TEXTE
55/2015

Accounting Systems for Short-lived Climate Pollutants and Greenhouse Gas Mitigation in the Waste Management Sector

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Accounting systems for Short-lived Climate Pollutants and Greenhouse Gas Mitigation in the Waste Management Sector

by

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Zusammenfassung

Die „Municipal Solid Waste Initiative“ (MSWI) der “Climate and Clean Air Coalition” (CCAC) ist auf der Suche nach einem Emissionsrechner, der kurzlebige klimawirksame Substanzen und andere Treibhausgase berücksichtigt und der in teilnehmenden Städten eingesetzt werden kann. Als deutscher Beitrag im Kontext der Mitarbeit in der MSW Initiative wurden bestehende Emissionsrechner recherchiert und in Bezug auf ihre Eignung, Treibhausgasbilanzen im Abfallsektor zu berechnen, genauer untersucht sowie auf die Möglichkeit hin, Black Carbon zu integrieren.

Aus einer Reihe von Emissionsrechnern wurden zwei ermittelt, die für Modifikationen geeignet sind, um die Anforderungen der MSW Initiative zu erfüllen. Die grundsätzlich notwendigen Modifikationen sind beschrieben. Hierzu zählt, dass die Ergebnisse sowohl in kg pro Schadstoff als auch in kg CO_2-Äq angegeben werden sollten, unter Anwendung des GWP100 für den direkten Strahlungsantrieb. Auch muss die im Rechner abgebildete Abfallbehandlung die aktuelle Situation berücksichtigen, wie sie in vielen Schwellen- und Entwicklungsländern gegeben ist (verschiedene Deponietypen, Deponiefeuer, offene Verbrennung). Die stoffliche Verwertung sollte über parametrisierte Emissionsfaktoren abgebildet werden, unter Angabe von Richtwerten mit einer Anleitung für Anwender (s.u.). Weiter detaillierte Empfehlungen für Modifikationen, die die beiden Emissionsrechner im Einzelnen betreffen, sind separat aufgelistet. Bei beiden Rechnern müsste die Möglichkeit zu Monitoring und Berichterstattung ergänzt werden, und bei beiden Rechnern wäre Black Carbon zu integrieren, letzteres unter Beachtung einiger Aspekte:

Für Black Carbon gibt es nur wenige Emissionsfaktoren. In der Abfallwirtschaft sind relevante Emissionsquellen die offene Verbrennung und Deponiefeuer. Bei dieser unvollständigen Verbrennung wird auch Organic Carbon freigesetzt, das für den Treibhauseffekt berücksichtigt werden muss, da es einen negativen Strahlungsantrieb aufweist. Die Ergebnisse sollten auch in CO_2-Äq angegeben werden, unter Verwendung des GWP100 für den direkten Strahlungsantrieb. Allerdings sind der Strahlungsantrieb und damit auch der Treibhauseffekt von Black Carbon und Organic Carbon mit sehr hohen Unsicherheiten verbunden. Deswegen sollten die berechneten Beiträge zur globalen Erwärmung separat von anderen Treibhausgasemissionen berichtet werden. Als Sensitivität sollte auch der Treibhauseffekt unter Anwendung der GWP20-Werte berechnet werden sowie unter Verwendung der Werte für den gesamten Strahlungsantrieb.

Bei Treibhausgasbilanzen im Abfallsektor haben vermiedene Emissionen einen hohen Einfluss auf das Ergebnis. Um Städte vergleichen zu können, wäre es am besten die gleichen Emissionsfaktoren zu verwenden. Allerdings ist die Bewertung der eigenen konkreten Situation von größerem Interesse. Deswegen sollten, wenn immer möglich, eigene Emissionsfaktoren verwendet werden, und Anwender sollten aufgefordert werden eigene Daten zu ermitteln. Als Ausgangsbasis sollte der Emissionsrechner Richtwerte für mindestens fünf Weltregionen bereitstellen (harmonisierte Datensätze). Entsprechende Daten sollten aus öffentlich verfügbaren Daten von Ökobilanzexperten ausgewählt werden. Einfach und angemessen wäre es, Daten aus abfallwirtschaftlichen Studien zu verwenden, die für die nationale Ebene von offiziellen Stellen beauftragt wurden. Die Daten für den Rechner sollten transparent beschrieben sein (Berechnungen und Datenquellen), mit Anleitungen für Anwender. Für den Vergleich zwischen Städten sollten direkte und vermiedene Emissionen separat ausgewiesen werden.

Grundsätzlich sollte die Entwicklung des Emissionsrechners von einem Beratungsausschuss begleitet werden. Der Ausschuss sollte sich zu Beginn treffen, um die identifizierten Modifikationen zu verifizieren. Weitere Treffen sollten zur Diskussion einer Entwurfsfassung erfolgen und abschließend zur Abnahme der Endfassung des Emissionsrechners.

Abstract

The Climate and Clean Air Coalition (CCAC) Municipal Solid Waste Initiative (MSW Initiative) is looking for an emission quantification tool focused on short-lived climate pollutants (SLCPs) and other greenhouse gases (GHGs) to be used in participating cities. As a German contribution to the MSW Initiative, existing tools were screened and investigated more intensely with regard to their eligibility to be used for GHG accounting in the waste management sector including the possibility to integrate black carbon.

