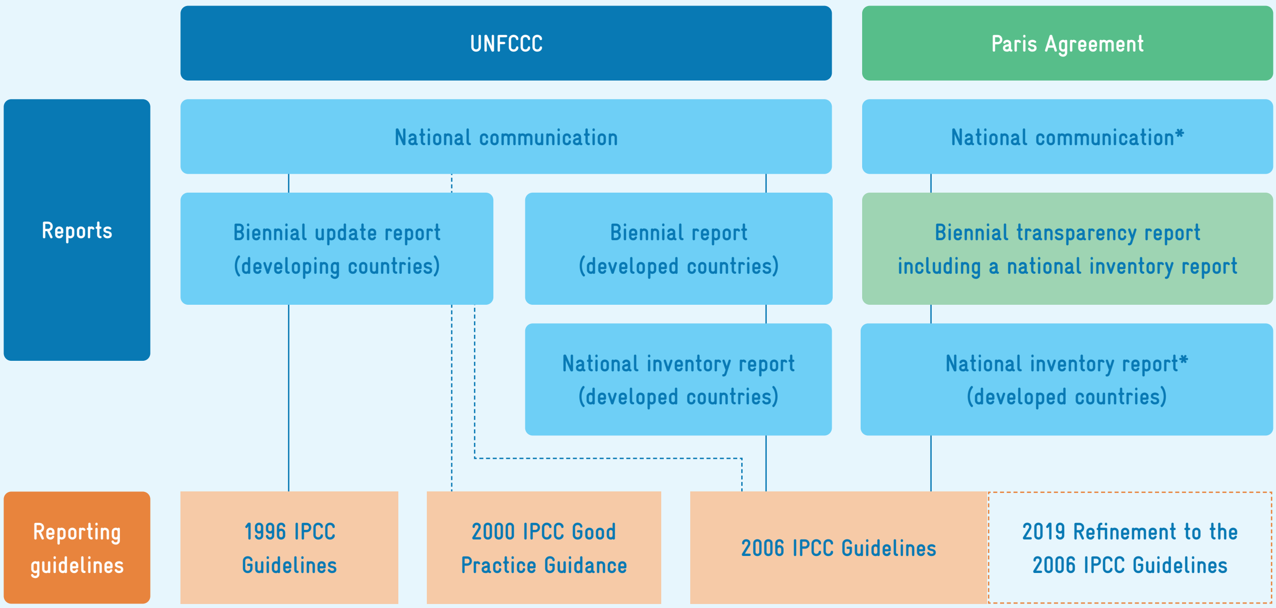
- The institutionalisation of the system, by developing and agreeing processes to avoid "starting from scratch" whenever an inventory is prepared. Together with adequate documentation of assumptions, data sources and calculations, this greatly facilitates inventory preparation for each subsequent report.
- Conducting key category analysis in order to allocate resources and efforts to the most relevant categories.
- Using IPCC methodologies and default values to gap-fill missing data.
- Ensuring time series consistency in the transition from one source to the other if different data sets are combined.
- Improving the quality of the inventory as part of a continuous Quality Assurance / Quality Control (QA/QC) process, which should include an inventory improvement plan.

1. Introduction

Parties to the UNFCCC have been compiling GHG inventories for many years. While developed countries have experience in compiling annual greenhouse gas inventories, developing countries generally prepare and submit these inventories less frequently. The reporting arrangements under the UNFCCC and under the Paris Agreement are depicted in Figure 2. Under the UNFCCC, developing countries are requested to prepare Biennial Update Reports (BURs) every two years. One of the chapters of the BUR is an updated GHG inventory covering all sources and gases.

Under the Paris Agreement, all Parties are required to submit a Biennial Transparency Report (BTR), which includes national GHG inventory information. The first BTRs are due by the end of 2024 at the latest. For additional information on reporting requirements under the UNFCCC and under the Paris Agreement, please refer to the German International Cooperation Agency's (GIZ) *Next steps under the Paris Agreement and the Katowice Climate Package.*[1]

Figure 2: Reports under the UNFCCC and Paris Agreement, and IPCC Reporting guidelines



* Besides the reporting framework under the Paris Agreement, some reporting obligations under the UNFCCC remain in place: Parties still submit national communications, and developed country Parties submit national inventory reports in years when they do not submit them as part of a biennial transparency report.

Source: Öko-Institut, based on UNFCCC reporting guidelines.

1 https://www.transparency-partnership.net/documents-tools/guidance-policy-makers-ndcs-and-etf

One of the sources that needs to be covered by the inventory are GHG emissions from waste treatment and disposal. According to the IPCC Guidelines for GHG inventory compilation[2], relevant activities are solid waste disposal, biological treatment of organic waste, waste burning, and wastewater treatment and discharge. While the GHG emissions from this sector are relatively low compared to other sectors, they were responsible for 4.9% of global emissions in 2018 (without land use, land-use change and forestry (LULUCF), using global warming potentials from the IPCC's Fifth Assessment Report; and based on emissions data from Gütschow et al. 2021), and they have risen continuously in developing countries. At the same time, it is one of the sectors in which significant reductions are possible and affordable, as experiences with Clean Development Mechanism (CDM) projects have shown over the past decade. Reducing emissions from waste treatment, implementing modern waste management techniques and the avoidance of unregulated waste dumping and burning also have important co-benefits: Countries often put in place waste management policies to improve public service delivery and basic sanitation, protect public health and minimise leachate and gaseous emissions to the environment.

GHG emissions from the waste sector can also be mitigated by reducing the volume of deposited waste. This is the case in a society that is moving towards a circular economy and in which consumers value sustainable production and consumption. Secondary raw materials from recovered waste enhance resource efficiency of the industry. Measures also prolong landfill capacities, improve the working conditions of the semi- and informal waste sector, create new opportunities especially for jobs with higher qualifications, and reduce subsidies through appropriate cost recovery schemes. Furthermore, co-benefits in terms of climate resilience and adaptation include the suitability of sites for waste management facilities, reduced impacts of flooding caused by the clogging of waterways while methane management options reduce explosion and fire risks at disposal sites.

Due to the emission reduction potential and the clear co-benefits, many countries are implementing Nationally Appropriate Mitigation Actions (NAMAs) in the sector. To be able to develop adequate policies for the waste sector, it is necessary to have good data on current and expected future waste quantities and waste composition – data which could come from the GHG inventory for this sector.

2 IPCC Guidelines are available at: https://www.ipcc-nggip.iges.or.jp/public/index.html

1.1. Purpose and contents of the study

The purpose of this study is to support the preparation of GHG inventories in the waste sector through good practice examples which can be adopted in other countries. It is meant as a complement to the IPCC Guidelines and other training materials relevant to the waste sector and shows how some common problems have been solved in different countries. The study is directed at persons involved in the compilation of GHG inventories in the waste sector, especially in developing countries. It provides an overview of the relevant IPCC Guidelines for general GHG inventory preparation and offers guidance and good practice examples on the compilation of GHG inventories specific to the waste sector. Based on the Guidelines and country examples, specific recommendations are given for all source categories within the waste sector. In addition, the study analyses the interlinkages between inventories and emission mitigation actions in the sector and provides an overview of different models and data sources for waste inventories. While national conditions in each country are different, there are some common problems such as lack of activity data, incomplete information, lack of capacity, and limited resources for inventory development. The analysis is based on a screening of publicly available information from 35 countries and interviews with practitioners from six countries.

This report constitutes an update of the original study published in 2015 (Graichen et al. 2015). The update was conducted on behalf of the Partnership on Transparency in the Paris Agreement (PATPA), which supports international efforts to engage in practical exchanges and political dialogue on climate transparency.

1.2. Scope of the study

The countries included in the study and documents used are shown in Annex II in Table 7-1; links to all publicly available documents used are included in Annex II and in the bibliography.

Under the current UNFCCC reporting requirements, developing countries should use the 1996 IPCC Guidelines; in addition, they are encouraged to use the 2000 IPCC Good Practice Guidance. Under the Paris Agreement's Enhanced Transparency Framework, all Parties are required to use the 2006 IPCC Guidelines.

The methodologies, explanations, and availability of default values in the 2006 IPCC Guidelines are greatly improved compared to the previous versions. The provision of a First Order Decay tool for solid waste disposal (see Chapter 3.1) especially facilitates the preparation of GHG inventories greatly. Many developing countries are using the 2006 Guidelines and will do so more in the future as their use will become mandatory by 2024. Hence, this study focuses on the methods contained in the 2006 IPCC Guidelines.

2. Good practice in GHG inventory development

2.1. Background

This chapter aims to introduce the contents of the 2006 IPCC Guidelines relevant for the preparation of GHG inventories in general. Specifics that apply to the waste sector alone are included in Chapters 3.1 to 3.4. This background information is directed at readers unfamiliar with the Guidelines and explains the underlying concepts and methodologies. However, it does not cover all relevant details and is therefore insufficient as a standalone guide for the preparation of a national GHG inventory.

Preparing a complete national GHG inventory for any source category is a multi-stepped process which has to be repeated each time a new inventory report is prepared.

Figure 3 shows a typical inventory cycle; additional details on good practice for the individual steps are provided below. Developing countries will not always be able to implement good practice for all steps and all sectors and are currently not required to do so by the UNFCCC. However, if circumstances allow, they are encouraged to implement these steps to improve their GHG inventories, and many elements of good practice will become mandatory under the Paris Agreement (cf. Boxes 2 to 6). Good practice allows the identification and prioritisation of areas for improvement and therefore a more efficient allocation of available resources.

Box 1: Good practice in inventory development

The IPCC Guidelines refer to good practice as "a collection of methodological principals, actions and procedures […] to promote the development of high-quality national greenhouse gas inventories. […] Inventories consistent with **good practice** are those which **contain neither over- nor under-estimates so far as can be judged, and in which uncertainties are reduced as far as practicable.**" (IPCC 2006). This definition implies that good practice depends on national circumstances, e.g. availability of activity data and existing resources for inventory development.

In this report, whenever a reference is made to good practice it refers to the IPCC definition and the procedures in the IPCC Guidelines. All country examples given are deemed good practice based on the available information. This does not mean that they are "best practice" in the sense of having minimal uncertainties in the emission estimates. For example, if a country has no activity data for some historic years, it is good practice to apply the IPCC methodologies for gap-filling. Best practice would require complete activity data for all years which might not be practicable (i.e. not required for good practice).

Figure 3: Typical GHG inventory cycle

Source: US EPA quoted in (UNFCCC 2014)

2.2. Good practice requirements

2.2.1. Key categories and methodologies

According to the IPCC, it is good practice to conduct a key source analysis to identify those source categories which contribute most to the absolute emissions (level assessment) and/or to the change in GHG emissions over the years (trend assessment) in a country. Depending on previous inventories, there are three options for conducting a key source analysis (IPCC 2006):

- Qualitative assessment: if no previous inventories are available, if previous inventories are incomplete, or to identify additional key sources based on further information,
- Approach 1: based on previous emission estimates,
- Approach 2: based on previous emission estimates and uncertainties.

These approaches are cumulative, i.e. a country implementing Approach 2 should also apply Approach 1. The qualitative approach can then also be used to identify sources which are expected to become key, e.g. because of adopted policies that are expected to have a significant impact on future emissions.

Based on the above-mentioned analysis, the inventory compilers should consider the following for those categories identified as key:

- focusing available resources on key categories,
- applying higher methodological tiers (i.e. methods with higher levels of complexity) without jeopardising resources for other key categories; and
- focusing QA/QC procedures on these key categories.

In most but not all source categories, the Guidelines provide different tiers for the estimation of GHG emissions and removals. While non-key categories can always be estimated using Tier 1, it is generally good practice to apply at least Tier 2 for key sources. In many cases, the difference between the three tiers is as follows:

- Tier 1: use of national activity data but adopting default emission factors and other parameters as provided in the IPCC Guidelines.
- Tier 2: use of national activity data, emission factors, and other parameters.
- Tier 3: use of site-specific activity data, emission factors, and other parameters.

Details on the selection of the best tier are provided in decision trees for each source category in the respective volumes of the Guidelines.

Box 2: Requirements for key categories and methodologies under the Paris Agreement

At the latest by 31 December 2024, Parties to the Paris Agreement shall submit their first biennial transparency report and national inventory report. Many of the good practice requirements described here will become mandatory under the Paris Agreement, with flexibility for those developing country Parties that need it in the light of their capacities. These requirements are defined in the "Modalities, procedures and guidelines (MPGs) for the transparency framework for action and support referred to in Article 13 of the Paris Agreement" (UNFCCC 2018).

According to the MPGs, "each Party shall use the 2006 IPCC Guidelines […] and should make every effort to use a recommended method (tier level) for key categories in accordance with those IPCC guidelines".Key categories are identified using a pre-determined cumulative emissions threshold. Key categories are those that, when summed together in descending order of magnitude, add up to 95% of the total level.Each Party shall identify key categories for the starting year and the latest reporting year [...], for both level and trend assessment, by implementing a key category analysis consistent with the IPCC guidelines […]; those developing country Parties that need flexibility in the light of their capacities with respect to this provision have the flexibility to instead identify key categories using a threshold no lower than 85 per cent in place of the 95 per cent threshold defined in the IPCC guidelines […], allowing a focus on improving fewer categories and prioritizing resources.

2.2.2. Data collection and time series consistency

Although it is not a requirement for all Parties to the UNFCCC, it is good practice to prepare annual inventories for all years since 1990. This requires the availability of the necessary activity data and other parameters for those years.

Depending on national circumstances, source category and methodology, not all necessary information may be available. It is good practice to focus personnel and financial resources on those categories identified as key. The 2006 IPCC Guidelines include a list of potential national and international data sources, recommendations for data generation, and the use of expert judgement.

Often it is not possible to use one data source for the entire time period. Despite this, it is good practice to ensure a consistent time series, i.e. to avoid breaks and jumps between data sets. The Guidelines include methodologies for gap filling and for combining different data sources. Time series consistency could also become an issue if the applied methodologies change within an inventory or between inventory submissions. Examples of this are when necessary data for higher tiers is only available for some years or when a source becomes key. In such cases, it is good practice to ensure consistency and recalculate the entire time series if applicable.

Box 3: Requirements for time series consistency under the Paris Agreement

Under the Paris Agreement, each Party is required to report a consistent annual time series starting from 1990, but a flexibility provision exists for developing countries that need it in the light of their capacities. To ensure time-series consistency, each Party should use the same methods and a consistent approach to underlying activity data and emission factors for each reported year.

2.2.3. Uncertainties

Estimates of GHG emissions in national inventories are never exact. Uncertainties in input data, incomplete coverage, and errors in methodologies amongst others will lead to uncertainties in the estimation of GHG emissions and removals. It is good practice to estimate these uncertainties. Having detailed uncertainty estimates helps to prioritise the allocation of resources: it allows the application of the Approach 2 in the key source analysis and can identify parameters with the highest impact on the overall uncertainty of a source category. Providing detailed guidance on estimating uncertainty for GHG inventories goes beyond the scope of this study[3]. The 2006 IPCC Guidelines provide detailed information on uncertainty estimates.

Box 4: Requirements for the uncertainty assessment under the Paris Agreement

As part of inventory preparation under the Paris Agreement, each Party shall quantitatively estimate and qualitatively discuss the uncertainty of the emission and removal estimates for all source and sink categories, including inventory totals, for at least the starting year and the latest reporting year of the inventory time series.

Each Party shall also estimate the trend uncertainty of emission and removal estimates for all source and sink categories, including totals, between the starting year and the latest reporting year of the inventory time series, using at least approach 1, as provided in the IPCC Guidelines; those developing country Parties that need flexibility in the light of their capacities with respect to this provision have the flexibility to instead provide, at a minimum, a qualitative discussion of uncertainty for key categories […], and are encouraged to provide a quantitative estimate of uncertainty for all source and sink categories of the GHG inventory.

3 A short practical introduction about developing GHG projections provides the paper "Projections of Greenhouse Gas Emissions and Removals", available online at https://transparency-partnership.net/publications-tools/projections-greenhouse-gas-emissions-and-removals-introductory-guide

2.2.4. Quality Assurance and Quality Control

According to the 2006 IPCC Guidelines, QA/QC and verification procedures contribute to the objectives of good practice in inventory development, namely to improve transparency, consistency, comparability, completeness, and accuracy of national greenhouse gas inventories. In short, QC aims at minimising errors in the inventory preparation, e.g. through automated checks of input data regarding completeness and order or magnitude of the data values. QA aims to check whether the methodologies and data used are the most appropriate ones and is conducted after the inventory has been compiled. Verification is based on independent data to establish the reliability of the inventory. It can be an extension of both QC and QA.

It is good practice to implement QA/QC and verification activities. This involves:

- developing a QA/QC plan with measurable objectives,
- defining roles and responsibilities,
- implementing general and source-specific QC procedures,
- QA and verification procedures,
- reporting and documenting of data, assumptions, calculations, and QA/QC procedures used for the inventory.

Box 5: Requirements for quality assurance and quality control under the Paris Agreement

According to the MPGs for the transparency framework (UNFCCC 2018), “each Party shall elaborate an inventory QA/QC plan in accordance with the IPCC guidelines […]; those developing country Parties that need flexibility in the light of their capacities […] are instead encouraged to elaborate an inventory QA/QC plan […].”

Each Party shall implement and provide information on general inventory QC procedures in accordance with its QA/QC plan and the IPCC Guidelines; those developing countries that need flexibility in light of their capacities are instead encouraged to implement and provide information on such general inventory QC procedures.

In addition, Parties should apply category-specific QC procedures for key categories and for those individual categories in which significant methodological changes and/or data revisions have occurred. Parties should also implement QA procedures by conducting a basic expert peer review of their inventories in accordance with the IPCC guidelines.

2.2.5. Reporting

The reporting of GHG inventories consists of data tables and a detailed report:

- Pre-defined data tables for each source category for emissions and activity data by gas and year;
- Additional information, inter alia on methodologies, data sources, emission factors and other parameters, uncertainties and QA/QC procedures.

Data tables allow an easy access to all the relevant emission estimates and some underlying data for readers familiar with the format. For National Communications (NCs) and BURs, developing country Parties only need to fill out tables at an aggregated level; for a detailed list, see UN-FCCC (2014). It is good practice to complete all sheets and fill all cells. Notation keys can be used to explain otherwise empty cells, e.g. if a source does not occur in a country or if emissions are reported under another source category.

The additional information should facilitate the assessment and replication of the inventory by third parties. This implies that all relevant information, sources and assumptions should be listed in the report.

Box 6: Requirements for reporting under the Paris Agreement

According to the Paris Agreement, each Party shall provide a national inventory report of anthropogenic emissions by sources and removals by sinks of GHGs. The national inventory report consists of a national inventory document (NID) and the common reporting tables (CRT). The CRT for the electronic reporting can be found in the transparency guidance (https://unfccc.int/sites/default/files/resource/cma3_auv_5_transparency_0.pdf) in its Annex I and the outline of the NID in its Annex V.