From a series of tools two were identified to be suitable for modifications to meet the requirements of the MSW Initiative. General necessary modifications are recommended, including that results should be presented in kg emission and kg CO_2eq for each pollutant using the GWP100 for the direct radiative forcing. Waste treatment has to be considered with main focus on the current practise in many developing and emerging countries (various types of landfill, landfill fires, open burning). For recycling, emission factors should be set as parameters and default values should be provided with guidance for use (see below). Further recommendations for modifications are listed in detail for each of the tools. For both tools the possibility for reporting and monitoring would have to be added, and both tools would need to integrate black carbon. The latter should recognize several aspects:

There exist only few emission factors for black carbon. Relevant sources in waste management are open burning and landfill fires. These incomplete combustion practices also emit organic carbon which is relevant and has also to be taken into account due to its negative radiative forcing. As mentioned above results should also be given in kg CO_2eq using the GWP100 for direct radiative forcing. Due to very high uncertainties these GWP results for black carbon and for organic carbon should be reported separately from other GHG emissions. Sensitivities should be calculated using the GWP20 and values for total climate forcing.

In GHG accounting in the waste sector emission factors for avoided processes have a high influence on results. To ensure comparability between cities it would be best to use one and the same set of emission factors. Nevertheless, the assessment of the cities situation and conditions is of higher interest. Therefore, regional emission factors should be used whenever possible, and users should be encouraged to collect own data. To start with, a tool should provide default values for at least five world regions (harmonised data sets). It is recommended that such data should be derived from publicly available data by LCA experts. An easy and adequate approach would be to use data which are available from studies for waste management on a national level on behalf of national authorities. The data should be transparently described (calculations and data sources) with guidance for users. For comparison with other cities direct and avoided emissions should be reported separately.

In general, it is recommended that the development of a tool should be accompanied by an advisory council. This council could meet at the beginning to verify the identified modifications, on an interim phase to discuss a draft version, and at the end of the project to verify the final version.

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Abbreviation

BC	Black carbon
CHP	Combined Heat and Power Unit
CCAC	Climate and Clean Air Coalition
DOC	Degradable organic carbon
EASEWASTE	Environmental Assessment of Solid Waste Systems and Technologies
EpE	Entreprises pour l'Environnement
Fe-metal	Ferrous metal
GHG	Greenhouse Gas
GHG-SWM Calculator	Solid Waste Management Greenhouse Gases Calculator
GWP	Global Warming Potential
IGES	Institute for Global Environmental Studies (Japan)
IPCC	Intergovernmental Panel on Climate Change
MBT	Mechanical-biological treatment
MBS	Mechanical-biological stabilization
MCF	Methane correction factor
MSW	Municipal Solid Waste
MSW-DST	Municipal Solid Waste Decision Support Tool
NF-metal	Non-ferrous metal
POA	Primary organic aerosols
RDF	Refuse derived fuel
RF	Radiative Forcing
SLCP	Short-lived climate pollutants
TMP	Thermochemical pulp
UBA	Umweltbundesamt (German Federal Environment Agency)
UNFCCC	United Nations Framework Convention on Climate Change
US EPA	United States Environmental Protection Agency
WARM	Waste Reduction Model

1 Background and objective

The German Federal Environment Agency (UBA) promoted and obtained a comprehensive knowledge regarding climate protection potentials in the waste management sector through projects and environmental research. The importance of the potential contribution of the waste management sector to mitigate greenhouse gas (GHG) emissions is increasingly recognized on an international level. This considerable contribution can be an incentive to take measures for the implementation of an integrated waste management in developing and emerging countries.

Currently, UBA is working on selected topics in the Climate and Clean Air Coalition (CCAC) which was funded in February 2012 and joined by Germany. The UBA division III 2.4 represents Germany in the Municipal Solid Waste Initiative (MSW Initiative). The MSW Initiative's aim is the mitigation of short-lived climate pollutants (SLCPs) like methane and black carbon in the waste management sector. The CCAC MSW Initiative is working with the world's largest leading cities to undertake a number of actions to tackle the largest sources of emissions from waste, including capping and closing open dumps, capturing and utilizing landfill gas, proper waste handling, organics management and recycling. In this context these cities need to have access to appropriate quantification tools to demonstrate the emissions reductions from their actions.

Principally, existing tools could be used to calculate the GHG mitigation. But as there exists a variety of emission quantification methodologies as a first step it is very important to understand which tool or which methodology should be used in what context. Reporting tools should be used for reporting only, and the LCA approach should be used to support decision making. Additionally, it is very important to understand the significance of certain boundary conditions in calculation tools which can lead to very different results and possibly to misinterpretation. For example, methane emissions from landfilling have to be calculated related to the amount of waste deposited and not on a yearly basis if the overall effect of landfilling over a long term time period should be recognized.

It was the task of this consultancy project to communicate the different approaches and methodologies for emission quantification to the CCAC MSW Initiative. Therefore, telephone conferences of the Initiative were attended as well as a workshop of ISWA/UNEP in September 19-20, 2013 in Paris. Furthermore, existing tools were screened and partially examined in-depth in accordance to their eligibility to be used as quantification tool in the partner cities of the CCAC MSW Initiative.

Questions to be answered were:

- Which existing tools may be used?
- What elements are essential for decision making?
- How can black carbon emissions be incorporated in existing tools?
- What amendments are necessary due to calculations and to data needed?

This report provides information on the outcomes of the ISWA/UNEP workshop on GHGs and SLCPs in Paris. Furthermore, possibilities to incorporate and assess black carbon emissions are described. The main focus of this report lies on the evaluation of existing tools, the further in-depth investigation of selected tools and final recommendations for tool modifications and amendments.

2 ISWA/UNEP Workshop on GHGs and SLCPs

The **objective** of the workshop in Paris, on September 19-20, 2013, organized by ISWA and UNEP was to bring together experts and practitioners to discuss and evaluate available GHG and SLCP emission quantification methodologies. An aim of the organizers was to provide a guidance document for cities. The guidelines should present the characteristics of various tools and how they can be applied based on the outcomes of the workshop discussion sessions.

The workshop provided background information through various **presentations**, starting with a presentation from Terry Coleman (ERM) who clarified that the decision for a certain methodology and/or for a certain tool depends on the question to be answered. He emphasized several key factors that should be noticed like waste composition, waste characteristics, electricity grid, landfill gas generation and recovery, while others are of minor importance (vehicle use, transport distances, aggregate use). Joseph Donahue (Stratus) presented the results of a study prepared for the US EPA (Stratus 2013) on a comparison of several quantification tools and opportunities for incorporating black carbon. Then two quantification tools using the LCA approach were presented – the SWM-GHG Calculator by the consultant (Regine Vogt) and the GHG Calculator for Solid Waste by Nirmala Menikpura (IGES). During the presentation of the SWM-GHG Calculator, emphasis was given on important aspects that should be realized in a tool to be used in the context of the CCAC MSW Initiative. As a third tool the EpE Waste Sector Protocol was presented by Alexandra Lalet (Suez Environment) which is a tool following the GHG protocol and is meant for reporting. Finally, Johan Kuylenstierna (SEI) gave information on a toolkit developed for the CCAC SNAP Initiative (supporting national planning for action on SLCPs) which focuses on all sectors and estimates the impact of SLCP emissions (black carbon, methane, tropospheric ozone, some hydrofluorocarbons) calculating the endpoint indicators "premature mortality avoided" and "crop yields". The tool has a simple structure, e.g. emissions are calculated as emission factor multiplied by activity rate. For the time being there only exist a handful of black carbon emission factors for open burning which are not very reliable but not completely out of range.

In **break-out sessions** four topics were discussed:

Topic 1: Developing a quick evaluation calculator for initial City assessment
Topic 2: Establishing a more detailed City "Benchmark"
Topic 3: Key considerations for tool(s) for regular monitoring and verification
Topic 4: Key recommendations for quantifying fugitive landfill methane emissions (using existing first order decay models)

Recommendations for Topic 1 were that a quick evaluation calculator should be developed by a model development group followed by an implementation group. Instead of designing a new tool also the IGES tool or the SWM-GHG Calculator could be used as basis for decision support especially for developing countries. The needs of industrialized countries could be addressed with further progress in detailed analysis. Primary input data required are population, waste quantities (generated and collected), waste composition, treatment methods, recycling rates and type and amount of energy consumption. Everything else can be default values for a start with the possibility to replace these values by more detailed or measured data which the user should be encouraged to collect. The inclusion of black carbon should be done by inclusion of all emissions associated with incomplete combustion. Data should be peer reviewed inventories for emission factors, published with guidance for use (possibly later expanded to harmonized emission factors, for example, five world regions). Whenever possible, it is better to use location specific default values and/or emission factors (e.g. electricity grid). Reporting would need additional different calculations (landfill), which could be provided in the tool or separately and transferred into a yearly reporting file.

Findings of the break-out session for Topic 2 were that a benchmark is needed for comparison, to allow an exchange between cities. In this sense a benchmark is mainly a matter of a minimum level of consistency, for example, for data elements, waste numbers and how to get them. There should be a harmonized approach in the data collection phase to get a similar data set for the basic data. The role of a quick assessment tool (Topic 1) would be to build a baseline and to show optimization potentials. From this, further phases would be the implementation phase and the monitoring phase. A harmonized approach could be supported by indicators and/or a check list. For example, a decision tree with yes/no questions like "is there a landfill", "is there a high organics content", "is there open burning" and so on. To establish a more detailed city benchmark targets should be defined, for example, for recycling.

The break-out session on Topic 3 came to the conclusion that monitoring must be a simple process. A "light reporting" every five years seems sufficient. All cities should use one and the same tool and one and the same baseline should be used for city comparison and ongoing monitoring. Regarding the presented existing tools the following aspects should be added:

- black carbon
- uncollected waste
- less advanced treatment technologies
- check if recycling calculation fits to the needs/situation in developing countries
- find out emission factors according to the regions (for emission factors of minor importance default values may be sufficient)
- work needs to be done to adapt a monitoring tool, maybe based on the EpE-tool maybe another one already existing which meets expectations better (not too detailed)
- cities should be trained to use the tool, maybe online training, maybe personal training, and annual meeting exchange with CCAC

From the discussion some questions, recommendations and comments were pointed out:

- Who will define the baseline?
- A regular update should be considered for emission factors which are likely to change rapidly.
- Who will fund the tool development and/or adjustment?
- The SNAP Initiative collects emission factors for SLCPs to develop a data base for all sectors; maybe the research could be coordinated and started with the waste sector, this would have to be clarified with the SNAP secretariat.