2.3. Country examples for general GHG inventory development

2.3.1. National GHG inventory systems and institutional settings

For compiling an inventory that complies with the requirements above, governments need to set up an institutional structure for data collection and reporting. Responsibilities for the different sectors should be assigned to the appropriate ministries and/or agencies; staff has to be trained and agreements with data providers have to be set up. The tables below – Table 2-1 and Table 2-2 – show examples of how the process of inventory compilation works in selected countries, with a focus on the waste sector.

In most of the selected countries, environmental ministries or agencies are responsible for compiling the GHG inventory. Many countries received external support for inventory compilation or outsourced the first inventories to external contractors while there were no capacities within the government available. Ideally, trainings on inventory preparation with external experts resulted in developing sufficient capacity to prepare subsequent inventories in-house without depending on external support (see Table 2-1 Vietnam).

Table 2-1: Inventory compilation and capacity building

Countries	Description
Chile	The Office of Climate Change of the Ministry of the Environment of Chile coordinates the national inventory preparation under the National GHG Inventory System. The national inventory is the result of the collective and permanent effort of the Ministries of Agriculture, Energy, and Environment. This cross-cutting effort has strengthened the development of the Chilean inventory by adding the expert knowledge of the different participating sectoral ministries. Under the National GHG Inventory System, experts who could collaborate with the system are evaluated permanently, and the participation of these experts is determined by the requirements of the technical teams. For example, support from statistical experts helped to overcome information gaps in the area of municipal solid waste (Chile 2020).
Ghana	The Environmental Protection Agency in Ghana is responsible for the national GHG inventory and is also the leading agency for the waste inventory. The team compiling the National Communication grew with each reporting round. For the compilation of the Fourth National Communication, more institutions and experts joined the team to provide data and underwent training in the country and abroad (Ghana 2020).
Indonesia	Indonesia's Third National Communication and Second Biennial Update Report were prepared under the responsibility of the Directorate General of Climate Change of the Ministry of Environment and Forestry (Indonesia 2017). The Ministry of Public Works and the Ministry of Environment carry the responsibility for the waste sector in Indonesia. Waste statistics are provided by the latter; the former deals with waste management issues. Within the Ministry of Environment, a team that is responsible for the compilation of GHG inventories has been set up. Indonesia receives external support on waste management and climate change issues, which is provided by the Japan International Cooperation Agency (JICA) and the GIZ (Indonesia 2015).
Vietnam	For earlier GHG inventories (2005 and 2010), support was provided by JICA. The 2010 inventory for the waste sector was compiled by an expert from the Vietnam Environmental Administration. Japanese consultants provided support during the inventory preparation and guidance to the expert. The inventories for the years 2012 onwards were compiled in-house without external support (Vietnam 2015), although various capacity-building activities have been carried out in recent years in the area of climate change mitigation (Vietnam 2020b).

Source: Compilation by Öko-Institut.

Having a functional national system for GHG inventories in place makes inventory compilation much easier (see Table 2-2 Vietnam). Where statistical offices already collect activity data on waste management (see Table 2-2 Indonesia), this data decreases the efforts for inventory development in the waste sector.

Table 2-2: National system and data availability

Countries	Overview
Ghana	Ghana launched its national system for inventory preparation in 2013. The Environmental Protection Agency is the national entity for the GHG inventory. It works with several public and private institutions to compile the inventory, and each organisation has an assigned role at every stage of the inventory cycle. For each of the IPCC sectors, a team is assigned, including a competent organisation selected to lead the team (Ghana 2020). Together with its Fourth National Communication, Ghana submitted a separate National Inventory Report (Ghana 2019), which provides additional details on the national inventory system and on the data sources.
Indonesia	Activity data is available from the National Statistical Bureau that has branches in all cities in Indonesia. Data is collected regularly on an annual basis. Data provided by the National Statistical Bureau is used as activity data in the waste inventory. Some specific data on waste composition etc. is available from research projects initiated by the World Bank, GIZ and JICA (Indonesia 2015). For its Second Biennial Update Report, which was submitted in 2018, Indonesia provided updated recent inventory data, namely a time series up to 2016 (Indonesia 2018).
Vietnam	In Vietnam, a national GHG inventory system is in place based on a Prime Minister's Decision. The Department of Climate Change of the Ministry of Natural Resources and Environment is responsible for developing the GHG inventory plan and for compiling the technical report. The General Statistics Office collects data from various ministries and from regional and city authorities. It provides the activity data and related information to the Department of Climate Change. Other agencies and organisations outside the national GHG system also serve as data providers (Vietnam 2020a).

Source: Compilation by Öko-Institut.

The motivation for preparing GHG inventories in most developing countries was to comply with the UNFCCC reporting requirements. Data collection in the waste sector can be complex and time-consuming and ideally the results should be used for purposes beyond inventory compilation. Activity data used to calculate emissions from landfilling, open burning, incineration, mechanical-biological treatment (MBT), composting, and digestion is identical to the activity data needed to identify mitigation potentials and to estimate the effects of reducing, re-using, or recycling of waste (see also Chapter 5). It can also be used for the reporting of air quality and inventories of pollutants. If inventory data can be used for other purposes like management decisions or the estimates of mitigation potentials, the benefits of inventory compilation increase. This is shown in the case of Chile, where the motivation for setting up a complete and reliable inventory increased with the use of inventory data for national policy development. Table 2-3 below shows some countries in which inventory data is used for other purposes.

Table 2-3: Additional use of inventory data

Countries	Overview
Chile	The principal objective of the GHG inventories has moved from reporting to policy advice. In the past, the inventories were mainly prepared to comply with UNFCCC requirements. In recent years, the focus has shifted to providing a scientific basis for national policy development in the waste sector. This has led to higher requirements concerning completeness, accuracy and regional disaggregation (Chile 2015).
Tunisia	Inventory results will be used for the development of NAMAs and can be very helpful for setting up new projects to receive further funding to tackle climate change (Tunisia 2015).

Source: Compilation by Öko-Institut.

2.3.2. QA/QC and uncertainties

Almost all countries have established Quality Assurance and Quality Control procedures. These include checklists, use of automated software and voluntary review by third parties (see Table 2-4 Armenia, Jamaica, Namibia). Closely linked to such activities are uncertainty estimates; large uncertainties trigger more in-depth QA/QC activities. One important aspect is that the errors detected and the recommendations provided during these checks are acted upon. In minor cases (e.g. errors in units or transcription errors), corrections can be implemented directly; in other cases, they should be documented and followed up in future inventory submissions (see Table 2-4 Ghana).

Table 2-4: QA/QC and uncertainties

Country	Description
Armenia	QA/QC procedures include multiple manual and automated checks of input data, parameter values and time series consistency. The IPCC inventory software with its automated checks provides another layer of QC. All data sources used for calculating emissions have been archived and listed. To ensure time series consistency, Armenia compares and analyses the estimates with previously made inventories (Armenia 2014). Before finalising a national GHG inventory report, quality control is ensured through the internal review of the draft report by the Ministry of Nature Protection and the working group of the Inter-agency Coordinating Council followed by the handover to the stakeholder ministries and organisations for review. At the next stage, the draft report is submitted to and verified by the Interagency Coordinating Council (Armenia 2018).
Chile	Since 2015, the National GHG Inventory System has a QA/QC system in place, in accordance with IPCC good practices. The general responsibility for QA/QC rests with the coordinator of the technical team; both in the implementation of quality controls for the final inventory and in the coordination of the quality assurance process. The sectorial teams are responsible for applying quality control procedures to their respective sector. As part of the continuous improvement plan, reviews by external experts are carried out regularly (Chile 2020).
Ghana	Ghana adopted a country-specific QA/QC plan and GHG inventory manual. The GHG plan clearly articulates the inventory steps, institutional responsibilities, and timelines. The recommendations in the plan inform the training of existing experts. Quality-related procedures include quality control throughout the inventory cycle, quality assurance measures involving the review by other experts, and third-party reviews. In 2018, Ghana underwent a voluntary in-country review organised by the UNFCCC Secretariat (Ghana 2020). Detailed information on QA/QC procedures is provided in the sector chapters of the separate National Inventory Report (Ghana 2019) (Ghana 2020).

Jamaica	In Jamaica's Third National Communication (Jamaica 2018), QA/QC procedures are described for each sector. In the waste sector, QC checks were conducted that are specific to the way the activity data are handled in the emissions inventory. The comparison with activity data from other countries by using simple metrics, such as waste generated by capita, provided a useful quality check.
Namibia	QA/QC procedures, as defined in the 2006 IPCC Guidelines have been implemented during the preparation of the inventory. Namibia requested the UNFCCC and Global Support Programme to undertake a QA exercise on its inventory compilation process adopted for the Third Biennial Update Report. Most of the recommendations were addressed during inventory compilation for the subsequent report (the Fourth National Communication and the remaining ones included for action in the National Inventory Improvement Plan (Namibia 2020)).
South Africa	South Africa's QA/QC management plan is presented in its National Inventory Report (South Africa 2019). It covers the responsibilities in terms of the QA/QC process, the QA/QC plan including timeframes and quality objectives, and quality control procedures and checks. Quality assurance includes internal peer reviews of specific sectors, a public review and commenting process, and external reviews (South Africa 2019).
Tunisia	Uncertainties have been estimated for waste generation (60% uncertainty), quantities delivered to landfills (2% uncertainty of weighbridges), waste composition (20%-60% depending on landfill type) and the amount of methane flared (0.5%) (Tunisia 2014).

Source: Compilation by Öko-Institut.

2.4. Recommendations for general GHG inventory development

INSTITUTIONALISATION

With the two-year reporting cycle, which was introduced for BURs under the UNFCCC and will continue under the Paris Agreement, it has become important for developing countries to formulate and agree processes to avoid 'starting from scratch' whenever an inventory is prepared. Together with adequate documentation of assumptions, data sources and calculations, this greatly facilitates inventory preparation for each report.

KEY CATEGORIES AND METHODOLOGICAL CHOICE

It is recommended that key category analysis is conducted, and resources and efforts are dedicated to the categories identified as key. Also, it is desirable to aim to apply higher tiers in the categories identified as key.

DATA COLLECTION AND TIME SERIES CONSISTENCY

It is recommended that IPCC methodologies are used to gap-fill missing data. If different data sets are combined, ensure time series consistency in the transition from one source to the other.

QA/QC

Improving the quality of the inventory should be considered a continuous process. The elaboration of an inventory QA/QC plan is part of the reporting requirements under the Paris Agreement. Any issues and recommendations identified either during inventory preparation or during the QA/QC activities should be compiled in an inventory improvement plan if they cannot be implemented directly. At the start of a new inventory cycle, the improvement plan should be reviewed and points to be included should be identified.

3. GHG inventories in the waste sector

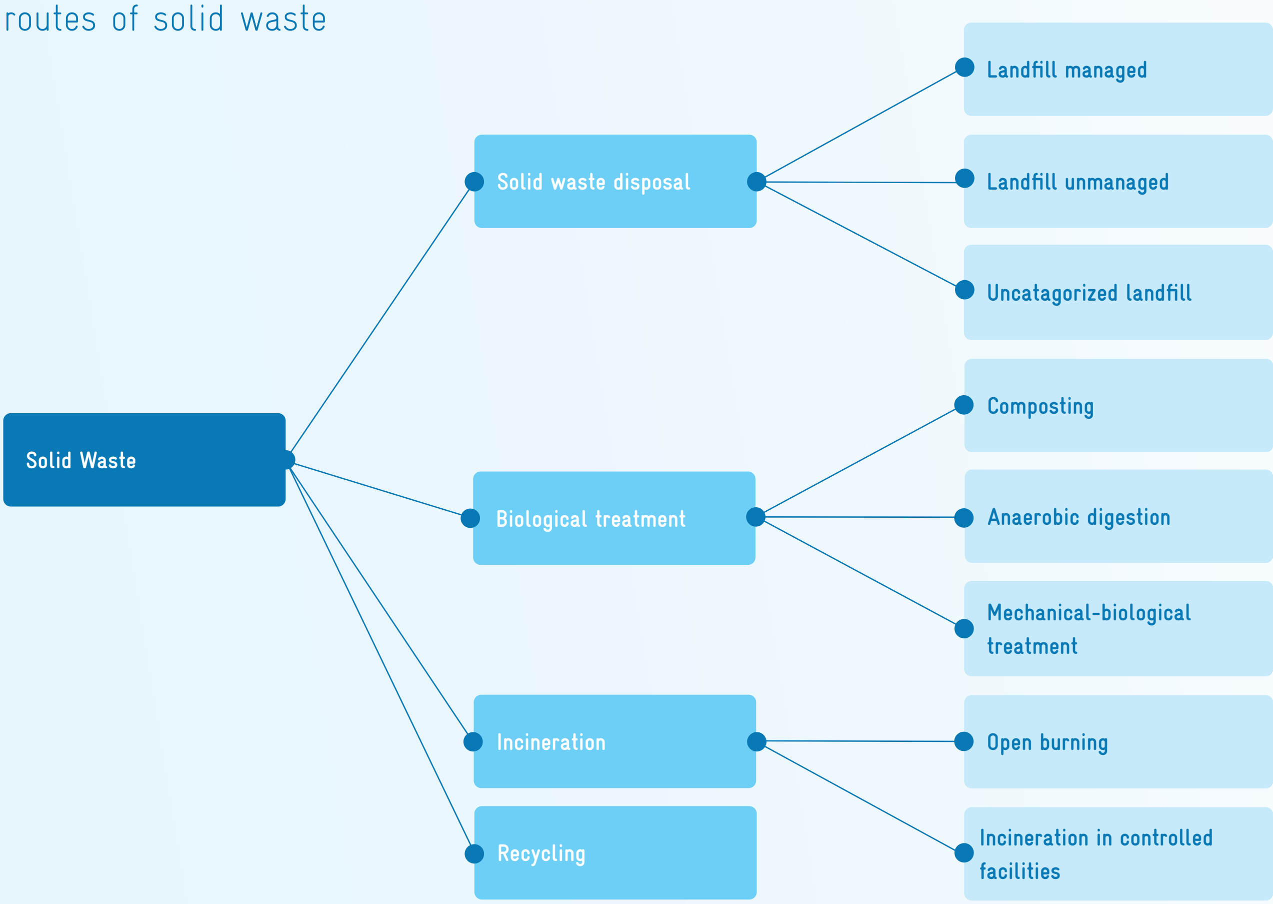
GHG emissions are generated from the treatment and disposal of liquid and solid waste. These emissions need to be reported along with those of other sectors within BURs and National Communications to the UNFCCC. Methodologies and guidance are provided in the IPCC Guidelines. According to the 2006 IPCC Guidelines, the emission estimates in the waste sector need to be carried out for four sub-categories:

1. solid waste disposal,
2. biological treatment of solid waste,
3. incineration and open burning, and
4. wastewater treatment and discharge.

The compilation of a GHG inventory in the waste sector requires the availability of sometimes complex activity data that comes from different actors and stakeholders or from national statistics.

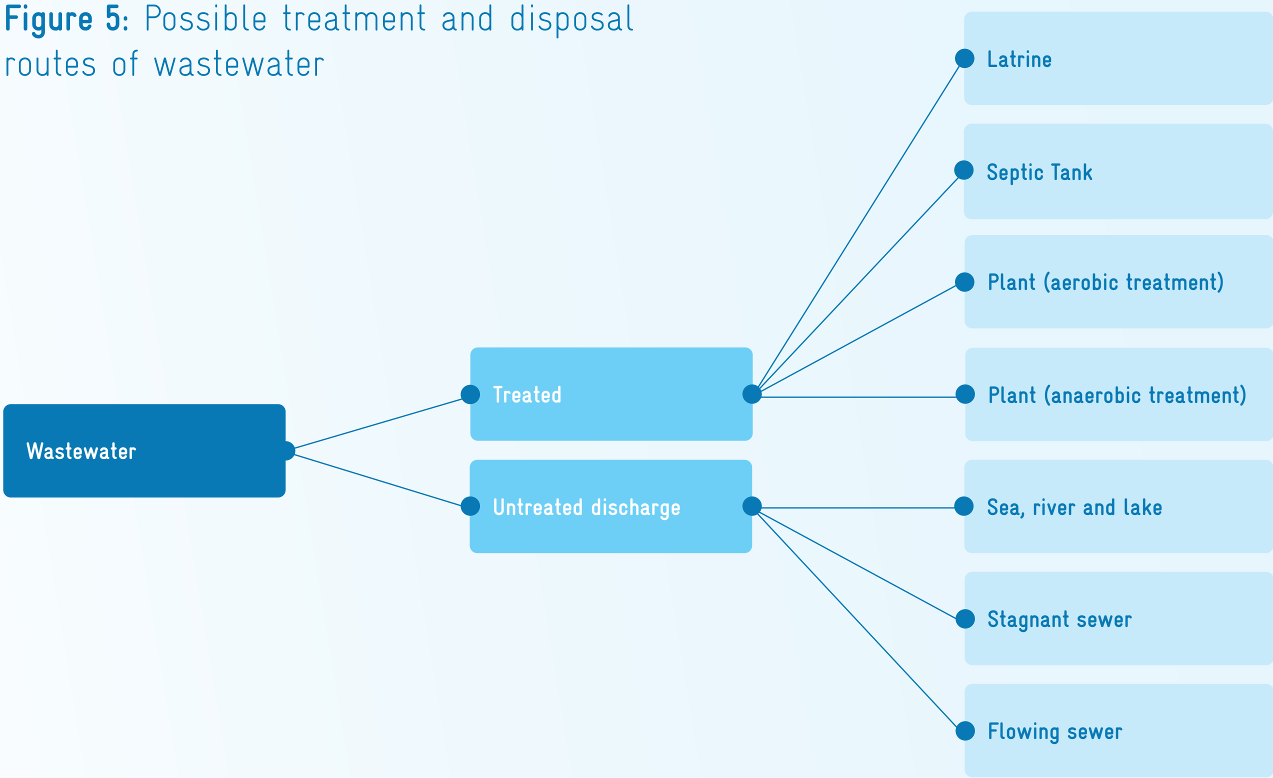
The first three categories listed mainly refer to possible routes for treatment and disposal of solid waste. An overview of pathways is shown in Figure 4 below.

Figure 4: Possible treatment and disposal routes of solid waste



Source: Compilation by GIZ.

Figure 5: Possible treatment and disposal routes of wastewater



Source: Compilation by Öko-Institut.

In the case of the fourth category, wastewater treatment and discharge, different paths exist, according to whether wastewater is treated or just discharged to the environment or sewers without any treatment. Figure 5 below provides an overview of the treatment and discharge options for wastewater.

The information provided in the following sub-chapters (3.1–3.4) is based on the guidance provided in the 2006 IPCC Guidelines and complemented by examples from some selected countries' National Inventory Reports, National Communications, Biennial Update Reports, and other national documents (see Annex II). All sub-chapters follow the same structure: an overview of the source category is provided, followed by a description of methodological issues such as those related to the choice of method, the choice of activity data and data sources, emission factors and its applicability and other characteristics of the category based on the 2006 IPCC Guidelines. At the end of the methodological overview, the changes resulting from the 2019 refinement of the 2006 guidelines are briefly presented. However, this refinement has not yet been mandated for inventory compilation under the UNFCCC or the Paris Agreement. Countries may still decide to make use of the methods or emission factors contained in the refinement, if they are appropriate for their national circumstances.

Subsequently, examples of approaches to reporting GHG emissions when limited national data is available and problems encountered from various selected countries are discussed. These approaches, which are based on the experience of developing countries, might provide orientation for countries facing similar problems. Each sub-chapter concludes with a set of recommendations for the inventory development of the sub-category.

3.1. Solid waste disposal

3.1.1. Overview

The disposal of solid waste including municipal waste, industrial waste, sludge, and other solid waste on solid waste disposal sites (SWDS), commonly known as landfills, produces methane emissions (CH_4) and carbon dioxide emissions (CO_2). Nitrous oxide emissions (N_2O) also occur to a small extent but are not significant. Methane is produced by the anaerobic microbial decomposition of organic matter in SWDS over time. A main driving force of CH_4 emissions from waste disposal on land is the amount of biodegradable waste such as food waste, garden waste, or wood disposed at landfills. If the waste is not compacted properly, the decomposition of organic material from biodegradable waste will instead release CO_2 emissions as it takes place under aerobic conditions (see Box 7). According to the IPCC Guidelines, the CO_2 emissions are not accounted for in the national GHG emission totals as they are of biogenic origin.[4] The emissions related to their production are included under the Agriculture, Forestry and Other Land Use (AFOLU) sector.

Emissions from solid waste disposal are relatively low but they have risen continuously in developing countries due to changing production and consumption patterns as well as growing populations. The amount of total waste generation is strongly related to the population numbers and can be determined based on waste generation rate per capita.[5]

To estimate the CH_4 emissions arising from solid waste disposal, the following steps need to be followed:

1. The population numbers of the country need to be determined for the last 50 years,
2. Waste generation rates in kg/cap need to be estimated for these years,
3. The share of total solid waste deposited in waste disposal sites needs to be estimated,
4. The share of the different types of waste disposal sites (managed/unmanaged) needs to be determined,
5. The waste composition of the waste landfilled needs to be estimated.

In most developing countries, there is a strong difference between the living standards in rural and urban areas. This has very large effects on consumption patterns, infrastructure and affects the whole waste sector; waste generation rates, waste collections systems, waste disposal, waste treatment, and waste composition may differ largely between urban and rural areas in a country and might need to be estimated separately.

The basis for management decisions in the waste sector is activity data as collected for the inventory compilation. The amount of generated waste per capita in relation to projections on population and the share of waste disposed can indicate the size and number of landfills needed, whereas the knowledge on the waste composition can be used for setting up recycling strategies, potentials for biogas generation, or increased composting.

Box 7: Aerobic and anaerobic decomposition

Microbial decomposition of organic material can take place under aerobic or anaerobic conditions. Under aerobic conditions, i.e. if sufficient oxygen is present, the degradable carbon is oxidised to CO_2. If the carbon comes from organic sources (e.g. food waste or sewage) the CO_2 emissions are of biological origin and are not included in the national GHG emission totals. Aerobic conditions typically occur in shallow SWDS which have not been compacted, in shallow ponds or during composting. In contrast during anaerobic decomposition no oxygen is present, and the carbon will be converted to CH_4. This typically occurs in compacted and/or deep landfills, in deep ponds, and during anaerobic digestion. In most cases both aerobic and anaerobic decomposition take place in parallel in different layers or pockets of a landfill, ponds or other treatment site.

4 Plants and trees bind CO_2 from the air, as they need this for photosynthesis. According to the IPCC Guidelines the same amount of CO_2 that is used by the plants will be released again during decomposition under aerobic conditions. Thus, this amount of CO_2 is not accounted for as GHG emissions in the national totals, as it has been stored by the plants while growing. Emissions from deforestation and land conversion are reported under AFOLU.

5 Waste generation rates are usually influenced by consumerism linked to GDP growth, use of packaging materials in the country and incentive/disincentive policies governing waste avoidance.

3.1.2. General methodological considerations

According to the 2006 IPCC Guidelines, the estimation of emissions from solid waste disposal sites should be based on the First Order Decay (FOD) method. The method accounts for the fact that the degradable organic components decay slowly over decades. Food waste or wood does not completely decompose in the year in which it is landfilled, but rather has a maturing period ranging from one year for the more labile components to over 35 years for those with the lowest biodegradation rates. FOD is based on the premise that CH_4 production is solely dependent on the amount of organic matter remaining in the waste body. In the first years when the amount of carbon remaining in the waste is highest, the CH_4 emissions are higher and then decline. According to the IPCC Guidelines, it is good practice to estimate CH_4 emissions from solid waste disposal for a period of at least 50 years. This ensures that all carbon included in the waste disposed is decomposed and related emissions are estimated in the year in which they occur.

Emission estimates can be carried out according to three different tier methods that determine the level of detail and the use of default values. All tier methods provided in the 2006 IPCC Guidelines include the application of the FOD methodology. For Tier 1 default activity data and default parameters can be applied.[6] Tier 2 applies default parameters but requires national activity data on current and historic waste disposal. Historic data needs to be country-specific for at least the last 10 years. The Tier 3 method includes good quality country-specific activity data and nationally developed key parameters or measurement derived country-specific parameters.

The 2006 IPCC Guidelines provide an Excel model[7] that includes country- and region- specific default activity data and parameters that are applicable to a calculation according to the Tier 1 method (see Chapter 4.2). The model can be applied with very limited additional data for Tier 1; it can also be used to estimate emissions using higher tiers.

In the 1996 IPCC Guidelines and the 2000 Good Practice Guidelines, the so-called mass balance method could be applied as a Tier 1 method to calculate emissions from solid waste disposal. According to the mass balance method, all emissions occur in the same year in which the waste is disposed, not taking into account the slow decomposition of the organic material over years. This leads to "correct" results if waste generation and treatment practices remain constant over decades. In the case of developing countries for which the population and the amount of generated and disposed waste are increasing, the application of this method generally leads to an overestimation of emissions as solid waste disposal was lower in historic years. If this method is applied to countries that experienced a reduction of waste landfilled and an increase of recycling, composting and landfill gas recovery, the GHG emissions would be underestimated. For calculations using the mass balance method, activity data is only required for the year of calculation.

In comparison to the 1996 IPCC Guidelines, considerably improved default data was used in the 2006 Guidelines, and default activity data was provided for more countries and regions. The use of the mass balance approach is no longer deemed good practice in most circumstances.

3.1.3. Compilation of activity data

The 2006 IPCC Guidelines provide default data on country- or region-specific levels. As a starting point, a good basis for a GHG inventory for the waste sector is to use default data if limited national statistics and resources are available; collecting country-specific activity data will make the calculation of emissions from solid waste disposal more accurate. In most cases, having national activity data on waste generation is also the basis for data on biological treatment, incineration, and open burning of waste.

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6 Default activity data and default emission factors or other default parameters are collected from different studies by literature reviews and included in the IPCC Guidelines to ensure that each country is able to calculate emissions for each category. If no country specific data is available countries should use the default value provided in the IPCC Guidelines for the country or the region the country is located or apply the default value of a country that is nearby and has similar conditions.

7 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 5. Waste: http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol5.html

Activity data needed to estimate CH_4 emissions from solid waste disposal include population data, waste generation rates, waste composition, as well as information on the amount of waste landfilled and the type of waste disposal sites. Historical data for about 50 years on all these parameters is ideally needed for estimating emissions using the First Order Decay method. For calculating CH_4 emissions from solid waste disposal, the first step is to check which data sources are available and can be used:

1. Are national statistics available on waste generation, waste disposal and waste composition? For which time period? Does a periodical update of the data occur?
2. Are research studies available on waste generation, waste disposal, and waste composition? For which years?
3. Which experts are available that can be approached and whose assumptions can be used?

If there are no sources for activity data available, IPCC default values may be used. Alternatively, the country or region can collect its own activity data for the purpose of inventory preparation if sufficient resources are available. The 2006 IPCC Guidelines include guidance and information on activity data collection. Field samples and questionnaires are common methods for collecting activity data in the waste sector.

3.1.3.1. Waste generation

a) Municipal solid waste generation

OVERVIEW

Waste generation differs widely between countries and sub-national units as they depend on consumption and production patterns. With increasing living standards, the amount of generated waste increases as well. The total waste generation is the basis for activity data that is used for the calculation of solid waste disposal, biological treatment of solid waste and incineration and open burning.

METHODOLOGICAL ISSUES

According to the 2006 IPCC Guidelines, the amount of municipal solid waste (MSW) generated is estimated based on population numbers and a generation rate of waste per capita in kg/cap/year. MSW generally includes household waste, garden and park waste, and commercial/institutional waste. Regional default values for waste generation per capita are provided in the 2006 IPCC Guidelines (Vol. 5, Ch. 2, Table 2.1). Available default data for waste generation is based on studies from the late 1990s and early 2000s; they are applicable for the more recent years. For establishing a time series for historic years, the IPCC Guidelines suggest adapting waste generation rates per capita using extrapolation or interpolation methods or other drivers such as urban population or economic indicators.

The Guidelines suggest using national population statistics or – if these are not available – international databases, such as United Nations (UN) data for population numbers (see Annex II). If waste is collected only from the urban population, only the urban population should be used for the emission estimates.

Box 8: IPCC Refinement 2019 – IPCC Waste Model – Waste generation, waste composition

According to the new IPCC waste model, which is part of the 2019 refinement, regional data and waste composition data has been updated. Updated data is available for the share of waste composition (Paper, Textiles, Food waste, Wood etc.) but also information on the waste generation rate per capita, the fraction of municipal waste disposed on landfills and the regional average Degradable Organic Carbon (DOC) has been updated.

GOOD PRACTICE COUNTRY EXAMPLES

Estimating waste generation differs among population groups in many developing countries. Given the differences in the economic situation and lifestyles that affect the waste generation rates, some countries divide population data used for emission estimates from SWDS into urban and rural population (see Table 3-1 Tunisia), while others separate population data into high income and low income urban population (see Table 3-1 Namibia). The following Table 3-1 presents an overview of the disaggregation, use of population data, and other data according to climatic zones and the split into rural and urban areas.

Table 3-1: Examples of the disaggregation of population statistics and other data

Countries	Description
Chile	National figures were disaggregated into climatic macro zones to identify different waste degradation conditions. The Northern Zone is classified as "boreal and dry temperate" and the Southern Zone is classified as "boreal and wet temperate" (Chile 2020).
Namibia	Population data is split into "high income" and "low income" urban regions for 2010. The need for this categorisation was prompted by the sustained and significant population migration from rural to urban regions with the emergence of fast-expanding suburbs to the main cities in which the dwellers' lifestyle is urban with a relatively lower purchasing power (Namibia 2014; Namibia 2020, p. 122).
Tunisia	Population data are available from 1950 onwards from Tunisia's National Statistics Institute. A distinction is made between the rural and urban population and different generation rates are applied (Tunisia 2014).
South Africa	Population data for the period 1950 to 2001 was sourced from United Nations population statistics. Statistics South Africa population data was used for the period 2002 to 2015 (South Africa 2019, p. 259).

Source: Compilation by Öko-Institut.

The population is estimated either by national statistics available in many countries or by using UN statistics (see Table 3-1), but most countries lack information on the total amount of waste generated in the country, especially along the time series. In practice, countries apply different approaches to estimate the total waste generation, depending on data availability and the circumstances in the country. An adaptation along the time series is applied in many countries.

The effect of increased living standards in relation to higher waste generation rates is reflected in the low historic waste generation rates used by Tunisia and Vietnam, including the use of different waste generation rates for urban and rural areas. Common practice applied by Afghanistan and India is the estimation of waste generation rate proportional to urban population or in relation to economic factors as applied in Namibia and South Africa.

Meanwhile, national data on waste generation rates are used in many countries for the more recent years. They are based on national studies or expert judgement (Afghanistan) or even estimated based on own landfill data (Namibia).

The following Table 3-2 shows some examples of how countries are estimating their waste generation rates for the whole time series.

Table 3-2: Examples of estimating waste generation rates in different countries

Country	Description
Afghanistan	To estimate the annual waste generation for Afghanistan, information on municipal solid waste generation rates for the urban and the rural population was collected. The data is based on studies and expert judgement by national experts from Independent Directorate of Local Governance, Municipality of Kabul and National Environmental Protection Agency, University of Kabul and Kabul Polytechnic University (Afghanistan 2020).
Brazil	The amount of MSW was calculated based on the Urban Population data and per capita waste generation rate, which was calculated by linear interpolation between the years 1970 and 2008 (national MSW rate), and from 2008 to 2016 data from angular and linear coefficients of waste generation were used for several regions. In addition, cities with more than 500,000 inhabitants had their data estimated separately (Brazil 2020).
India	According to studies from India's National Environmental Engineering Research Institute, there is a wide variation in per capita waste generation. The average value (0.55 kg/capita/day) of these quantities was used for calculations. The value is close to the average regional value for South Central Asia. As no waste generation data is available for the last 50 years, the waste quantities of historic years are only proportional to urban population (Falconer et al. 2014; India 2018).
Mexico	Mexico's Secretariat of Environment and Natural Resources provided an estimate for generated waste for each of the 32 federal entities in 2012. For the 2015 inventory, these estimates were complemented with a survey sent to the federal entities in 2016. The survey addressed each solid waste disposal site and requested general information, e.g. opening year, geographic location, depth, estimated closure year and method used for estimating annual waste. Considered methods include weighing upon entry, estimation based on the number of trucks accessing the site, estimation based on per/capita waste generation multiplied by habitants of the served municipality/municipalities. The survey gathered information for 111 of the 2637 SWDS (Mexico 2018).
Namibia	Estimates of solid waste generation for rural regions for 2010 were subsequently made by discounting solid wastes which are typically generated by urban dwellers from the landfills data available. These solid waste generation potentials were also compared with those in the 2006 IPCC Guidelines (Volume 5: Waste, p. 2.5, Table 2.1). Using the 2001, 2006 and 2011 Population and Housing Census Reports (interpolated or extrapolated for non-census years) and other data source such as the Food and Agriculture Organization (FAO); adjusting for socio-economic factors and extrapolating waste generation from Windhoek data, estimates for solid waste generation were made for the period 1995 to 2015. The process of calculating solid waste generation was not straightforward because of the lack of data (Namibia 2020).
Tunisia	Gross Domestic Product (GDP) growth is used as an indicator for the development of waste generation rates along the time series. The per capita waste generation rate for 1990 is available in a United Nations Development Programme (UNDP) study (0.5 kg/cap/day average of the urban and rural population). The 2005 generation rate of 1.3 kg/cap/day for urban areas is available in a study by the National Agency for Waste Management. The waste generation rate in 1950 is assumed to be 0.2 kg/cap/day in urban areas and 0.1 kg/cap/day in rural areas (Tunisia 2014).

South Africa	The total waste generation rate for South Africa in 1990 was assumed to be 318 kg/cap/yr. After careful examination of the generation rates and the disparities of generation rates per province, this amount was deemed to be too low. The estimated 318 kg/cap/yr was presumed to be more representative if it were related to the organic fraction of MSW only and not presenting the whole waste generation rate per capita. Using this estimate with 1990 as the base year, the MSW quantities generated and disposed of in landfills were calculated for the period of 1950 to 2000. For these calculations, the following assumptions were made. Firstly, the waste growth rate from 1990 to 2000 was assumed to follow GDP growth. Secondly, a lower waste growth rate was assumed for the earlier period (2% for the period of 1950 to 1960 and 1% for the period of 1961 to 1989) (South Africa 2009). The waste generation rate per capita was assumed to be constant (578.73 kg/cap/yr) (national weighted average from State of Environment Outlook Report) throughout the time series 2000–2015 (South Africa 2019).
Vietnam	Data on total waste generation in urban areas is available from 2004 onwards. The waste generation rate before 2004 (1990-2003) is estimated by using waste generation of 0.7 kg/person/day in urban areas. According to the National environment report 2011, the waste generation rate for rural areas is 0.3 kg/cap/day between 1995-2010 and slightly increases in the following years (Vietnam 2020a).

b) Industrial waste generation

OVERVIEW

Industrial waste that is landfilled can include very diverse components, inter alia organic materials, plastics, paper as well as construction and demolition waste. For the GHG inventory in the waste sector, only industrial waste that contains degradable organic carbon (DOC) or fossil carbon needs to be reported (e.g. wood or plastics). In most developing countries industrial waste is included under MSW as there is no separation between industrial and municipal waste.

METHODOLOGICAL ISSUES

Some default activity data on industrial waste generation is available in Table 2.1 and Table 2A.1 (Vol. 5, Ch. 2, waste data) of the 2006 IPCC Guidelines. There is no default data available for developing countries except for some Asian countries. The IPCC Guidelines suggest applying default data from countries with similar circumstances if no national activity data is available.

GOOD PRACTICE COUNTRY EXAMPLES

Information on industrial waste is provided by Afghanistan, Jamaica, Indonesia and Tunisia (see Table 3-3). Activity data on industrial waste generation is correlated to production rates in Indonesia. Tunisia calculates the amount of industrial waste proportional to GDP development. Jamaica reports only emissions from the largest industry in the country, which is not representative, but is an option if no other information is available.