For Topic 4 it was stated that emissions have to be calculated over the lifetime for decision making, but for monitoring the FOD method[1] should be used including the past years. Following the IPCC approach using mainly default activity data and default parameters (Tier 1[2])

[1] The "first order decay (FOD) method" from the IPCC guidelines produces a time-dependent emission profile that reflects the true pattern of the degradation process over time.

[2] IPCC (2006) distinguish "Tier 1" (default data), "Tier 2" (some default parameter, but good quality country specific activity rate (*waste amount landfilled*) and historical waste disposal (for 10 years or more), and "Tier 3"

is ok to start with. A working group shall improve the data for waste composition by doing researches or initiating own measurements, following the existing advice on how to do representative sampling. All sensitive data (data uncertainties) should be highlighted. Apart from waste composition further key parameters are temperature and rain fall, and maintenance (compaction, coverage, etc.). The most important reduction measure is gas collection and use. Wild dumps lower than 0.5 m should be capped to minimize damages to health. Health aspects should also be addressed in a tool so the user can see the benefit from undertaking measures.

The workshop concluded with a **summary** expressing that there is a road map now, that there was a great exchange of knowledge and also an interesting exchange on further existing tools (brief presentations, further information have been provided after the workshop by participants via email). Summaries asked for from the moderators of the sessions will be combined and send to all participants by ISWA. Following this, ISWA/UNEP will prepare and circulate a proposed outline for a guidance document for cities. (Not yet happened).

3 Accounting possibilities for black carbon

So far black carbon (BC) is not calculated in any known existing calculation tool for GHG emissions in the waste management sector. There are two different challenges with implementing black carbon emissions. First of all the data base for emission factors is rather poor, and secondly the impact on climate change is highly uncertain due to overlapping effects and the dependency on region and time of emission.

3.1 Black carbon emissions

According to Bond et al. (2013) black carbon is a distinct type of carbonaceous material, formed only in flames during combustion of carbon-based fuels. It is distinguishable from other forms of carbon and carbon compounds contained in atmospheric aerosol because it has a unique combination of the following physical properties:

1. It strongly absorbs visible light with a mass absorption cross section of at least 5 m^2/g at a wavelength of 550 nm.
2. It is refractory; that is, it retains its basic form at very high temperatures, with a vaporization temperature near 4000 K.
3. It is insoluble in water, in organic solvents including methanol and acetone, and in other components of atmospheric aerosol.
4. It exists as an aggregate of small carbon spherules.

The strong absorption of visible light at all visible wavelengths by black carbon is the distinguishing characteristic that has raised interest in studies of atmospheric radiative transfer. No other substance with such strong light absorption per unit mass is present in the atmosphere in significant quantities. BC has very low chemical reactivity in the atmosphere; its primary removal process is wet or dry deposition to the surface. BC is generally found in

(activity data as Tier 2, and either nationally developed key parameters or measurement derived country specific parameters).

atmospheric aerosol particles containing a number of other materials, many of which are co-emitted with BC from a variety of sources.

In general, black carbon refers to any number of strongly light absorbing combustion particles, the strongest of which is soot. The particles vary in size but generally they are much smaller than PM2.5 (particulate matter with aerodynamic diameter less than 2.5 micrometers) and may not even get as large as PM0.1. Black carbon is always a component of particulate matter emitted from combustion sources, but the emission rates - and also those of co-emissions like organic carbon or sulfur dioxide – depend on the combustion process, including fuel composition (type of fuel), flame temperature, mixing between fuel and air during combustion, and post-combustion treatment of the exhaust (performance of emission control technology or practice).

In general, carbonaceous aerosols can be avoided if the exhaust is kept hot and well mixed with air. Large, properly operating combustors, such as power plants and some modern installations using biofuel, tend to achieve this burnout, resulting in little emitted BC. Mixing between fuel and air before combustion also limits BC formation, so that gasoline engines emit much less BC than do diesel engines. Finally, BC may be removed through end-of-pipe controls that capture fine particles, as it is in particulate filters after diesel engines.

With this, controlled incineration processes with high combustion efficiency or filter technologies are low BC emitters. This is mainly the case in industrialized countries due to high emission standards. In developing and emerging countries also poorly functioning vehicles with very high emissions or "superemitters" are in operation. Nevertheless, globally, the main sources for black carbon emissions are open burning of biomass (fields, forests) and residential stoves and heating units fired by solid fuels. BC emissions from industrial sources are relevant for small scale combustion units like coal fired boilers, brick and lime kilns or coke production for the steel industry.

Table 1 shows emission factors for these main sources and other sources, presenting the following ranges:

- field open burning: 0.2 g BC/kg (peat) to 1.3 g BC/kg (chaparral)
- domestic cooking: 0.36 g BC/kg (wood) to 8 g BC/kg (coal)
- domestic heating: 0.53 g BC/kg (dung) to 1.09 g BC/kg (wood)
- transport: 0.47 g BC/kg (Euro II) to 3 g BC/kg (superemitter)
- industry: 0.01 g BC/kg (coal boiler) to 5 g BC/kg (low-tech brick kiln)
- open burning waste: 0.381 g BC/kg (waste landfilled) to 5.5 g BC/kg (MSW)

The emission factors were taken from different literature sources and partially refer to different time horizons. It is not always possible to explain the differences in emission factors. For example, it is not clear why the emission factor for a coal stove in Bond et al. (2005) is nearly 14 times higher than that in Bond et al. (2013).

In principle, emission factors depend on the conditions of the measurement. For example, emissions from vehicles or small boilers and stoves depend on the operating conditions. Very cold conditions or startup phases promote poor efficiency and high emissions, while on the other hand testing or tests may not include the poorest quality fuels.

In addition, different emissions result from different analysis methods. Optical absorption measurements lead to higher emission factors. It is possible that the use of imperfect thermal oxidation methods yields BC emission factors that are too low (Bond et al. 2013, p. 5419). These method-dependent biases are more critical for biomass-burning emissions than for other sources, because these emissions pyrolyze and also contain materials that catalyze BC emission. Comparisons between chemical and optical measurements would increase confidence in biomass-burning emission factors for BC.

The error range of emission factors for field open burning is 0.6 to 4 (Bond et al. 2013, p. 5417). Open fires have a high inherent variability. Some emission factors and characteristics are inferred from small, better-controlled fires in laboratory settings. The combustion intensity and the burning and airflow characteristics of these small fires may differ from those of fires in the real world.

Table 1: Emission factors (EF) for black carbon

Process	"Fuel type" / "source"	EF in g BC/kg fuel	Reference
Field open burning	forest (tropical)	0.52	Akagi et al. (2011)
	forest	0.56	Bond et al. (2013)
	chaparral (kalifornische „Eiche")	1.30	Akagi et al. (2011)
	peatland	0.20	Akagi et al. (2011)
	savanna	0.37	Akagi et al. (2011)
	pasture maintenance	0.91	Akagi et al. (2011)
	crop residues	0.75	Akagi et al. (2011)
	unspecified	0.69	Bond et al. (2013)
Domestic cooking	open, mainly wood	0.83	Akagi et al. (2011)
	patsari stove	0.74	Akagi et al. (2011)
	mud stove	0.80	Bond et al. (2013)
	wood stove	0.70	Bond et al. (2005)
	wood stove	0.36	Bond et al. (2013)
	coal stove	8.00	Bond et al. (2005)
	coal stove	0.58	Bond et al. (2013)
Domestic heating	charcoal	1.00	Akagi et al. (2011)
	dung	0.53	Akagi et al. (2011)
	wood boiler	1.09	Bond et al. (2013)
Transport	Euro II heavy-duty vehicle	0.47	Bond et al. (2013)
	diesel current light vehicle	0.90	Bond et al. (2005)
	diesel superemitting light vehicle	3.00	Bond et al. (2005)
	pre-regulation truck	2.00	Bond et al. (2005)
	pre-regulation truck	2.39	Bond et al. (2013)
	gasoline: 2-stroke engine	1.00	Bond et al. (2005)
Industry	bull's trench brick kiln [1]	2.44	Bond et al. (2013)
	low-tech brick kiln	5.00	Bond et al. (2005)
	industrial coal boiler	0.01	Bond et al. (2013)
Open burning waste	uncontrolled landfill fire	EC[2]: 0.381	Christian et al. (2010)
	uncontrolled landfill fire	EC[2]: 0.924	Christian et al. (2010)
	uncontrolled landfill fire	EC[2]: 0.634	Christian et al. (2010)
	uncontrolled landfill fire [3]	0.65	Akagi et al. (2011) [2]
	waste [4]	5.50	UNEP (2013) [3]
	waste [5]	1.76	EEA (2013) [4]

1) Indian brick kiln which uses low-sulfur coal
2) Thermal optical transmission measures of EC (elementary carbon); filter data for two flaming and one smoldering fire
3) Mean value from Christian et al. (2010) and Lemieux et al. 2000; field and laboratory measurements
4) Cited source: Bond et al. 2004
5) Calculated as 42% of PM2.5; Cited sources: Jenkins et al. 1996 and Turn et al. 1997

Global BC emissions are given in Bond et al. (2013) as bottom-up best estimate values for year 2000. The BC values as well as emission values for primary organic aerosols (POA) are given in Table 2. Based on the before mentioned error range of emission factors for open burning of 0.6 to 4, the uncertainty range was assessed to 0.29 to 5 considering error propagation (neglecting the independent error estimates from agricultural waste burning and assuming that errors are independent). The ranges for BC and for POA are quite asymmetric.