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Table 3-3: Information on industrial waste

Countries	Description
Afghanistan	As historical data on industrial production (amount and/or value of production, by industry type) was not available, the historical disposal of industrial waste was estimated proportional to the GDP as recommended by 2006 IPCC Guidelines. The historical data of the GDP for 1950–1969 were provided in the unit 'million 1990 International Geary-Khamis dollars', so adjustments had to be undertaken. The trend of the period 1950–1969 was applied to the time series and first reported value (1970) of GDP in the unit 'GDP at constant 2010 prices' provided by UN statistics division. Given that the DOC and fossil carbon in industrial waste are the main parameters affecting the CH_4 emissions from solid waste disposal only the GDP of the subcategory 'Manufacturing' was used. For the estimation of the annual industrial waste from subcategory manufacturing the following industries were included: food, beverage, & tobacco, textile, wearing apparel & leather, wood & wood prod. incl. furniture, paper, paper prod. printing, publishing, chemicals & chem petroleum, coal, rubber, plastic. Only data for the period 2002-2017 was available, as such, the value of the year 2002 was applied to the period 1950–2001: 17% of GDP is from manufacturing industries. The industrial waste generation rate for small-scale industries in kg/capita/day for 2014 is based on data from a study from Bangladesh. Using the GDP of Afghanistan and Bangladesh provided by UN statistic division an industrial waste generation rate for the year 1970 and 2014 were calculated. As the industrial generation rate in Gigagram (Gg)/$million GDP/year reflects more the trend in annual industrial production, the above-mentioned industrial waste generation rate in kg/capita/day was transferred to Gg/$m GDP/year which is needed by the IPCC FOD model (Afghanistan 2020).
Jamaica	No data on the quantity of industrial waste disposed to the four municipal SWDS was provided by the National Solid Waste Management Agency. In order to determine the emissions from the most established industrial waste landfills, data was collected from the Jamaica Bauxite Institute. There are five bauxite/alumina plants in Jamaica. The industrial waste deposited to landfills comprises of boiler scales, filter press cloth and other waste material from the bauxite alumina plants. It was assumed that 50% of the waste will degrade under anaerobic conditions resulting in methane emissions. Whilst this is relatively high in uncertainty, it represents the best expert judgement available at the time. It was also assumed that 100% industrial waste goes to the disposal sites. Other industrial waste generated by bauxite alumina plants which are landfilled are red mud tailings and calcium oxalate. These were not included in the inventory as they do not comprise a biodegradable form of waste which releases greenhouse gases (Jamaica 2018).
Tunisia	In addition to domestic waste, industrial waste, medical waste, and sewage sludge have historically been stored in landfills. The share of this waste has evolved over the years, mainly due to economic development and waste policy. The evolution of industrial waste is indexed to Tunisia's GDP history (Tunisia 2014).

Source: Compilation by Öko-Institut.

c) Sludge disposal on landfills

OVERVIEW

Some countries dispose of sludge from domestic and industrial wastewater plants in landfills. The amount of sludge from domestic wastewater might be included under municipal waste or sludge from industrial wastewater may be included under industrial waste. If sludge is not disposed of in landfills, it can be composted or incinerated. In some countries, sludge is also used as organic fertilizer and applied to agricultural land. Double counting needs to be avoided by reporting a consistent amount of sludge that is disposed of on SWDS; only sludge that goes along with solid waste has to be accounted under this category. All other sludge that is composted, incinerated, treated in wastewater plants or applied to agricultural land should be accounted under other categories.

METHODOLOGICAL ISSUES

There is no IPCC default activity data available. If no country-specific activity data is available on the amount of sludge that is disposed of, composted, incinerated or spread on agricultural land, all emissions from sludge are included under wastewater treatment.

GOOD PRACTICE COUNTRY EXAMPLES

Chile, Namibia, and Tunisia provide relevant information on the estimation of activity data for sludge disposal in landfills (see Table 3-4). In Tunisia the amount of sludge disposed of in landfills is calculated proportional to the population connected to wastewater treatment plants.

Table 3-4: Information on activity data for sludge

Countries	Description
Chile	For recent years, the amount of sludge from wastewater treatment plants that is deposited in landfills is available from the Superintendency of Sanitary Services. For earlier years, the amount was estimated based on average data available for the different plants, taking into account the years when they started operating. It is known that a percentage of sludge is applied to soils. However, due to lack of data, it is assumed that the total amount of sludge is deposited in landfills (Chile 2020).
Indonesia	GHG emissions were estimated from sludge of landfilled pulp and paper, sludge of composted pulp and paper, and sludge handling in the paper industry. These emissions were estimated based on data directly obtained from pulp and paper industry. The data consisted of production level (capacity), organic parameter of wastewater treated in wastewater treatment plans, and sludge removal and treatment. Plant data were only obtained for period of 2010-2016, hence the estimates of 2000-2009 cannot be made yet (Indonesia 2018).
Namibia	The amount of sludge generated per capita for 2010 was estimated using that year's data for Windhoek City Council. Using this factor and urban population, the amount of sludge generated for the period of 1990 to 2014 was then estimated for the other urban areas (Namibia 2020).
Tunisia	Sewage sludge has historically been dumped in landfills. The evolution of sludge generation is indexed to the population connected to a wastewater treatment plant (Tunisia 2014).

Source: Compilation by Öko-Institut.

3.1.3.2. Share of solid waste landfilled

OVERVIEW

Total waste generated does not equal the amount of total waste landfilled. Along the waste stream, waste is collected, parts of the collected waste is recycled, other parts may be composted or incinerated or dumped in the landscape and the remaining waste is landfilled. Due to inadequate collection systems, waste collection rates are very low in most developing countries, especially in rural areas, and open burning of waste that is not collected is a common practice. Due to developments of waste policies as well as improvements in the collection system and infrastructure, the share of waste disposed of in landfills and thereby emissions from SWDS can increase over the time series. Recycling, composting, methane recovery, and waste-to-energy are policies that have led to a decrease of waste disposal on landfills and/or reduce GHG emissions.

The data on the fraction of solid waste disposed may be obtained from a national waste stream analysis as suggested by IPCC (2006 IPCC, Vol. 5, Box 2.1, pp. 2.6-2.7). Although this exercise is already of a higher tier, having this picture supports country-level confidence in data.

METHODOLOGICAL ISSUES

Default data on the share of waste landfilled is available in Table 2.1 and Table 2A.1 of the 2006 Guidelines (IPCC 2006). No further information on the share of waste landfilled is provided.

GOOD PRACTICE COUNTRY EXAMPLES

The amount of waste disposal is closely correlated to the amount of waste collected (e.g. Namibia, Vietnam, see Table 3-5). In Kazakhstan, the share of waste landfilled is almost 100%, while only a small share of waste is recycled. Different shares for waste disposals are applied for rural and urban areas, given a higher share in urban areas (see Namibia, Indonesia and Vietnam). The following Table 3-5 presents an overview of how different countries have made assumptions on the share of waste landfilled.

Table 3-5: Information on the share of waste landfilled in different countries

Countries	Description
Indonesia	According to Indonesian official statistics, in urban areas almost 60% of waste is taken to solid waste disposal sites while in rural areas or small cities this figure is only 30% (Indonesia 2010).
Kazakhstan	About 97% of solid waste is placed in landfills for disposal and only 3% is recycled (Kazakhstan 2014).
Mexico	For 2015, the total mass of landfilled waste was determined for each of the over 2 000 landfills in the country, by consulting state governments and state waste management programmes. The historical time series was estimated using population growth data at national level (Mexico 2018).
Namibia	It is estimated that in 2015, the waste and garbage of about 41% of Namibian households was sent to waste disposal sites, about 36% being collected on a regular basis, and 5% being collected irregularly. There is a sharp contrast between urban and rural areas; while the waste of 73% of urban households was collected on a regular (65%) or irregular (8%) basis, only about 7% of the rural households has the same service (5% on a regular basis and 2% irregularly) (Namibia 2020).
Tunisia	The amount of household waste, industrial, and medical waste disposed of in landfills since 1950 is estimated based on national data. Domestic waste, industrial waste, medical waste, and sewage sludge have historically been landfilled. The share of this waste has increased over the period mainly due to economic development and waste policy. The amount of "other" waste landfilled is estimated based on the results of a diagnostic study and the determination of the characteristics of wild dumpsites (uncontrolled landfills). Experts believe that part of the waste of the rural population is burnt. This amount, which corresponds to 12% of the waste generated by the rural population (this fraction is considered constant over the entire period), is subtracted from the quantities stored (Tunisia 2014).

South Africa	The National Waste Information Baseline Report (DEA 2012) indicated that 11% of waste was recycled in 2011 and then a further 9% goes to open burning. Due to a lack of data for other years, these values were assumed to be constant over the time period and so the percentage of generated waste which goes to solid waste disposal sites was set at 80% (South Africa 2019).
Vietnam	There is a close correlation between waste collection and waste disposal; waste that is collected is usually taken to landfills. The ratio of the share landfilled is based on the collection ratio and was assumed to be 20% in the year 1990, 40% in the year 2000 and 47.5% between 2010 and 2016 in rural areas. For urban areas, from 1995-2013, the amount of urban solid waste disposed at sites was calculated based on the average rate of solid waste per person/day and the rate of urban solid waste disposal at site. For the period 2014 to 2016, activity data (AD) of the total volume of solid waste collected and treated according to national technical standards and regulations was taken from the National environmental status report 2017 and the Viet Nam Statistical yearbook 2016 (Vietnam 2020a).

Source: Compilation by Öko-Institut.

3.1.3.3. Type of waste disposal sites (landfill managed/unmanaged)

OVERVIEW

The characteristics of waste disposal sites are very different, depending on the control, the placement and the management of the waste. In small uncontrolled rubbish pits or road dumping sites, waste is disposed without any management, whereas in managed landfills waste is compacted and covered after it is disposed. Deep and compacted landfills have the highest CH_4 emissions as waste decomposes under anaerobic conditions. In shallow and unmanaged landfills the waste is loosely stored and might decompose aerobically as enough oxygen is available (see also Box 7). The management practices of waste disposal sites have changed over time. Whereas in historic years most waste went to shallow unmanaged waste disposal sites due to missing regulations and collection systems, managed landfills have been opened or waste has been landfilled in deeper unmanaged disposal sites in more recent years due to increased population and waste generation. Some countries have also set up their own regulations that define which landfill is managed and which is unmanaged. For example, for EU Member States, the Directive 1999/31/EC on the landfill of waste defines the requirements for managed landfills.

METHODOLOGICAL ISSUES

The amount of methane produced depends on the characteristics of the landfill, as unmanaged shallow landfills produce less CH_4 than managed landfills because the organic fractions of the waste decompose under aerobic conditions. For calculating CH_4 emissions of solid waste disposal, the Methane Correction Factor (MCF) reflects the way in which MSW is managed and the effect of management practices on CH_4 generation as explained in Section 3.1.4. To apply the MCF, the share of waste disposed of at different types of waste disposal sites needs to be available.

The 2006 Guidelines define four different types of waste disposal sites and include the category of “uncategorized landfills” as a fifth option:

1. Anaerobic managed solid waste disposal sites: These 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.

2. Semi-aerobic managed solid waste disposal sites: These must have controlled placement of waste and will include all the following structures for introducing air to waste layer: (i) permeable cover material; (ii) leachate drainage system; (iii) regulating pondage; and (iv) gas ventilation system.

3. Unmanaged solid waste disposal sites – deep and/or with high water table: All SWDS not meeting the criteria of managed SWDS and which have depths of greater than or equal to 5 metres and/or high water table at near ground level. Latter situation corresponds to filling of inland waters such as ponds, rivers or wetlands with waste.

4. Unmanaged shallow solid waste disposal sites; all SWDS not meeting the criteria of managed SWDS and which have a depth of less than 5 metres.

5. Uncategorised solid waste disposal sites: only if countries cannot assign their SWDS to the four categories of managed and unmanaged SWDS above can the MCF be used for this category.

The 2006 IPCC Guidelines do not provide country- or region-specific default data for the share of waste disposed in one of the four waste disposal categories.

Box 9: IPCC Refinement 2019 – IPCC Waste Model - MCF

According to the new IPCC waste model, which is part of the 2019 refinement, there are more types of solid waste disposal sites included.

- "Managed – semi-aerobic" category is split into "Managed well – semi-aerobic" and "Managed poorly–semi-aerobic" which correspond to MCF of 0.5 and 0.7, respectively.

- Additionally, two new categories of solid waste disposal sites are added: "Managed – well active-aeration" and "Managed poorly – active-aeration" which correspond to MCF of 0.4 and 0.7, respectively.

GOOD PRACTICE COUNTRY EXAMPLES

Estimates of the disposal of waste according to the four categories are available from inventories or statistics in Armenia, Jamaica, and Kazakhstan. They use available data on managed landfills for large cities and categorise all landfills located in small cities or settlements as unmanaged. Surveys or expert judgement are used to set up estimates of the share of waste disposed in different landfill sites in Afghanistan. Tunisia measures the amount of waste disposed of in managed landfills and subtracts this amount from the total waste landfilled. Mexico provides information on the use of activity data along the time series (see Table 3-6).

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Table 3-6: Assumptions on the share of waste disposal in different countries according to the four disposal categories

Country	Description
Afghanistan	The allocation of the MSW to the various waste treatment techniques is done for the pillar years 1950, 1960, 1970, 1980, 1990, 2000, 2010, 2017 and is again based on expert judgement by national experts from Independent Directorate of Local Governance, Municipality of Kabul and National Protection Agency, University of Kabul and Kabul Polytechnic University. For the years between the pillar ones, interpolation was used. For this exercise the rural and nomadic population is considered as one group since it is assumed that the waste generation rate and disposal routes are comparable (Afghanistan 2020).
Armenia	All landfills, except for the largest landfill located in Yerevan, are non-managed. Until 2006, 100% of solid wate, and from 2006 onwards - 70% of solid waste in the capital city of Yerevan has been transported to the largest managed landfill in the country – Nubarashen landfill, with anaerobic treatment of solid waste. Starting from 2006, 30% of Yerevan's solid waste is transported to deep-layered non-managed landfills in Jrvezh, Spandaryan and Sasunik. In the cities of Gyumri and Vanadzor, solid waste is being transported to deep-layered non-managed landfills, as well; in 45 other cities of the country – to non-deep-layered non-managed landfills (Armenia 2020a).
Chile	Chile made use of cadastre data to determine the fraction of waste disposed of by type of disposal site. Each disposal site was classified according to its authorisation as a sanitary landfill, landfill or dump. Additionally, according to expert criteria, the sanitary landfills were separated into anaerobic and semi-aerobic according to whether more than 100 t per day were deposited for the first case and less than 100 t per day for the second (Chile 2020).
Jamaica	The National Solid Waste Management Authority provided descriptions of the solid waste disposal sites that are currently in operation. This allowed for the categorisation of the waste management sites into managed, unmanaged deep, unmanaged shallow, managed semi-aerobic and uncategorised. The percentage of waste going to each category was calculated for 2006-2012 using the data provided by the National Solid Waste Management Agency (Jamaica 2018).
Kazakhstan	In rural areas, waste is placed on unmanaged waste dumps and decomposed aerobically; no methane generation occurs. Landfills near large cities meet almost all the requirements for disposal of solid waste: waste is placed in layers, in a controlled way, in a certain place. All landfills located in and around the cities Almaty and Astana are identified as managed landfills, whereas all landfills in other cities are defined as unmanaged shallow solid waste disposal sites (Kazakhstan 2014).(Kazakhstan 2014).
Mexico	100% of waste was disposed of in uncategorised landfills from 1950 to 1989. For 1990 onwards, country-specific activity data is available (Mexico 2012). In 2015, a share of 12% of waste is landfilled in anaerobic managed solid waste disposal sites, 8% are disposed of in semi-aerobic managed solid waste disposal sites and the rest are distributed to unmanaged landfills (Mexico 2012/2018). In 2015. a share of 12% of waste is landfilled in anaerobic managed solid waste disposal sites, 8% are disposed of in semi-aerobic managed solid waste disposal sites and the rest are distributed to unmanaged landfills (Mexico 2018).

Tunisia	The distribution of the quantities landfilled by type of discharge (controlled/ uncontrolled) is performed based on knowledge of the quantities entering managed landfills (weighing at site entrance). In these landfills, waste is deposited and compacted. Once filled, it is equipped with a collection system and covered. The landfill is therefore anaerobic. The difference between the total amount of waste generated and the amount measured on managed landfills is attributed to uncontrolled landfills. The first managed landfill opened in 1999. By 2010, ten landfills opened in Tunisia which receive more than 85% of the stored waste annually. The distribution of the quantities disposed of in non-controlled deep discharge (lower or higher than 5 meters) is based on a corresponding study. This study of twenty dumps has calculated that 68% of waste disposed of in landfills in 2005 is less than 5 meters deep. Unable to determine this parameter more accurately, this value is applied to the entire time series (Tunisia 2014).
South Africa	Only GHG's generated from managed disposal landfills in South Africa were included since data on unmanaged sites are not documented and the sites are generally shallow. A periodic survey is still needed to assess the percentage share of unmanaged sites and semi-managed sites (South Africa 2019).

Source: Compilation by Öko-Institut.

3.1.3.4. Waste composition

OVERVIEW

In addition to waste generation and waste management practices, to calculate CH_4 emissions, it is important to know the composition of the waste disposed since only those residues with a carbon fraction will contribute to CH_4 emissions. Metal or glass does not contain carbon; plastics or electronic waste contain fossil carbon, but this is hardly degradable. Fractions with large degradable organic carbon content such as paper or food waste will contribute the most to the CH_4 emissions from solid waste disposal. Thus, the amount of CH_4 emissions is very sensitive to the size of the fraction that is inert or hardly degradable.

The variability in waste composition is very high, depending on consumption patterns, recycling rates, size of settlements and distance to cities. It also changes throughout the year in the same city; reliable data on waste composition is hardly available, especially for the long time series beginning in 1960.

METHODOLOGICAL ISSUES

The waste disposed of in landfills belongs to different waste fractions that can be grouped according to the amount of carbon included:

- Waste types with high DOC content: Food waste, garden and park waste, paper and cardboard, wood, textiles;
- Waste types with small amount or hardly degradable amount of non-fossil carbon: Ash, dust, rubber, leather;
- Inert waste with only fossil carbon or no carbon contents: Plastics, metal and glass, electronic waste.

To estimate emissions from solid waste disposal, the share of food, garden residues, paper, wood, textiles, and nappies in the total amount of waste landfilled needs to be available.

The 2006 IPCC Guidelines provide default data on waste composition for 19 regions (IPCC 2006). The default data is based on research studies on waste composition in the 1990s and the early 2000s.

Box 10: IPCC Refinement 2019 – IPCC Waste Model – Degradable organic carbon

According to the new IPCC waste model, which is part of the 2019 refinement, default values of the fraction of DOC which decomposes (DOCf) are provided for less (0.1), moderate (0.5) and highly decomposable (0.7) waste types and reflected in "Food", "Garden", "Paper", "Wood", "Textile", "Nappies" and "MSW" worksheets. In the previous model the DOCf was 0.5 for all waste types.

GOOD PRACTICE COUNTRY EXAMPLES

The following Table 3-7 presents an overview of how selected countries have made assumptions on their national waste composition. Data on waste composition is based on research studies in many countries (see Table 3-7, Brazil, Jamaica, Tunisia). This data has been generalized and applied to the total amount of MSW landfilled. Mexico uses IPCC default data for historic years and applies country-specific data since they are available. In South Africa national data is available. However, it differs so much from IPCC default data that they do not have confidence in their national data.