Table 2: Best-estimate bottom-up values for BC and POA emissions in Year 2000 (Bond et al. 2013)

Source	BC in Gg		POA in Gg	
		Range		Range
Total	7530	2020 to 28800	47000	17800 to 179000
Energy related	4770	1220 to 15000	15900	8800 to 23800
Open burning	2760	800 to 13800	31100	9000 to 156000

Total emissions from open biomass burning are considerably uncertain not only due to the uncertainty for emission factors but also due to uncertainties in the quantification of burned area. Current satellite retrievals cannot detect burn scars much smaller than 1 km^2, and the size of the burned area is sometimes wrongly determined. Active fires can be detected when they are larger than about 0.1 ha, but many fires cannot be observed during their flaming stage because of incomplete coverage of satellite orbits or clouds obscuring the scene. Given the current resolution of satellite instruments that are used for burned area retrievals (typically 0.25 to 1 km^2 at the sub-satellite point and 5 to 10 times larger at swath edges), only burn scars with a size of at least 12 to 40 ha can be detected from space. Field data and satellite retrievals of fire radiative power show that the majority of fires are smaller, particularly in tropical regions. Uncertainties arising from the limited spatial resolution of current instruments could be as large as -30% to +40%, but in reality they are smaller due to compensating errors. It is estimated that burned areas are probably underestimated by about 10% on average (Bond et al. 2013, p. 5417).

According to the best-estimate in Bond et al. (2013) the total BC emissions can be assigned to approximately:

40% open biomass burning
25% residential solid fuels (coal, wood, dung for cooking and heating)
20% diesel engines (excluding ships)
9% industrial coal
6% others (ships, planes, flaring in oil/gas industry)

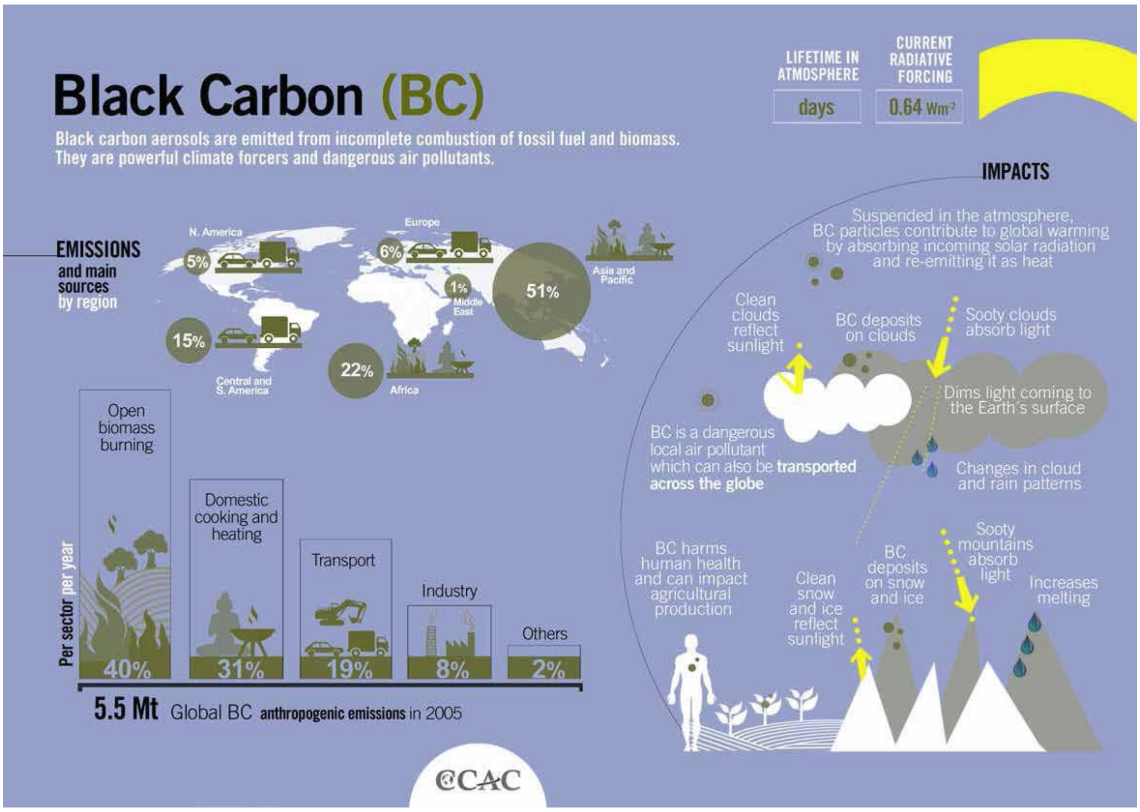
Figure 1 also shows BC emissions per sector with similar shares as in Bond et al. (2013). A higher share of 31% is given for domestic cooking and heating and therefore a lower share for industry and others (10%). The overall global BC emissions are given for the year 2005 with 5500 Gg, approx. 30% less than the value given in Bond et al. (2013) for year 2000.

In addition, Figure 1 shows BC emissions and main sources by region. The main emissions occur in Asia and Pacific and in Africa and are mainly caused by open biomass burning and domestic cooking and heating. In industrialized countries BC emissions are much lower and mainly derive from transport (diesel engines).

Total BC emissions from waste management – waste burning or landfill fires – are not separately mentioned in the different studies. Waste burning is included in Bond et al. (2013, p.5409) and is estimated using per-capita waste generation rates, along with fraction burned and emission factors. Nevertheless, neither the background data nor the results are documented. It is expected that BC emissions from the waste sector are of minor importance.

Apart from emission values and the regional and sectoral distribution Figure 1 also shows the effects of BC on global warming. These aspects will be explained in more detail in the following chapter.

Figure 1: Black Carbon emissions and impacts (Source: UNEP[3])



3.2 Radiative forcing effects of black carbon

Radiative forcing (RF) is defined as the difference of radiant energy received by the Earth and energy radiated back to space. Typically, radiative forcing is quantified at the tropopause in units of watts per square meter (W/m^2) of the Earth's surface. A positive forcing (more incoming energy) warms the system, while negative forcing (more outgoing energy) cools it. Radiative forcing caused by black carbon emissions can be direct, indirect or semi-direct. In addition, black carbon produces positive radiative forcing by changing the reflectivity or albedo of bright surfaces like snow and ice.

Direct radiative forcing is caused by absorption and scattering of sunlight, depending on the aerosol optical properties. Black carbon strongly absorbs light and converts that energy to heat. Direct radiative forcing is the most commonly cited climate forcing associated with black carbon. Bond et al. (2013) estimate the direct radiative forcing of black carbon in the atmosphere for the industrial era (1750-2005) to +0.71 W/m^2 with 90% uncertainty bounds of +0.08 to +1.27 W/m^2. IPCC (2007) estimates that through this effect black carbon is responsible for about +0.34 W/m^2 [± 0.25]. The alteration is explained in Bond et al. (2013) that they

[3] http://www.unep.org/ccac/Short-LivedClimatePollutants/Definitions/tabid/130285/language/en-US/Default.aspx

adjusted global aerosol models with observational estimates of black carbon absorption optical depth as done in some previous studies.

Indirect and **semi-direct effects** are related to **cloud effects**. The *indirect effect* is the mechanism by which aerosols modify the microphysical and hence radiative properties, amount and lifetime of clouds. Three indirect effects are distinguished: the effect on the cloud droplet number and hence the cloud droplet size, with the liquid water content held fixed was called the 'first indirect effect' (or 'cloud albedo effect', 'Twomey effect'); the effect on the liquid water content, cloud height and lifetime of clouds was called the 'second indirect effect' (or 'cloud lifetime effect', 'Albrecht effect'); the third effect is the effect on ice-clouds. Bond et al. (2013) assumed the first and second indirect effect to cause positive climate forcing (+0.2 and +0.18 W/m²), and did not consider the effect on ice-clouds as, at present, even the sign (negative or positive) for this effect is unknown. The first two cloud-effects are summarized and estimated with substantial uncertainty to +0.23 W/m² (90% uncertainty range -0.47 to +1 W/m²). IPCC (2007) did not quantify the effect of clouds. The cloud albedo effect was considered to be a key uncertainty in the RF of climate. A best estimate of the RF was not assigned but the range of RF in the context of liquid water clouds was shown with 0 to -2 W/m². The other indirect effects were not considered to be RFs because, in suppressing drizzle, increasing the cloud height or the cloud lifetime in atmospheric models, the hydrological cycle is invariably altered (IPCC 2007, chapter 2). The effect on ice-clouds was discussed but quantification of an RF was not considered appropriate given the host of uncertainties and unknowns surrounding ice cloud nucleation and physics. In the *semi-direct effect* light absorption (conversion to heat) by black carbon alters the atmospheric temperature structure within, below, or above clouds and consequently alters cloud distribution (influences cloud formation and lifetime). This effect may have either negative (cooling) or positive (warming) climate forcing effects. Bond et al. (2013) concludes as best estimate a negative climate forcing of-0.2 W/m². In IPCC (2007) the semi-direct effect is not strictly considered a RF because of modifications to the hydrological cycle. The various indirect effects and the semi-direct effect as described in IPCC (2007) are shown in Figure 2.

Figure 2: Schematic diagram showing indirect and semi-direct effects of aerosols (IPCC 2007, chapter 2)