Table 3-7: Assumptions on waste composition in selected countries

Country	Description
Afghanistan	For Afghanistan it was possible to collect country-specific data on waste composition. The data used in the inventory is based on expert judgement by national experts from the Independent Directorate of Local Governance, the Municipality of Kabul, and the National Environmental Protection Agency. The country specific data on waste composition is in the range of the IPCC default. Lower values for wood and food waste than those IPCC default values were estimated. The lower value for wood is due to the use of wood in the households as firewood, due to lack of other fuels. The lower value for food waste is due to the socio-economic situation of Afghanistan (Afghanistan 2020).
Armenia	The results of the composition of the largest landfill in Armenia have been generalized. There is more data from other landfills available and also results of studies on the methane capture potential have been used. Based on this information a DOC parameter for the time series of 1990-2012 has been developed. During the last decade, there has been an increase in the solid waste fraction containing degradable organic carbon (e.g. food waste, paper, cardboard) (Armenia 2014).
Brazil	For the determination of DOC more than 100 analyses of MSW for different cities between 1970 and 2010 were carried out, determining the coefficients that describe the variation of the DOC of each state or region (Brazil 2020).
Jamaica	The 2010 State of the Environment Report and the National Solid Waste Management Authority provided data on the composition of waste going to SWDS based on waste characterisation studies that were done at the four wastesheds* (Jamaica 2018).
Mexico	Waste composition is available on a state-by state basis from the National Institute for Statistics and Geography (Mexico 2018)
South Africa	The inventory compilers noted that the information on national waste composition presented in the National Waste Baseline Information Report (DEA, 2012) was not compatible with the approach set out in the 2006 IPCC Guidelines, therefore, even though domestic information on waste composition was available, it could not be used for the purposes of this inventory. Instead, default IPCC waste composition values were used (South Africa 2019).
Tunisia	The composition of the waste comes from a study conducted in 2007. This composition is also verified in the context of CDM projects on landfills (Tunisia 2014).

* "Wasteshed" means a regional area of the state usually composed of multiple counties that share a common solid waste disposal and recycling system which uses the same infrastructure including landfills and recycling facilities.

Source: Compilation by Öko-Institut

3.1.3.5. Landfill gas used

OVERVIEW

Generated CH_4 in landfills can be recovered and used for power generation or it can be flared, if recovery systems that capture CH_4 are installed at the landfills. The amount of CH_4 that is recovered has to be subtracted from the total CH_4 emissions that are generated.

METHODOLOGICAL ISSUES

According to the 2006 IPCC Guidelines CH_4 recovery should only be reported if good documentation on the amount of CH_4 recovered is available. In all other cases, the default value of zero has to be applied for CH_4 recovery. The emissions that arise from the use of the recovered gas for energy use have to be reported in the energy sector.

GOOD PRACTICE COUNTRY EXAMPLES

Landfill gas recovery is still very uncommon in most developing countries. Within the framework of the CDM, some projects that capture biogas from landfills have been established. Armenia, Brazil and Tunisia are using information available in CDM reports to estimate the amount of CH_4 recovery. South Africa starts to build up and use a database for mitigation projects. Despite this, not all countries have available data on CH_4 recovery.

Table 3-8: Information on landfill gas recovery in selected countries

Countries	Description
Armenia	In December 2009 an Armenian-Japanese joint project was launched in Nubarashen SWDS, within the framework of the CDM, for methane capture from landfill as well as burning and incineration. According to the Project Monitoring Report (2010), 85 tons of CH_4 gas were captured monthly under this project which is equivalent to a about 1.02 Gg CH_4 annually (Armenia 2014).
Brazil	Recovered methane data was based on landfill CDM project monitoring reports for the years 1990-2016 (Brazil 2020).
Chile	The amount of methane recovered is obtained for each of the disposal sites that carries out methane recovery (Chile 2020). The assumptions made for estimations were always validated by the experts responsible for compiling waste disposal data on the national level (2014).
South Africa	No detailed analysis of the methane recovery from landfills was accounted for between 2000 and 2015. As noted in the previous inventory, the recovery of methane from landfills commenced on a large-scale after 2000, with some sites having a lifespan of about 21 years. To address these data limitations, the National Climate Change Response Database was implemented, which captures valuable data from mitigation and adaptation projects for future GHG estimates from landfills. This tool will be used in the future to identify and implement methane recovery projects. However, at present there are limited publicly accessible data on the quantities of methane recovered annually from managed landfills in South Africa (South Africa 2019).
Tunisia	Amounts of CH_4 began to be captured and flared from 2008. The data on the amounts of CH_4 is particularly well documented to the extent that it is part of CDM projects (2014).

Source: Compilation by Öko-Institut.

3.1.4. Choice of emission factors and parameters for estimating CH_4 emissions from solid waste disposal

OVERVIEW

Besides the activity data, different parameters are part of the calculation of CH_4 emissions from solid waste disposal according to the FOD methodology. Parameters that need to be available include the degradable organic content in the different waste types expressed in Gg C per Gg waste, the half-life value that reflects the years which the degradable organic carbon needs to decompose, the methane correction factor given as a percentage, which reflects the waste management at the disposal sites and other parameters. These parameters are mainly based on chemical analysis and the variation is rather low or only related to different climatic conditions.

In the IPCC waste model, all default parameters and emission factors are already included and can be used for each country. A short introduction on the single parameters and factors are included below. Further information is provided in the IPCC Guidelines.

METHODOLOGICAL ISSUES

According to the three Tier methods described in the 2006 IPCC Guidelines the default parameters provided in the model and the Guidelines can be applied in the Tier 1 and the Tier 2 method. Only for estimating CH_4 emissions from solid waste disposal based on a Tier 3 method nationally developed key parameters or measurement derived country specific parameters have to be used.

Based on the activity data the amount of each single waste fraction including food waste, garden, paper, wood and straw, textiles, disposable nappies and sewage sludge that is deposited in landfills could be calculated in Gg. To calculate the CH_4 emissions from the total amount of food waste and the other waste fractions deposited in landfills their amounts need to be multiplied with several parameters or emission factors. Relevant parameters that are needed for the calculation include:

- **DOC content:** Not all the carbon contained in the waste fraction will decompose. The relevant waste fractions (food waste, garden, paper, wood and straw, textiles, disposable nappies and sewage sludge) have different DOC contents that are accessible to biochemical decomposition (Default: 2006 IPCC, Vol. 5, Table 2.4, p. 2.14). The DOCs have to be measured on a wet weight basis. Thus, as food waste contains a high proportion of water the DOC for food waste is lower than for wood waste or other waste fractions with a lower water content.

- **Fraction of DOC which decomposes (DOCf):** The DOCf represents an estimate of the carbon content that is actually degraded and emitted into the atmosphere. It is assumed that about 50% of the DOC is actually degraded.

- **MCF:** The methane correction factor accounts for the fact that unmanaged/uncontrolled landfills emit less methane per volume of waste than managed landfills. The factor reflects the type of landfill management (IPCC 2006).

- **Methane generation rate constant (k) or half-life time:** The decomposition of the organic carbon in the waste takes several years. The methane generation rate constant represents the time taken for the degradable organic matter in waste to decay to half its initial mass (IPCC 2006). The half-life is affected by a wide variety of factors related to the waste composition, climatic conditions of the place at which the SWDS is located, characteristics of the SWDS, waste disposal practices and others. For countries with limited data availability on waste composition, the IPCC guidelines 2006 suggest two approaches:

  - Bulk waste option: The bulk waste option is suitable for countries without data or with limited data on waste composition, but with good information on bulk waste disposed at SWDS. Default values are estimated as a function of the climate zone.
  - Waste composition option: The waste composition option is applicable for countries which have data on waste composition. Specification of the half-life (t1/2) of each component of the waste stream (IPCC 2000) is required to achieve acceptably accurate results. If no national data is available on bulk waste, it is good practice to use the waste composition option in the spreadsheets, using the provided IPCC default data for waste composition.

For both options, default half-life values are estimated as a function of the climate zone.

- **Oxidation factor (OX):** The oxidation factor reflects the amount of methane from landfills which is oxidized in the soil or in another material covering the waste material (IPCC 2006). The oxidation factor increases with higher temperature and is highly dependent on the type and thickness of the material that covers the landfill. The OX is highly variable depending on the conditions in the individual landfill. Generalization of field or laboratory research results is not recommended and can lead to an overestimation of emissions. If the landfill is completely covered and no leakage occurs than there is no oxidation at all and the factor is zero. A factor of 1 needs to be applied if there is no coverage and complete oxidation. The use of the oxidation value of 0.1 is justified for covered, well-managed SWDS.

- **Fraction of CH_4 in generated landfill gas (F):** Landfill gas consists mainly of CH_4 and CO_2. It is necessary to determine the proportion of methane in landfill gas. The methane concentration in gas generated in SWDS is typically around 50%.

- **Methane recovery:** This is the share of methane that does not escape but is captured and used for energy or flared (landfill gas). The default value is 0 according to the IPCC, as the recovered methane varies from country to country and can only be determined nationally.

- **Delay time:** The production of CH_4 does not begin immediately after disposal in waste disposal sites. Time estimates for the delay are uncertain and will probably vary with waste composition and climatic conditions. The IPCC default value is 6 months.

GOOD PRACTICE COUNTRY EXAMPLES

Within the literature review, all selected countries except Mexico applied default parameters to calculate the emissions arising from solid waste disposal. Hence, a table with country-specific examples is not provided in this section.

3.1.5. Recommendations for estimating CH_4 emissions from solid waste disposal

3.1.5.1. Overview

To estimate CH_4 emissions from solid waste disposal it is recommended that the 2006 IPCC Guidelines are applied, as updated and more detailed default data is available. For the calculation, the use of the IPCC Excel model (see Section 4.2) is highly recommended. As this calculation is based on the FOD method, it presupposes the availability of activity data for 50 years. The following recommendations introduce step-by-step the procedure to collect and establish activity data for a time series of 50 years. The recommendations mainly include the adjustment of default or country-specific activity data along the time series. The application of constant activity data from 1950 onwards would overestimate emissions from solid waste disposal. Especially in developing countries there is an increase of total waste generated due to increased living standards and urbanisation trends. Applying recent activity data or default values relating to 1950 would not take this into account. Thus, the focus of the recommendations is based on the adjustment of activity data along the time series according to country-specific circumstances.

Activity data needed to estimate CH_4 emissions from solid waste disposal include population data, waste generation rate, share of total waste landfilled according to different types of waste disposal sites and waste composition. Besides the activity data, further parameters are needed in the calculation. These parameters are available as IPCC default data.

Solid waste that is disposed of in landfills includes MSW, industrial waste, sludge, and other waste. As MSW disposed of in landfills has the highest share and only a few countries have activity data on other solid waste types available, the recommendations focus on MSW. If data is available on the other waste types, the recommendations also apply for industrial waste, sludge, and other waste. Only waste generation rates are calculated differently (see Table 3-3, Table 3-4).

3.1.5.2. Calculation of total waste generation

To calculate the amount of total waste generated in a country, the total population has to be multiplied with a country-specific waste generation rate.

Population data is available from the UN for all countries from 1950 onwards. If no national statistics are available or if national statistics lack a consistent time series, UN data can be used. Emission estimates depending on population data are sensitive to the share of population living in different climate zones in the country and to the share of population living in urban and rural areas. Therefore, it is recommended that the CH_4 emissions from solid waste disposal are calculated by using separate population data for urban and rural population and separate population data for different climate zones.

Climate zone

Data sources	Country-specific population data according to different climate zones.
Methodology / recommendation	If there are different climate zones in the country, calculate estimates for each climate zone separately by including the share of population living in the climate zone and selecting the right region in the IPCC model. Data on the share of waste landfilled, type of landfill site, and waste composition can be applied to all climatic zones, if there is no detailed data available.
Exemption	If population cannot be distributed to different climate zones, choose the zone in which most of the population lives.
Country examples	Chile (Table 3-1), in many countries not relevant.

Share of rural – urban population

Data sources	If no national statistics are available, use UN data (see Annex II).
Methodology / recommendation	Calculate the share of urban and rural population, and allocate different waste generation rates, waste landfilled shares, and waste treatment data. Prepare two waste models: one for the urban and one for the rural population. Insert urban population, urban waste generation rates, waste landfilled shares, disposal according to the type of treatment sites and waste composition data for urban areas. Insert rural population, waste generation rates in urban areas etc. into a separate model. Add together the CH_4 emissions estimated from urban and rural waste models to determine the total CH_4 emissions from solid waste disposal of the country.
Exemptions	If it is not possible to estimate urban and rural population separately due to lack of different waste generation rates etc. and no other assumptions can be made, estimate CH_4 emissions for total population in one model.
Country examples	Namibia, Tunisia (Table 3-1), and Vietnam (Table 3-2).

Waste generation rate per capita

Waste generation increases with higher income level and growing urbanisation. According to IPCC defaults, waste generation rates range from 210 kg/cap/year in Central Asia and Central America and 290 kg/cap/year for Africa to 640 kg/cap/year in Northern Europe.

Waste generation rates that are based on a research study or on IPCC defaults are generally only available for one or a few years in the time series. If they are based on statistics, data might be available for the most recent years, but there is almost no data source available that includes waste generation rates from 1950 onwards.

According to the IPCC Guidelines, defaults are applicable for the year 2000. As waste generation follows consumption and production tendencies, it is more likely that waste generation per capita in 1950 is lower than in the year 2000 and higher in the year 2010. To estimate CH_4 emissions from solid waste disposal, it is recommended that the waste generation rate is adapted along the time series.

Data sources	National statistics, national studies, data from CDM projects, measurements, IPCC default data.
Methodology / recommendation	Example of the calculation of historic waste generation rate: 1. Use country-specific data if available for the most recent year; if no national data is available, apply IPCC default data 2. Download a time series for GDP development in changes in percent (national data or UN data) for the last 50 years, a) Instead of GDP development annual changes in percent of urban population growth can also be applied or a constant percentage change between 1% and 5% can be used. 3. Subtract the changes in percent from the GDP development from the waste generation rate applied in 2010 for each single year in the time series according to the calculation shown in the table below. 4. Historic waste generation rates in 1960 should not be below 0.2 or 0.1 kg/cap/day (this is equivalent to 36 – 73 kg/cap/year). 5. For the rural population, it is recommended that a lower waste generation rate is applied (see Tunisia or Vietnam Table 3-2). **Example calculation:**
Country examples	India, Tunisia, Brazil, Vietnam (Table 3-2).

Year	2010	2009	2008	...	1961	1960
Waste generation rate [Unit]	550	536	511.6	...	85.7	82.2
Annual Change GDP %		+2.5%	+4.6%	...	0.0%	+4.0%
Calculation		=550-(550*2.5%)	=536-(536*4.6%)	...	=85.7-(85.7*0%)	=85.7-(85.7*4%)

Total waste generation to be used as activity data for the other subcategories

Based on the population and on the waste generation rate per capita, the total amount of waste generated in the country is available and can be used for further calculations. The total amount of generated waste is the basic activity data for solid waste landfilled, biological treatment (e.g. composting), incineration, and open burning. Based on country-specific circumstances, the shares of the different activities vary. To avoid double counting, the sum of all activity data used for the different management practices must be similar to the total amount of waste generated. The following box provides an example of the calculation on the amount of total waste generated that is used in the different subsectors of solid waste.

Box 11: Example calculation of activity data for waste landfilled, composted, open burned incinerated and other

Total amount of waste generated: 71 million inhabitants x 250 kg/cap/year = 17 719 Gg MSW

Amount of waste landfilled:	55%	x	17 719	=	9 745 Gg
Amount of waste composted	10%	x	17 719	=	1 772 Gg
Amount of waste open burned	20%	x	17 719	=	3 544 Gg
Amount of waste incinerated:	5%	x	17 719	=	886 Gg
Amount of waste recycled or unknown:	10%	x	17 719	=	1 772 Gg

Total amount of waste landfilled, composted, open burned, incinerated and recycled:

9 745 + 1 772 + 3 544 + 886 + 1 772 = **17 719 Gg MSW**

3.1.5.3. Share of solid waste landfilled

The amount of waste landfilled varies widely and is strongly related to the amount of waste collected. Collection rates in low income countries are generally lower than in high income countries ranging from 39% in low income countries up to 96% in high income countries (Kaza et al. 2018).

Data sources	Statistical data, data from CDM projects, expert judgments, IPCC defaults.
Methodology	If statistical data on the share of waste landfilled is available, this data is used for the most recent years. The share of waste landfilled must have been lower in historic years and might be lower in rural areas. It is recommended that the recent share of waste landfilled is downscaled in a similar way to the adaptation of the waste generation rate by x% per year, if no data is available for the time series.
Exemption	Some parts of total waste generated may be recycled, open burned etc., thus only a share is landfilled. Some countries may not know the exact share of the waste landfilled from total waste generation but have data available that measures all incoming trucks at the landfills and can estimate the total amount of waste landfilled in gigagram by counting the trucks. Instead of the total waste generation and the share landfilled the measured amount of waste landfilled can be included under "total waste generation" in the waste model and the share set to 100%. The share of waste landfilled can increase due to improved collection systems. The share of waste landfilled can decrease if more recycling takes place or waste policies ban special waste types from disposal on landfills.
Country examples	Vietnam (Table 3-5).

3.1.5.4. Categories of waste disposal sites (managed, unmanaged landfills)

Countries need to estimate the share of waste that is disposed of in different landfill site categories. As this task is very region- and country-specific, there are no IPCC default values provided. The IPCC model includes some dummy data, this means data that is not very useful or realistic to apply for most countries.

Data sources	Statistical data, data from CDM projects, measurements, research studies or expert judgement.
Methodology / recommendation	Consider the relation of managed or unmanaged deep landfills in large cities and shallow unmanaged landfills in small cities and rural areas. The MCF of managed or unmanaged deep landfills would have to be applied to waste generation rate times population of large cities, etc. If no country-specific data is available for the most recent years (from 2000 onwards), the data included in the IPCC model can be used. For historic years and rural areas, the category of "unmanaged shallow" might be appropriate. Otherwise it has to be assumed that 100% of waste is disposed in "uncategorized" landfills.
Calculation example	Total population: 10 mn; population living in large cities: 6 mn (60% of total population); population living in small cities: 1 mn (10% of total population); population living in rural areas: 3 mn (30% of total population). Share of waste going to anaerobic managed waste disposal sites = 60% Share of waste going to unmanaged deep waste disposal sites = 10% Share of waste disposed on unmanaged shallow waste disposal sites = 30%
Note	IPCC defaults included in the model for distribution of waste to the different landfill categories are not appropriate for most developing countries. The data already included in the model assumes that 25% of the waste in 1950 is disposed of in managed landfills, which is not realistic. Please follow the recommendation provided above.
Country examples	Armenia, Kazakhstan, Namibia, Mexico (see Table 3-6).

3.1.5.5. Waste composition

The share of food waste, paper, wood, textiles, nappies and plastics is influenced inter alia by economic development, culture and climate. It varies between regions and throughout the year. Low income countries have the highest share of organic waste (above 60%), while in high income countries the share of food waste is below 30% and the share of paper, plastics, and other inorganic materials increases (World Bank 2012).

Data sources	Statistical data or research study, data from CDM projects, IPCC defaults.
Methodology	Apply country-specific data (if available) or IPCC default data. Generalize research study results for the total amount of waste disposed and keep it constant along the whole time series if no better data is provided. If there is good data on bulk waste[8] available, choose the bulk waste option in the IPCC model; otherwise, use the default composition data as included in the IPCC model.
Country example	Armenia, India (Table 3-7).

8 Bulk waste is a waste type that can contain all waste categories (e.g. garden waste, furniture, wood). The detailed composition of the different waste fractions for bulk waste is not known. IPCC default values are based on different studies.

3.1.5.6. Time series

For solid waste disposal including MSW, as well as industrial solid waste, sewage sludge, and other waste, a long time series of about 50 years needs to be established if the FOD method is applied. There are different methodologies for how to set up a time series for such a long period and what data sources can be applied.

<table>
<tr><td>Step 1</td><td>If possible, divide the long time series of 1960-2010 into different periods according to differences in economic growth, waste management, waste policies or data availability.</td></tr>
<tr><td>Step 2</td><td>Apply different assumptions based on data from studies, surveys or expert judgements on waste generation, waste landfilled, waste treatment in the different periods, e.g. the period before the opening of managed landfills and the period after the opening of managed landfills when most parts of the landfilled waste is disposed of in managed landfills.</td></tr>
<tr><td>Option for Step 2</td><td>If recent data on waste generation and waste landfilled is available it can be scaled for historic years based on the development of economic indicators or other drivers (see Section 3.1.5.2).</td></tr>
<tr><td>Calculation example</td><td>Waste generation rate in 2010 = 459 kg/cap/yr
Downscaling factor per year: 0.5% (e.g. based on annual GDP growth or changes of the urban population).
Waste generation rate in 2009: 459 * 99.5% = 457
Waste generation rate in 2008: 457 * 99.5% = 454</td></tr>
<tr><td>Option for Step 2</td><td>Mix default data with country-specific data, if data is not available along the time series. Mexico divided the long time series into two periods 1950 to 1990 and 1990 to 2010. For the first period no data is available, thus IPCC default data has been applied. In the second period from 1990 onwards, country-specific data could be applied.</td></tr>
<tr><td>Option for Step 2</td><td>Apply (weighted) average values if studies for different regions are available or use study results for different years (see Table 3-2 Brazil).</td></tr>
<tr><td>Step 3</td><td>Use research studies, survey, expert judgements or statistical methods like interpolation or regression formulas to fill in missing years in the time series.</td></tr>
<tr><td>Note</td><td>Check that default data or country-specific data in historic years is lower than in recent years (waste generation, share landfilled etc.). Most default data applied for historic years needs to be downscaled as described under Section 3.1.5.2 as it is more applicable to recent years than to historic years. For some countries, default data might be very low in comparison to the recent activity data and can be applied to historic years. Nevertheless, if default data is applied it needs to be checked that historic data on waste generation rate etc. is lower in historic years.</td></tr>
<tr><td>Example</td><td>In the example, there is country-specific data for waste generation from 2000 onwards available. For the years 1960 to 1990 default data has been applied. This default data is higher for the years 1960 to 1990 than in the year 2000, which is not realistic.
<table>
<tr><td></td><td></td><td>1960</td><td>1970</td><td>1980</td><td>1990</td><td>2000</td><td>2010</td></tr>
<tr><td></td><td></td><td colspan="4">IPCC default</td><td colspan="2">country-specific</td></tr>
<tr><td>Waste generation rate</td><td>kg/cap/yr</td><td>415</td><td>415</td><td>415</td><td>415</td><td>395</td><td>445</td></tr>
</table>
In this case, it would be better to downscale the country specific data available for the year 2000 (see above) instead of using IPCC default data.</td></tr>
<tr><td>Documentation</td><td>Document all assumptions, research studies and methods applied.</td></tr>
</table>

3.1.5.7. IPCC defaults for parameters

In most countries there are no country-specific parameters available and as long as no Tier 3 method is applied it is not necessary to develop country-specific parameters. Default parameters are already included in the IPCC Waste Model (see Section 4.2). In the absence of national models and parameters, it is recommended that the IPCC model is applied with default parameters as described in Chapter 3.1.4.

Some countries have country-specific DOC values for different waste types. If these DOC values are used ensure that they are measured on a wet weight basis and not on a dry weight basis. The water content of food waste is very high in comparison to wood or paper; thus, the DOC of food waste is correspondingly lower.

3.2. Biological treatment of solid waste

3.2.1. Overview

The biological treatment of solid waste covers composting and anaerobic digestion of organic waste. Decomposition of biomass during biological treatment is much faster than on landfills and the CH_4 and N_2O emissions are estimated on an annual basis without the need for long time series as in the case of landfills.

The 2006 IPCC Guidelines introduced a methodology for the estimation of GHG emissions from composting, anaerobic digestion, and mechanical-biological treatment. The difference between composting and anaerobic digestion is that the former is mainly an aerobic process with anaerobic pockets whereas in the latter the decomposition takes places without oxygen under controlled environmental parameters. Mechanical-biological treatment can include composting, anaerobic digestion, burning, and recycling and needs to be analysed individually for each installation.

Methane and nitrous oxide emissions are estimated using the quantity of organic waste processed by treatment type (composting and anaerobic digestion) and the respective emission factors. Emissions from mechanical-biological treatment need to be calculated for each step according to the respective methodologies. Any methane recovered for flaring and/or energy use needs to be deducted from the calculated emissions.

3.2.2. Methodological issues

CHOICE OF ACTIVITY DATA

Activity data can come from the same sources as discussed in the sections on solid waste disposal. It is good practice to use national data if available. If no country-specific data is available, the IPCC Guidelines provide some regional default factors (IPCC 2006) and values used by individual countries (IPCC 2006) for the fraction of Municipal Solid Waste composted. The available information is rather incomplete: neither dataset has values for Africa, the Caribbean, Central America or Oceania. Anaerobic treatment is assumed to be non-existent if a country has no national data.

CHOICE OF EMISSION FACTOR

The IPCC Guidelines provide default emission factors for Tier 1. For anaerobic digestions, N_2O emissions are considered negligible. Tier 2 requires countries to develop a national emission factor; for Tier 3, emissions need to be calculated for each treatment plant separately using individual emission factors.

COMPLETENESS AND CONSISTENCY

To avoid double-counting or gaps in the inventory, the following approach should be taken:

- Emissions from the energy use of recovered methane should be reported as a memo item under the Energy Sector.
- Flaring should be reported under Biological Treatment. It is good practice not to estimate these emissions; any CO_2 is of biogenic origin and not accounted for, and N_2O and CH_4 emissions from flaring are considered negligible.
- If sludge from wastewater treatment is disposed of along with solid biological waste, emissions should be reported in this category and not under wastewater.

The 1996 IPCC Guidelines and 2000 Good Practice Guidance did not include this source category. It might therefore be challenging for countries to establish a complete time series if data is not available for all years.

Box 12: IPCC Refinement 2019 – Biological treatment

There is no refinement of the guidelines concerning the biological treatment of waste, hence the 2006 IPCC Guidelines remain the most recent guidelines.

3.2.3. Good practice country examples

Very few developing countries have reported emissions from composting or anaerobic digestion so far; the source category was not included in the 1996 IPCC Guidelines. All countries studied use the Tier 1 methodology with default emission factors; the uncertainty of the emission factor is considered high. The activity data is collected bottom-up using site-specific data in all cases. In some cases, the authorities are aware that the reported information is incomplete, which will lead to an underestimation of emissions from composting. In the absence of better data, such an approach is recommended compared to the situation of not estimating emissions from the sector at all.

Table 3-9: Information on biological treatment in various countries

Country	Description
Chile	A Tier 1 methodology that involved the use of default emission factors provided in the 2006 IPCC Guidelines was used. Activity data were collected from various sources: review of approved composting and aerobic digestion projects, waste recovery data from a study by the undersecretary of regional and administrative development, and data from the pollutant emission and transfer register (Chile 2020). The Chilean GHG inventory team also visited and contacted some companies and large municipalities that had composting programs in place (Chile 2014).
Mexico	Methane and N_2O emissions are estimated using a Tier 1 method and default emission factors from the 2006 IPCC Guidelines. As activity data, the installed capacity of composting plants for the years 1991 to 2015 is available, including their dates of start of operation (Mexico 2018).
Tunisia	Emissions for composting are estimated using default emission factors and national statistics. Operators are obliged to report the quantities of organic waste composted but it is unclear whether all operators report and are included in the statistics. The uncertainty is therefore assumed to be 20 %, doubling the normal uncertainty for Tunisian statistics; 100% uncertainty is assumed for the emission factor based on the range given by the IPCC (Tunisia 2014).
Vietnam	According to the National Environmental Status Report in 2017, five solid waste treatment technologies had been recognised, including two combustion technologies. Vietnam had about 35 solid waste treatment facilities/plants using bio-composting technology to make organic fertilisers. AD serving the calculation of emissions from biological treatment was based on data on the treatment capacity of factories/provinces in the National environmental status report 2017. Since no data on the total amount of solid waste treated by biotechnology was available, the assumption was based on the capacity of the biotech solid waste treatment plants in localities with total volume of solid waste treated equal to 70% of the maximum design capacity of factories/localities. Since no national-specific emission factor (EF) was available, the default EF of the 2006 IPCC Guidelines are used (Vietnam 2020a)

Source: Compilation by Öko-Institut.

3.2.4. Recommendations

Data on composting is incomplete in most countries. While the practice exists in many countries, it is often conducted at a local level with no data collection and/or reporting requirements. If possible, use existing data and apply the general gap-filling methodologies (e.g. Chile, Table 3-9). If a complete time series cannot be established, only calculate emissions for recent years. For earlier years, use notation key NO (Not Occurring) if the practice did not exist or NE (Not Estimated) if the practice existed but no emission estimate was possible. Ensure consistency with activity data in the other waste categories (i.e. in the case of biological treatment of sludge).

3.3. Incineration and open burning

3.3.1. Overview

Waste can be burned in installations, burned openly or self-ignite on unmanaged landfills. Open burning typically takes place on the ground, in barrels or in open dumps and is a common practice in many non-Annex I countries. In addition to the greenhouse gases covered by the reporting guidelines, open burning is also a source for black carbon[9] and other pollutants with resulting impacts for the air quality. Black carbon is also a driver for climate change, but it is not required to be reported under the IPCC Guidelines. Waste incineration is more common for hazardous and/or medical waste whereas incineration in controlled facilities rarely takes place in developing countries. The 1996 IPCC Guidelines and 2000 Good Practice Guidance only include a methodology for incineration; open burning was introduced in the 2006 IPCC Guidelines. The methodology for estimating emissions is the same for both types of combustion; they differ in the emission factors and oxidation rates.

CO_2, CH_4, and N_2O are generated during the combustion process. For CO_2 only emissions from fossil sources (e.g. plastics or some textiles) are included in the net national totals; emissions from biomass materials (e.g. paper or food) are not included. If the heat generated is used for energy purposes, emissions have to be reported under the energy chapter. Typically, this occurs with electricity generation or co-combustion for process heat, e.g. in cement installations.

9 Black carbon, or soot, is part of fine particulate air pollution (PM2.5) and is formed by the incomplete combustion of fossil fuels, wood and other fuels.

3.3.2. Methodological issues

CHOICE OF METHOD FOR CO_2 EMISSIONS

The methodology requires the calculation of fossil carbon burnt per waste type. To do so, it is necessary to estimate the fossil fraction per waste type. The Guidelines provide methodologies and default values to convert the wet or dry weight of the waste into fossil carbon. It is good practice to differentiate between different waste types if the information is available. For Tier 1, countries can use the default factors provided in the IPCC Guidelines; for Tier 2 and Tier 3, it is necessary to develop country-specific or installation specific data.

CHOICE OF METHOD FOR CH_4 AND N_2O EMISSIONS

To calculate emissions of methane and nitrous oxide, it is necessary to estimate the quantities of waste burned by type and combustion technology. For Tier 1, default emission factors and approaches for estimating activity data are provided; for higher tiers it is necessary to develop national or site-specific information. The activity data used per waste type should be identical for the calculation of all three greenhouse gases.

ACTIVITY DATA

Incineration of MSW typically takes place in a relatively low number of controlled installations if at all. It is good practice to collect data from these installations if possible. If not, some default and country-specific values are provided (IPCC 2006) but information for developing countries is very limited. It is good practice to analyse the composition of MSW incinerated as it might differ from the composition of MSW generated. If country-specific data is generated, it is important to ensure the representativeness of the samples. Hazardous and clinical waste is often burned on site in hospitals and industry and the collection of plant-specific data might not be possible.

Open burning of waste is a common practice and should be considered in detail. Burning can be intentional or due to self-ignition on unmanaged landfills. In the absence of official data, the guidelines provide a methodology to estimate the amount of waste burned openly. The following is required:

1. Population burning waste: This is the population for whom waste is not collected or waste is sent to open dumps where burning takes place; typically, this includes the rural population and some part of the urban population, depending on national circumstances.

2. Per capita waste generation rate for population burning waste: This might be different from the national average because open burning typically takes place in low-income areas but in the absence of detailed data, it is good practice to be consistent with the generation rates used for solid waste disposal and biological treatment.

3. Fraction of waste burned: Open burning of waste is an incomplete process. The default assumption is that 60% of the waste is oxidised; 40% remains together with the ashes on site.

EMISSION FACTORS

For CO_2 anthropogenic emissions depend on the fossil carbon content of the waste. The same parameters as used for solid waste disposal should be used to estimate fossil carbon. For open burning not all carbon is converted to CO_2; an oxidation factor of 58% is given as the default. Emissions of CH_4 and N_2O depend on the combustion technology. The 2006 Guidelines provide default values for different types of incineration installations and for open burning. If no country-specific information is available, it is good practice to use the default values.

COMPLETENESS AND CONSISTENCY

It is necessary to carefully reflect incineration and the open burning of waste in various source categories to avoid double counting or omissions:

- Energy: If the heat generated through incineration is used for electricity generation or for other energy use such as co-combustion in industry, related emissions should be reported under energy,

- AFOLU: Agricultural residue burning should be reported in the AFOLU sector,

- Solid waste disposal: The amount of waste burned might need to be deducted from the amount of waste which is transported to solid waste disposal sites depending on national circumstances. If open burning takes place in landfills, it reduces the available DOC; this should be estimated and reflected in the calculations for emissions from solid waste disposal.

It is good practice to ensure the consistency of data across all these source categories.

Box 13: IPCC Refinement 2019 – Incineration

5.C.1: New guidance on thermal technologies available, including pyrolysis, gasification and plasma.

5.C.2: Update of oxidation factor from 0.54 to 0.71.

3.3.3. Good practice country examples

Waste incineration in controlled installations is not yet practiced in most developing countries except for hazardous and/or medical waste. In the absence of official statistics, several countries use the quantity of hospital beds and waste generation rates per bed to estimate the necessary activity data.

Most developing countries use the population in rural areas as the basis for determining emissions from open burning of waste. The fraction of waste burned by the rural population varies according to national circumstances and information available from 20% (Tunisia) to 61% (Namibia) in the analysed countries. It is good practice to explain these values and document the assumptions made. Some countries have national data on MSW composition; for all other parameters default values from the IPCC Guidelines are used. Tunisia explicitly reported a mechanism to achieve consistency between waste and energy emission inventories concerning activity data and waste composition. It is good practice to ensure such consistency.

Table 3-10: Incineration and open burning of waste in various countries

Country	Description
Armenia	In rural areas of Armenia, vegetable waste (tree branches, dried leaves, grass, etc.) generated by gardens and land plots are burned on site. The amount of open waste incineration was calculated based on the number of the rural population. The national factor of 0.40 kg/person/day (or 0.146 ton/person/year) was used for determining the per capita SW generation ratio for rural population (Armenia 2020a).
Brazil	The amount of waste incinerated from 1990 to 2010 was defined based on installed capacity data and assumptions of operating incinerator usage rate from different data sources for different types of waste. Fraction of carbon content in waste (CCW), fossil carbon fraction (FCF) in the waste, and burn out efficiency of combustion of incinerators for waste values (EF) were used from the 2006 IPCC Guidelines (Brazil 2020).
Ghana	To improve data availability the responsible ministries will collect data on incineration of food and biomedical waste through local governments. The Environmental Protection Agency will analyse the reports and provide feedback directly to the data providers in order to improve data quality. For open burning, districts need to estimate the quantities and report to the Ghanaian local government ministry. Academia is involved in the data collection process in order to improve data quality (Ghana 2015).

Jamaica	Jamaica distinguishes into three types of waste that is incinerated, medical waste, MSW burned on backyards and MSW burned at landfills. Medical waste incinerated: There is very little documentation on the quantity of waste that is generated and incinerated by both public and private healthcare facilities. To determine the quantity of waste incinerated, data on the medical waste generation rate (kg/bed/day) and the number of beds in the hospitals categorised by region were collected. Hospitals are categorised into four regions (North, West, South, East). Studies have indicated a generation rate of 0.24-1kg/bed/day for Jamaican public hospitals. However, an average generation rate of 1.88kg waste/bed/day was calculated using the quantity of waste incinerated per day and the number of beds for St Ann's Bay hospital. This generation rate was considered to be generally representative of hospitals in Jamaica and was applied to the hospitals in the Southern and Western regions to determine the quantity of waste incinerated (in kg/yr), by calculating the product of the number of beds, their occupancy rates, and the waste generation rate of 1.88 kg/bed/day. Open burning: The fraction of the population that reportedly burned their waste in the backyard in 2006 and 2010 were 38% and 32% respectively. In the absence of year specific data, the percentage obtained for 2006 was applied to 2007- 2009 while 32% was used for 2010-2012. The fraction of municipal solid waste disposed to SWDS is reportedly 75% as discussed in section 7.2.2 above. It was therefore assumed that 50% of the amount disposed to the SWDS is burnt as not all the waste is burnt when there are fires at landfills. The 2006 IPCC Guidelines for National Greenhouse Gas Emissions Inventories, Section 5.3.2 suggests that if all waste is burned without leaving a residue, the fraction of waste burned relative to the amount of waste treated should be 1. For landfill fires, the fraction burned was estimated to be 0.6 as only this fraction of the waste is burnt with 40% of waste being residue. Backyard burning was estimated to be 0.9 as nearly all waste is burned with a small amount of ash residue. (Jamaica 2018)
Mexico	For waste incineration, a Tier 1 methodology in accordance with the 2006 IPCC Guidelines is used, applying default emission factors. The amounts of waste incinerated is available from information on the capacity of authorised incinerators. In line with data from the operating certificates for the year 2013, it is assumed that the amount incinerated corresponds to 50% of the installed capacity of the incinerators (Mexico 2018).
Namibia	It is estimated that at national level in 2015, the waste and garbage of some 32% of Namibian households were open burnt. A sharp contrast is observed between urban and rural areas: approx. 10% of urban households and some 61% of rural households use open burning to dispose of their solid waste (Namibia 2020).
Tunisia	The estimation of quantities of medical waste incinerated in 2010 is based on several parameters: capacity (number of beds) of institutions incinerating medical waste, medical waste per bed, and the bed occupancy rate for the year in question. Tunisia estimated the quantity of household waste disposed through open burning in the country based on expert judgements (20% of the waste generated by the rural population). National data on waste compositions and quantity together with IPCC default factors for all other parameters were used to estimate CO_2, CH_4, and N_2O emissions. An exchange takes place between the experts responsible for the energy sector and waste sector to ensure that all waste is accounted for and the same waste composition is used for municipal solid waste (2014).
Vietnam	The following types of waste are incinerated: • Domestic solid waste, which also includes non-hazardous waste from hospitals; • hazardous solid waste from industrial, medical, domestic (such as electronics) and agricultural sources (such as fertilizer and pesticide containers). The amount of medical waste generated was estimated based on the number of hospital beds. The amount of hazardous industrial waste was estimated based on waste generated, assuming that 75 % of waste generated are incinerated. The open burning of waste was assumed to account for 30 % of the total remaining waste not collected and treated (Vietnam 2020a).

Source: Compilation by Öko-Institut.

3.3.4. Recommendations

For the incineration of hazardous medical waste try to identify the incineration plants and collect activity data. If not possible use the number of hospital beds as a proxy for generation rates is available (e.g. Tunisia, Table 3-10). If waste incineration for MSW takes place, collect activity data directly.

Using national estimates, estimate emissions from open burning based on:

- the population not connected to formal waste collection systems and
- the quantity of waste going to open pits where waste is burned.

If possible, use national estimates for the share of waste burned (e.g. Table 3-10 Mexico). Ensure consistency with the activity data in the other waste categories and reporting under energy.

3.4. Wastewater treatment and discharge

3.4.1. Overview

Emissions from treatment and disposal of wastewater need to be reported here. Methane emissions occur under anaerobic conditions, i.e. in deep and slowly moving waters. They can originate during all stages from wastewater generation to final disposal. The emissions depend on the carbon content of the wastewater, the treatment or disposal method, and temperature. To calculate the emissions, wastewater generation needs to be estimated for domestic wastewater (i.e. mainly human sewage) and some industrial activities. For each type of wastewater, it is also necessary to estimate the share of each treatment or disposal method. In addition, nitrous oxide can also be emitted either directly during processing or indirectly after disposal of effluent.

Emissions from energy use of any methane generated and the emissions originating from disposal of sludge in landfills (see Chapter 3.1), on land (under AFOLU) or in anaerobic digestion (see Chapter 3.2) are not included in this source category.

3.4.2. Domestic wastewater

3.4.2.1. Methodological issues

All wastewater generated by households and any wastewater not disposed of on site in industrial installations are reported as domestic wastewater. Emissions from all wastewater collected through public sewers are reported here; typically, this includes industries and facilities in urban areas such as butchers, restaurants and grocery stores. To estimate methane emissions, it is necessary to:

1. determine the Total Organically Degradable Carbon in Wastewater (TOW);
2. determine emission factors for each pathway and system for wastewater treatment existing in the country (e.g. untreated discharge into rivers, aerobic treatment, and septic tanks); and
3. determine the relative share of each pathway and system and calculate corresponding emissions.

Total organically degradable carbon is based on the total population and the quantity of carbon discharged per person and day expressed in Biochemical Oxygen Demand (BOD). Default values are provided for some countries and it is good practice to use the value of a nearby comparable country. Default values are also provided to estimate the methane emission factors for each pathway and system. To determine the relative share of each pathway and system, it is good practice to categorize the entire population in three groups with distinctive wastewater treatment patterns:

- rural,
- urban low income,
- urban high income.

In countries with well-developed wastewater facilities, it is not necessary to differentiate the urban population. It is good practice to draw a diagram of the different treatment types and shares to ensure completeness. Some data on the fraction of the population in each category as well as the fraction of the relevant treatment types is provided in Table 6.5 of the Guidelines (IPCC 2006) for individual countries. To reflect industrial and commercial wastewater discharged into sewers, the population-based activity data is multiplied with a constant factor.

If methane is recovered and burned, the emissions from wastewater need to be adjusted accordingly. If sludge is removed from the wastewater, a corresponding quantity needs to be deducted from the TOW. Emissions from sludge decomposition are reported under solid waste disposal, biological treatment, burning or in the AFOLU sector depending on the disposal method. It is good practice to ensure that any sludge deducted under this source category is reported elsewhere.

Box 14: IPCC Refinement 2019 – CH_4 from wastewater handling – Update of default data

Overview on percentage of low-income country populations using pit latrines as a primary sanitation facility.

Default MCF values and resultant EFs for domestic wastewater by type of treatment system and discharge pathway (Table 6.3).

Box 15: IPCC Refinement 2019 – CH_4 from wastewater handling – Update of default MCF

Update of default MCF
- Tier 1: seas and lakes (0.1 to 0.11)
- Tier 2: new differentiation in of MCF for aquatic environments other than reservoirs, lakes and estuaries (0.035), and MCF for discharge to reservoirs, lakes and estuaries (0.19)
- No differentiation between “well managed” and “not well managed” centralised aerobic treatment systems anymore, default value of 0.03 should be applied.

New calculation step: Emissions from receiving waters.

Box 16: IPCC Refinement 2019 – CH_4 from wastewater handling – Sludge

Expanded guidance to include emissions from sludge handling from domestic wastewater.

New calculation step to estimate the organic component based on mass of sludge that is removed within a wastewater treatment pathway.

Default data available for the estimation of organic component of sludge by treatment type and for septic systems.

3.4.2.2. Good practice country examples

Most developing countries apply Tier 1 methodologies for wastewater. The main difficulties encountered are related to the types and shares of wastewater treatment/disposal pathways. The 2006 IPCC Guidelines recommend differentiating between three groups of the total population which have their own typical pathways:

- urban high income,
- urban low income and
- rural.

This approach is used by many countries but adapted to national circumstances. In Armenia the treatment type depends more on settlement size than on income class and the inventory is calculated accordingly. In Namibia, national data on wastewater treatment is available, which is used in combination with IPCC 2006 default data. For the other regions default values and expert judgements are applied. South Africa includes a detailed table with all relevant information in the national inventory report.

Table 3-11: Methane emissions from industrial wastewater

Country	Description
Afghanistan	Information from different data sources covering different years was used for mapping the wastewater treatment systems and discharge pathways according to national circumstances. The latest report of the Afghanistan Living Conditions Survey provided complete information regarding population, by main toilet facility, and by residence, which were taken as 'baseline 2016'. The data above was compared with international data provided for Afghanistan. The provided data was aggregated according to the type of treatment and discharge pathway/system, and a consistent time-series was prepared using interpolation and extrapolation (Afghanistan 2020).
Armenia	The 2006 IPCC Guidelines do not recommend any default values for BOD for Armenia, South Caucasian countries, or the former Soviet republics. For that reason, default values recommended by the Revised 1996 IPCC Guidelines for former Soviet republics are used. The population is classified into three groups based on settlement size: large cities, other towns, and villages. The respective treatment types are (Armenia 2014): - cities: 95% sewer, 5% latrines; - towns: 50% sewers, 50% latrines; - villages: 5% sewers, 95% latrines. Currently, the service area of wastewater system in Armenia is limited, serving only 70% of the population. In 2017, in large and medium cities, household and commercial wastewater was discharged through sewerage systems; in rural areas – mainly by drains and wells (Armenia 2020a).
Chile	For the estimation of methane emissions, a Tier 2 method according to the 2006 IPCC Guidelines is used with a country-specific per-capita BOD. The shares of the different types of wastewater treatment systems is available from national statistical data (Chile 2020).

Jamaica	The population in 2011 was divided by the total dwellings to determine the average number of persons per dwelling (3.17 persons/dwelling). The population fractions that were calculated were used to determine the population of the high-urban, low-urban, and rural areas for the other years (2006-2010 and 2012). To calculate the loading rate (g/yr), the capacities (L/yr) of the treatment plants and the BOD (mg/L) were collected from the National Water Commission and the National Environment and Planning Agency. The sewage treatment facilities for Jamaica are predominantly aerobic systems. The data on the performance of the systems (degree of utilisation in high-urban, low-urban and rural areas) were obtained from the Planning Institute of Jamaica and the Jamaica Survey of Living Conditions. The wastewater treatment plants in Jamaica fall into two main categories for which default MCF values were provided: for untreated systems with high organic loadings or for treated, not well managed systems (Jamaica 2018).
Namibia	The actual amount of domestic wastewater generated was not available at country level. However, the different types and usage levels of treatment or discharge as per the Namibia Population and Housing Census 2001, 2006, and 2011 census reports were used as well as the respective 2006 IPCC Guidelines (Vol 5.3 Ch 3 Table 3-1) default MCFs. The use the different waste systems have been harmonized into three main types: Centralised aerobic, septic tank, and latrines. Coupled with the use rate, the fraction of population living in the 3 different zones, high-urban, low-urban and rural was also generated in a timeseries as input in the software (Namibia 2020).
South Africa	The National Inventory Report (NIR) includes a detailed table on treatment type or discharge pathway (septic tank, latrine, sewer stagnant, sewer closed, sewer open & warm, sewer flowing, none, other) per income group (rural, urban high-income, urban low-income) (South Africa 2019).
Vietnam	The following activity data was used: 1) Population; 2) Proportion of population by high income and low income; 3) Proportion of wastewater treatment system type; and 4) BOD factor calculated according to the 2006 IPCC Guidelines (Vol 5 Ch 6 Equation 6.1). For urban areas, the proportion of domestic wastewater treated centrally by the aerobic method was determined from statistical data on wastewater treatment facilities. The shares of untreated wastewater and wastewater treated in septic systems, both in urban and rural areas, are based on the assumptions of waste experts (Vietnam 2020a).

3.4.2.3. Recommendations

Use appropriate groupings of the population, either along the lines of the IPCC Guidelines (urban high income, urban low income, rural) or using other criteria such as settlement size (e.g. Armenia, Table 3-11). Ensure that all wastewater is included in the calculations; this can be achieved by preparing a water flow diagram as suggested by the IPCC Guidelines (see section 3.4.2.1).

3.4.3. Industrial wastewater

3.4.3.1. Methodological issues

Emissions from industrial wastewater include all wastewater that is treated/disposed of on site and not sent to public sewers. The main sources for methane emissions from industrial wastewater are:

- pulp and paper manufacture,
- food and drink processing (e.g. meat and poultry processing, alcohol/starch production and dairy products) and
- organic chemicals production.

Due to the lack and methodological difficulties of obtaining site-specific data, it is good practice to use top-down approaches. Activity data is based on production output from the relevant industries and a Chemical Oxygen Demand per unit of output for each industry. Default values are provided, and it is good practice to use them in the absence of national data. Typically, only three to four industry sectors are relevant per country and it is good practice to focus efforts on these industries. It is good practice to re-evaluate all potentially relevant industrial sectors periodically. Once an industry sector is included, it should remain in all subsequent years in the inventory. If new sectors are included, countries should re-calculate the entire time series.

Box 17: IPCC Refinement 2019 – CH_4 from industrial wastewater handling – Update of default data

Default MCF values and resultant EFs for industrial wastewater (Table 6.8).

3.4.3.2. Good practice country examples

The main challenge for countries applying Tier 1 is to determine which industrial sectors are relevant, collect the respective activity data and the type of wastewater treatment. Some countries have detailed data. In Chile, for example, country-specific activity data and parameters for industrial wastewater are available from the Superintendency of the Environment. In India, the necessary data is collected from industries. In Vietnam, country-specific values for Chemical Oxygen Demand have been developed.

Table 3-12: Methane emissions from industrial wastewater

Country	Description
Brazil	Industrial production values were found out from the observation of the most important sectors in 2005 and the expert judgment for the period between 1990 and 2010. In order to obtain the industrial degradable organic component (Dind) as recommended by the IPCC (2000), a panel of experts was consulted to define the most appropriate Dind to be applied. Values of Maximum Methane Production Capacity were based on IPCC default data (2000). The fraction of wastewater treated by each certain treatment/discharge pathway or system and MCF were defined after consultation by an expert panel and default IPCC value (2000) due to the absence of an official survey regarding the technology employed and each treatment/discharge pathway or system fraction in the Brazilian industry (Brazil 2020).
Chile	Methane emissions were estimated using a Tier 2 method according to the 2006 IPCC Guidelines. Country-specific activity data and parameters were used, which were obtained from the regulatory entity and from the Superintendency of the Environment. These data include the volume of wastewater generated and the respective BOD values. As emission factors, default values were used (Chile 2020).
India	The industrial wastewater contribution to greenhouse gases is assessed based on methane emitting industries such as pulp and paper, sugar refining, tannery, food and beverages, poultry and meat industries. Activity data related to emission estimations including unit production, wastewater generation, amount of organic matter, handling of effluents were collected from industries (India 2018).
Jamaica	Default wastewater generation and the corresponding Chemical Oxygen Demand (COD) values were used for most of the primary industries generating wastewater in Jamaica. Country-specific data on total industrial product was used. In addition, country-specific data on COD for the sugar industry and the wastewater generation rate for the alcohol industry were used (Jamaica 2018).
Namibia	Exploitable data on industrial wastewater production was available only for the meat (beef and sheep) and fish industry. The total meat industry product and the amount of wastewater as provided by local authorities were used in conjunction with the respective 2006 IPCC Guidelines (Vol 5.3 Ch 3 Table 3.1) defaults for calculation of emissions (Namibia 2020).

Vietnam	Activity data is collected in three steps: identification of major industries in the country and production quantities; estimation of wastewater generation from these industries per unit of output; country-specific Chemical Oxygen Demand for these industries. All relevant data is determined using national statistics and default values from the 2006 IPCC Guidelines. In a last step, the proportion of industrial wastewater treatment systems is determined. Since there is no specific AD, it is relied on expert judgement to estimate the share of the systems as follows: • Aerobic treatment: 30% • Semi-aerobic treatment: 40% • Anaerobic treatment: 0% • Discharge into sea, rivers and lakes: 30% (Vietnam 2020a).

Source: Compilation by Öko-Institut.

3.4.3.3. Recommendations

If possible collect data in three steps: (i) identification of major industries and production quantities; (ii) estimation of wastewater generation from these industries per unit of output; (iii) elaborate country specific Chemical Oxygen Demand for these industries (see Vietnam, Table 3-12).

3.4.4. Nitrous oxide emissions from wastewater

3.4.4.1. Methodological issues

Direct emissions of N_2O during processing only occur in countries with predominantly advanced centralised wastewater treatment plants with nitrification and denitrification steps. Indirect emissions come from wastewater treatment effluent discharged into aquatic environments. For direct emissions the quantity of wastewater treated in such facilities needs to be multiplied with a default emission factor. For indirect emissions, it is necessary to estimate the nitrogen in wastewater based on protein intake per person and correction factors to reflect non-consumed proteins and industrial/commercial co-discharged into the sewer system. If sludge is removed, a corresponding quantity of nitrogen needs to be deducted.

N_2O emissions from industrial wastewater sources are believed to be insignificant and do not need to be estimated.

Box 18: IPCC Refinement 2019 – Direct N_2O emissions from wastewater handling

New guidance for N_2O emissions from Wastewater treatment plants (WWTPs) with advanced systems including controlled nitrification and denitrification steps. N_2O emissions from WWTPs is considered to be substantially higher.

Box 19: IPCC Refinement 2019 – Indirect N_2O emissions from wastewater handling

Calculation of more variables that lead to N_2O emissions in wastewater handling including losses in nitrogen during treatment prior to disposal, additional nitrogen from household products, consideration of fraction of protein consumed and a fraction of nitrogen that is lost prior to discharge.

Box 20: IPCC Refinement 2019 – Direct N_2O emissions from industrial wastewater handling

New guidance for estimating N_2O emissions from industrial wastewater handling. Same data needed as for the calculation of domestic wastewater.

3.4.4.2. Good practice country examples

Calculating nitrous oxide emissions from wastewater is a relatively straightforward process requiring very little data. The IPCC Guidelines only contain a Tier 1 methodology, so it is good practice for all countries to use Tier 1 with default emission factors. Population statistics are available and the average annual protein intake is provided by the FAO. Some countries reported on their approach to gap-filling FAO data or nationally collected data for protein consumption. No analysed developing countries reported direct N_2O emissions from the treatment process itself.

Table 3-13: Nitrous oxide emissions from wastewater

Country	Description
Armenia	For protein consumption, the FAO gives averaged figures for the periods of 1990-2017 (Armenia 2020b).
Namibia	The protein content in the diet of the population is also needed as an activity data for calculation of emissions from domestic wastewater. FAO data for years 1999 to 2014 is available. Trending technique was applied to generate the data for years 1994 to 1997 (Namibia 2020).
Vietnam	National statistics are used for protein consumption. According to the report from the Vietnam Institute of Nutrition, the protein consumption per capita was 22.6 kg/person/year in 2000 and 27.1 kg/person/year in 2010. The estimated figure for 2016 was 30.5 kg/person/year (Vietnam 2020a).

Source: Compilation by Öko-Institut.

3.4.4.3. Recommendations

Use the same population statistics as for solid waste disposal to ensure internal consistency of the estimates. Apply Tier 1 and use default parameters as included in the 2006 IPCC Guidelines.

4. Waste emission models

4.1. Overview

Various models are available in the field of waste management that focus on different perspectives of waste management, GHG emissions, and life cycle assessment. Most models use the same input data that are used for calculating CH_4 emissions from solid waste, including waste generation rate, waste composition, and waste treatment. Models like the IPCC Model are used to calculate CH_4 emissions from solid waste disposal applying the complex FOD method. The results of the calculations are used in GHG emission inventories and can furthermore indicate the importance of this sub-sector regarding emission reduction potentials. In a second step, other models than the Solid Waste Management Model can be applied to calculate possible mitigation potentials, which is the first step of the NAMA development.

The following chapter introduces some models that can provide further assistance in compiling GHG inventories, activity data, and assessment of mitigation potentials in the waste sector. Specifically, this section introduces the IPCC waste model and the Solid Waste Management–GHG calculator and provides a short overview of goals and data input for other models available in the waste sector.

4.2. Recommended models for estimating GHG emissions from waste

Depending on the type of emissions, its source and the scope of the inventory, several models to choose from exist. In the following, two main models are presented in more detail; other relevant models are summarised in a table under 5.2.3. The reasons why the model was chosen are subsequently presented.

4.2.1. IPCC Waste model

Together with the 2006 IPCC Guidelines, a simple Excel spreadsheet model to calculate CH_4 emissions from solid waste disposal has been published. This model is developed based on the calculation according to the 2006 IPCC Guidelines and applies the First Order Decay method.

The focus of the model is the estimation of CH_4 emissions from solid waste disposal for inventory compilation.

As default data is already included in the model, each country can easily use this model to calculate emissions from solid waste disposal. If choosing a Tier 1 method, countries can use default values without having country-specific activity data available.

For the Tier 1 method, countries need to select or insert:

- region (the IPCC waste model includes 19 different regions),
- default data based on waste composition or on bulk waste,
- climatic conditions of the country (dry temperate, wet temperate, dry tropical, moist and wet tropical), and
- population in millions, beginning in 1950/1960 (available from national statistics or under the UN database).

Thus, by choosing the region, the climatic conditions of the country and entering the population data, the model spreadsheet calculates results for CH_4 emissions from solid waste disposal sites of the country using the FOD method. All countries should be able to calculate their CH_4 emissions from solid waste disposal according to the Tier 1 method by using the IPCC model. If countries want to apply higher tier methods and have more detailed activity data available, they can enter country-specific data into the model.

There is default data available for everything except population. The IPCC default data included in the model is based on studies from the 1990s and the early 2000s. By selecting the region in which the country is located, the default activity data and parameters that are applicable to the special region will be entered automatically to the model.

Default activity data included in the model and in the IPCC Guidelines is not adapted along the time series. Thus, IPCC default data for waste generation, waste disposal, disposal on different types of landfill sites, and waste composition is constant from 1950 to 2012. Especially for developing countries this is not appropriate and leads to overestimation of emissions from solid waste disposal. To produce more reliable results, it is recommended that the default data or the country-specific activity data over the time series is adapted as explained in Chapter 3.1.5.

The Excel model has also been adapted and updated and is provided with the 2019 IPCC refinement.

4.2.2. Solid Waste Management - GHG calculator (ifeu)

Whereas the IPCC model is applied to calculate emissions from solid waste disposal, the Solid Waste Management Model is used to identify mitigation potentials in the waste sector, which is a prerequisite for NAMA development (see Chapter 5).

The Solid Waste Management (SWM) – GHG calculator has been developed by the Institute for Energy and Environmental Research (ifeu) and shall be used to assess the climate effect of different waste management options. The IPCC Guidelines can be used to calculate emissions from waste, but they do not reflect the actual potential for reducing GHG emissions by the waste management sector. By applying the SWM-GHG calculator, the positive impacts of reducing, re-using or recycling of waste and waste-to-energy strategies on climate protection will become evident. Therefore, all waste management practices for solid waste are covered, including landfilling, open burning, incineration MBT, composting and digestion. The focus is on low- and middle-income countries that face the considerable challenge of managing increasing waste generation. By including the costs for single waste management options, countries will be able to calculate the costs of different waste management options and calculate how to reduce GHG emissions at comparably low costs and significantly improve health conditions and environmental protections (ifeu 2010).

The calculation is based on a life cycle assessment, that includes all steps of waste management (collection, recycling, burning, composting, disposing) and applies the Tier 1 approach of the 1996 IPCC Guidelines. Thus, as there is no FOD method applied, data needs to be available for only one year in time.

Besides the status quo, a probable baseline scenario and two other scenarios can be defined. The new scenarios can assume more advanced waste management such as increased waste collection and recycling or even modern waste management practices like waste to energy strategies.

The results are presented in single sheets for each scenario and include information on activity data as well as on emissions and avoided emissions distributed across the different management options. Information on the total costs of the calculated scenario as well as specific costs for one ton CO_2eq in the calculated scenario are also provided.

4.2.3. Short presentation of other selected waste models

Besides the IPCC model and the SWM-GHG calculator there are other models available that deal with different aspects of waste management. These models have been assessed to check whether they provide some further assistance (e.g. on activity data or default parameters) for calculating emissions or mitigation potentials from solid waste. A short summary of all models is provided in Table 4-1, which may be helpful in further improving the waste management and the inventories. All links to the relevant models are included in Annex II.

To estimate CH_4 emissions from solid waste disposal, the application of the IPCC waste model is recommended. As calculation is automatised, only activity data needs to be included and emissions are estimated based on the FOD method. Other models do not provide additional or easier guidance to calculate reliable CH_4 emissions from solid waste disposal.

The input activity data used in the IPCC model can be collected by the Urban Solid Waste Management Tool; it is useful to collect consistent activity data from all cities. If no national statistics or other data sources on municipal or regional level are available this tool can be distributed among regional governments and requested to be applied. Nevertheless, this model requires a lot of detailed activity data that exceeds the data input needed for the IPCC model.

To estimate emissions from the other solid waste sub-categories (composting, open burning etc.), the GHG calculator provided by the Institute for Global Environmental Studies (IGES) can be used, especially in Asian countries, for which the model has been developed. The Waste Management Model focuses on the calculation of reduction potentials in the waste sector; it is recommended that they are applied for NAMA development if no other sources on the calculation of mitigation potential in the waste sector are available.

Table 4-1: Model overview

Model	Objective	Sub-sectors covered	Method	Years	Default data	Usefulness
Data collection tool for solid waste management (Kaza et al. 2018)	Consistent data collection to help decision makers to make waste management plans	Collection, transfer, recycling, landfill, composting, waste to energy	-	One year, and projection for 2030, 2050, historical years can be added for landfills	No	Activity data can be used as input data for IPCC model. Very detailed information is required and will be hard to assess. Not all information is needed as there is data input for the IPCC model.
IPCC model	Calculation of CH_4 emissions from solid waste disposal	Solid waste disposal	FOD	At least 50 years	Yes	Calculation of reliable estimates of CH_4 emissions from solid waste disposal, if activity data is adapted over the time series. Also applicable if no activity data is available.
Solid Waste Management – GHG calculator (ifeu 2010)	Estimation of mitigation potentials from solid waste	Recycling, disposal, composting, digestion	Mass balance	One year	Least developed and middle-income countries	Very useful for the estimate of mitigation potentials, as different scenarios can be applied.
GHG calculator for solid waste sector (IGES 2013)	Calculation of emissions along the waste stream, decision-making	Disposal, composting, digestion, MBT, recycling, incineration, open burning, transportation of waste	FOD	Monthly waste generation	IPCC	Very useful for estimating emissions from other sub-categories (Open burning, incineration, composting etc.).
Waste Reduction Model (WARM) (US EPA, 2015)	Help solid waste planners to track and voluntarily report GHG emissions reductions from several different waste management practices	Source reduction, recycling, combustion, composting, and landfilling	Materials life-cycle approach			Useful to estimate emissions reductions from several different waste management practices **WARM is intended as planning tool and not as a GHG accounting tool**

Source: Compilation by GIZ and Öko-Institut.

5. Domestic mitigation measures in the waste sector and their relation to GHG inventories

Many countries are implementing measures that mitigate GHG emissions in the waste sector. Many of these measures have been motivated for reasons unrelated to climate change (e.g. health benefits) or list climate change only as a co-benefit. NAMAs however, are actions by developing countries specifically introduced to reduce emissions while tackling development challenges. According to the UNFCCC, NAMAs refer to any action that reduces emissions in developing countries and is prepared under the umbrella of a national governmental initiative. They have been agreed at the climate change conference in Cancún in 2010, and more than 50 countries have communicated NAMAs under the UNFCCC. Under the Paris Agreement, they will be replaced by domestic mitigation measures under its Article 4.

Mitigation measures can take many forms, from policies directed at transformational change within an economic sector, to actions across sectors for a broader national focus. NAMAs have the particularity that they need to have a Monitoring, Reporting and Verification (MRV) system and contribute to sustainable development in a country.[10] For mitigation measures under the Paris Agreement, MRV is also an important aspect. The objective of an MRV system is to determine the emission reductions achieved through a NAMA, addressing also some non-GHG impacts in line with national development goals. The MRV system can be similar or linked to the GHG inventory but there is not necessarily a need to estimate total emissions. Independent of the purpose of any policies and measures in the sector, there are linkages between the inventory and actions taken. This section explores how inventories can influence NAMAs and other mitigation measures and vice versa.

USING A GHG INVENTORY FOR POLICY DEVELOPMENT

A GHG inventory in the waste sector can be used in several ways during the identification and development of mitigation measures in the sector:

- **Identification of relevant (sub)sectors:** One of the first steps in developing a mitigation measure is the identification of reduction potentials. A GHG inventory can give a first indication for the relevance of different (sub) sectors and emission sources. For example, a measure intended to reduce GHG emission from industrial wastewater treatment can be designed with the help of the inventory information, identifying the most important industrial sectors. If a measure is aimed at other purposes such as air quality improvements, the ensuing GHG emissions reductions can be used as an additional justification of the action.
- **Identification of key parameters:** After relevant (sub) sectors have been identified the policy intervention needs to be developed. The parameters used in the inventory development can support this process if their respective relevance for the total GHG emissions is analysed. For example, country-specific waste composition data can help to focus on recycling and waste separation programs.
- **Estimation of the reduction potential:** The methodologies and data compiled for inventory identification can be used to estimate the reduction potentials and develop different scenarios (ex-ante). For example, the IPCC FOD model for solid waste disposal can easily be used to estimate the impact of an action that intends to introduce composting in a country. By changing the waste composition values, it is possible to estimate the impact of different levels of penetration of the mitigation measure (e.g. 5%, 10% and 50% collection rate for organic waste).

10 For an introduction to NAMAs see GIZ (2012).

- **MRV system:** The methodologies, data and parameters used in the inventory can sometimes be directly used in the MRV system of a NAMA or mitigation measure. In the example of a large-scale composting program in a country, a FOD model can be used to calculate baseline emissions (e.g. with fixed waste composition) and to calculate actual emissions in the project scenario. Such a direct use of inventory methods and data is not always possible; this is especially the case if the impact of the action is small compared to the total GHG emissions from a sector. Using the same example, the national inventory would not be a good basis for estimating the impact if waste separation is only introduced in one smaller city in the country. Still, even in such cases the methodologies and data are often useful in the development of the dedicated MRV system.

WASTE MITIGATION MEASURES AND THE GHG INVENTORY

Once a mitigation measure has been developed and implemented, it can also have impacts on the GHG inventory in the waste sector:

- **Inventory improvement:** If a mitigation measure has a dedicated MRV system which is separate from the GHG inventory the data gathered might help improve the quality of the inventory. For example, if the MRV system of an Industrial Wastewater NAMA measures country-specific Chemical Oxygen Demand, the results could be used either as a QA activity of the default values and/or directly for the inventory if the values are deemed to be representative for the whole country.

- **Reflecting the impacts of the mitigation measure:** A national GHG inventory should capture all emissions and removals without over- or underestimating actual emissions. The GHG inventory should therefore be able to reflect the impacts of any actions taken in the waste sector, independent of the monitoring system of the action. To do so, it might be necessary to improve the methodology used in the inventory. If we take the example in which organic waste is composted instead of deposited in a landfill, it may be necessary to refine the data used in the national GHG inventory. In order to make emissions reductions from the composting policy visible in the inventory, the quantity of composted waste has to be subtracted from the overall quantity of generated waste, and only the remaining quantity is used as activity data to estimate emissions from landfills in the GHG inventory. In the process of improving the method in the inventory, it might be necessary to move from IPCC default parameters for waste composition to country specific data.

6. Outlook and conclusions

As the report has shown, greenhouse gas inventories in the waste sector can serve multiple purposes:

1. compliance with international requirements under the UNFCCC and the Paris Agreement,
2. raising awareness about emissions and practices in the sector and
3. development of new and improvement of existing mitigation actions in the sector.

Such co-benefits of GHG inventories can help to justify the expense of inventory compilation and vice versa it can be useful to identify co-benefits and utilise them.

The 2006 IPCC Guidelines provide detailed instructions for inventory preparation. First estimates, applying Tier 1 and default values can be carried out even when there is very limited national data. Improving the quality and accuracy of the emission estimate can become more complex. Even in the absence of existing data, countries have managed to identify proxy information or develop new data gathering procedures to enable them to move to higher tiers.

One way of reducing the necessary effort and using available resources effectively is to develop a national inventory system which complies with the IPCC good practice requirements. These include conducting key source analysis and selecting appropriate methodologies, estimating uncertainties and the development of a QA/QC plan. Developing and implementing such an inventory system is especially useful if the GHG inventory is to be prepared frequently, e.g. every two years for BURs, and in the future for BTRs under the Paris Agreement. When countries improve their inventory methods over time, they may use the updated parameters and emissions factors which are available in the 2019 Refinement to the 2006 IPCC Guidelines.

Many countries have made good progress in developing the necessary capacities for inventory preparation. Different UN organisations, international donors, and implementing agencies and many national development agencies have funds and programmes which can support capacity development for the monitoring, reporting and verification of greenhouse gas emissions and mitigation measures. Countries in need of support should contact these agencies to explore possibilities. Some links to programmes and institutions are included in Annex II. The objective of such capacity building activities should always be to enable the country to develop inventories on their own. This has been achieved in many countries as the examples included in this study show.

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Annex I

Countries included in the study

Table 7-1: Information on countries included in the analysis

	Region			Subcategories							
Countries	Africa	Asia	Latin America	Inventory development	Solid waste disposal	Biological treatment	Incineration, open burning	Domestic wastewater	Industrial wastewater	Questionnaires	Sources
Afghanistan		X			X			X			NIR 2020
Armenia		X		X	X		X	X			BUR2 2018, NC4 2020, NIR 2014, NIR 2020
Brazil			X		X		X		X		BUR4 2020
Chile			X	X	X	X		X	X	X	NIR 2014, NIR 2020
Ghana	X			X			X			X	NC4 2020, NIR4 2019
India		X			X				X		BUR2 2018, NC2 2012
Indonesia		X		X	X					X	BUR2 2018, NC2 2010, NC3 2017
Jamaica			X	X			X	X	X		NC3 2018
Kazakhstan		X			X						NIR 2014
Mexico			X		X	X	X				NIR 2012, NIR 2018
Namibia	X			X	X		X	X	X		BUR1 2014, NC4 2020
South Africa	X			X	X						NIR 2009, NIR 2019
Tunisia	X			X	X	X	X			X	BUR1 2014
Vietnam		X		X		X	X	X	X	X	BUR3 2020, NIR 2004, NIR 2020

Notes: The table only shows which source categories have been analysed for a country for the preparation of this report. Most of the countries report emissions from all categories; the absence of a cross does not imply that a country does not report in that category.

Source: Compilation by Öko-Institut.

Annex II

Useful data and information sources

IPCC GUIDELINES

- Revised 1996 IPCC Guidelines: http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.html
- 2000 IPCC Good Practice Guidance: http://www.ipcc-nggip.iges.or.jp/public/gp/english/index.html
- 2006 IPCC Guidelines: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html
- 2019 IPCC Refinement: https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html

UNFCCC DOCUMENTS

- Biennial update reports and national inventory reports: https://unfccc.int/BURs
- National Communications and national inventory reports: https://unfccc.int/non-annex-I-NCs
- Information on reporting and review under the Paris Agreement: https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-paris-agreement

UN POPULATION DATA

- Total population from 1950 onwards: https://population.un.org/wpp/
- Urban and rural population data from 1950 onwards: https://population.un.org/wup/

MODELS AND DEFAULT VALUES FOR DIFFERENT PARAMETERS

- World Bank 2012: "What a waste" Country-specific default data on waste generation, composition, treatment: https://openknowledge.worldbank.org/handle/10986/17388
- World Bank (2018): What a waste global database: Data on solid waste management from around the world: https://datacatalog.worldbank.org/dataset/what-waste-global-database
- IFEU Solid Waste Management - GHG emissions calculator: Calculator to estimate emission reductions from solid waste disposal for different management options: https://www.ifeu.de/en/project/tool-for-calculating-greenhouse-gases-ghg-in-solid-waste-management-swm/
- IGES Estimation tool for GHG emissions from municipal solid waste management in a life cycle perspective: https://www.iges.or.jp/en/pub/ghg-calculator-solid-waste-ver-ii-2013/en
- US EPA Waste Reduction Model WARM: https://www.epa.gov/warm

INSTITUTIONS AND PROGRAMMES THAT PROVIDE SUPPORT FOR CAPACITY DEVELOPMENT FOR MRV OF GREENHOUSE GAS EMISSIONS AND MITIGATION ACTIONS

- UNFCCC Tools and Training Materials for non-Annex I Reporting: http://unfccc.int/national_reports/non-annex_i_natcom/training_material/methodological_documents/items/7914.php
- UNFCCC CGE Training Materials for the Preparation of National Communications from Non-Annex I Parties: http://unfccc.int/national_reports/non-annex_i_natcom/training_material/methodological_documents/items/349.php

- UNFCCC CGE Training Materials for the Preparation of Biennial Update Reports from non-Annex I Parties: http://unfccc.int/national_reports/non-annex_i_natcom/training_material/methodological_documents/items/7915.php
- UNFCCC CGE Technical handbook for developing country Parties on preparing for implementation of the enhanced transparency framework under the Paris Agreement: https://unfccc.int/process-and-meetings/bodies/constituted-bodies/consultative-group-of-experts-cge/cge-training-materials/enhanced-transparency-framework-technical-material#eq-1
- UNFCCC CGE Toolbox on institutional arrangements: https://unfccc.int/process-and-meetings/bodies/constituted-bodies/consultative-group-of-experts-cge/cge-toolbox-on-institutional-arrangements
- GIZ Secretariat to the Partnership on Transparency in the Paris Agreement (PATPA): https://www.transparency-partnership.net/
- Initiative for Climate Action Transparency (ICAT): https://climateactiontransparency.org/
- NDC Partnership Toolbox: https://ndcpartnership.org/ndc_toolbox_navigator?field_toolbox_sector_tid_1%5B%5D=450&search=waste#navi
- UNDP Low Emission Capacity Building Programme (LECB): https://www.adaptation-undp.org/low-emission-capacity-building-lecb-programme
- UNDP: Global support programme: https://www.un-gsp.org/about-global-support-programme

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