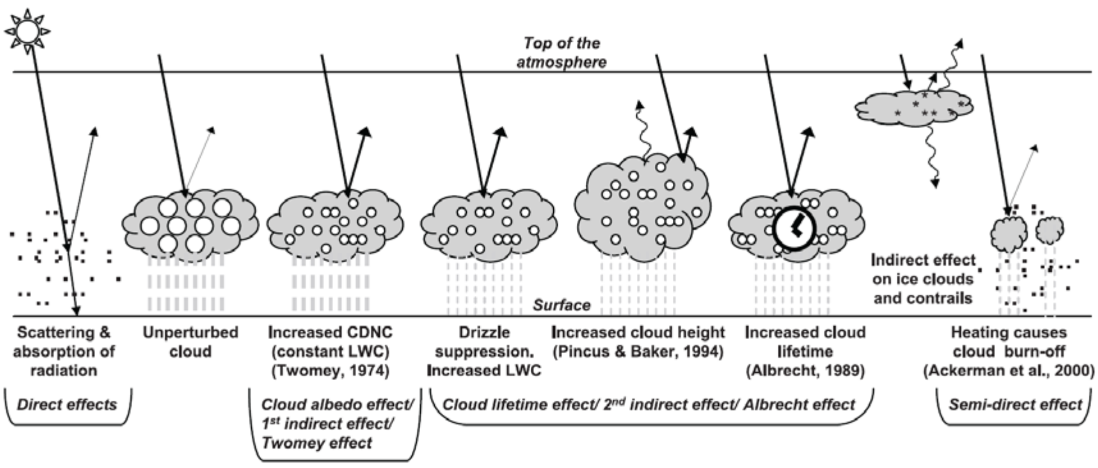


Figure 2.10. *Schematic diagram showing the various radiative mechanisms associated with cloud effects that have been identified as significant in relation to aerosols (modified from Haywood and Boucher, 2000). The small black dots represent aerosol particles; the larger open circles cloud droplets. Straight lines represent the incident and reflected solar radiation, and wavy lines represent terrestrial radiation. The filled white circles indicate cloud droplet number concentration (CDNC). The unperturbed cloud contains larger cloud drops as only natural aerosols are available as cloud condensation nuclei, while the perturbed cloud contains a greater number of smaller cloud drops as both natural and anthropogenic aerosols are available as cloud condensation nuclei (CCN). The vertical grey dashes represent rainfall, and LWC refers to the liquid water content.*

The **albedo effect** refers to the minimization of reflection of solar radiation through deposition of black carbon emissions on snow or ice surfaces, which causes positive climate forcing. The albedo effect also occurs with negative direct radiative forcing aerosols like organic carbon. According to Bond et al. (2013) the best estimate of climate forcing from black carbon deposition is +0.13 W/m^2 (90% uncertainty bounds of +0.04 to +0.33 W/m^2). The IPCC (2007) estimates the global albedo effect of black carbon on snow to be 0.1 W/m^2 [±0.1].

The **total climate forcing** summarizes all above mentioned effects and results in +1.1 W/m^2 (+0.17 to +2.1 W/m^2, 90% confidential range) according to Bond et al. (2013). This value ranks it as the second most important individual climate-warming agent after carbon dioxide (1.66 W/m^2 for 2005 in IPCC (2007), chapter 2). The large uncertainty derives principally from the indirect climate-forcing effects associated with the interactions of black carbon with cloud processes. Climate forcing from cloud drop inclusions, mixed phase cloud effects, and ice cloud effects together add considerable positive forcing and uncertainty. The total climate forcing of BC estimated by IPCC results in +0.44 W/m^2 [± 0.35], including direct radiative forcing and the albedo effect. This ranks black carbon as the third most important positive climate-forcing agent after carbon dioxide and methane (0.48 W/m^2 for 2005 in IPCC (2007), chapter 2).

Another issue for BC and other short-lived climate forcers is that their impact depends on the region and also on the timing of the emissions due to the short lifetime of BC. Once emitted, BC aerosols undergo regional and intercontinental transport and are removed from the atmosphere through wet (i.e., in precipitation) and dry deposition to the Earth's surface, resulting in an average atmospheric lifetime of only several days to weeks. The dependency of the effect of global warming of BC emissions due to time and region has so far only been investigated in two studies where normalized radiative forcings or GWPs of the direct effect and the albedo effect were calculated for regional emissions[4]. Studies of the climate forcing due to emissions during different seasons have not yet been accomplished. The two studies both find a regional variability of ±30−40% for the direct effect, with the largest forcings typically found for emissions from regions located at low degrees of latitude since there is more solar radiation available. For the snow albedo effect the regional variation is much larger with higher values for high degree of latitude regions where the emitted BC is more likely to be deposited on snow surfaces. The snow albedo effect ranges from practically zero for emissions in the tropics to values that reach 30 to 60% of the direct effect for emissions in Russia and the former Soviet Union, not including an enhanced efficacy factor for the snow albedo effect. Since there is a certain cancelation effect depending on the degree of latitude of the emissions (i.e., high direct forcing occurs with low snow-albedo forcing and vice versa) the total of the two mechanisms shows less regional dependence.

The mentioned effects underline the high uncertainty on assessing the climate forcing of black carbon emissions. This uncertainty is expanded when the effects of co-emissions are taken into account.

Co-emissions of incomplete combustion

Incomplete combustion as the source of BC emissions is also the source of many other pollutants. This is important due to the fact that while BC has a positive direct radiative forcing

4 [Rypdal et al., 2009b; Bond et al., 2011] cited in Bond et al. (2013)

effect the co-emitted pollutants especially organic matter and sulfur species introduce negative direct forcing (do not absorb but scatter sunlight). This has to be taken into account for assessing the effect on climate change of black carbon emissions and for the discussion on mitigation measurements. Emission sources that produce the lowest ratio of the components OC and SO_2 in relation to black carbon will cause the most positive forcing, and be therefore the most certain sources that can be addressed for mitigation measures without triggering a minus development.

The global emissions of primary organic aerosols (POA) which are emitted together with black carbon were shown in Table 2. Organic matter is mainly emitted from incomplete combustion of biogenic fuels. Therefore, the emission value from open burning in Table 2 is about 11 times higher than the corresponding BC emission value, while the ratio for the energy related emissions of POA to BC is only 3:1.

Organic matter was also determined in the measurements of open waste burning (landfill fires) in Christian et al. (2010) (see Table 1). In these measurements the OC emissions were higher than the EC emissions in all three cases, the OC/EC ratio ranged from 2.3 to 28.6.

The differing distribution of BC emissions and organic carbon (OC) emissions is also given in Bond et al. (2004) also showing that open biomass burning is the main source for OC:

BC: 42% open burning, 38% fossil fuel, 20% biofuel
OC: 74% open burning, 7% fossil fuel, 18% biofuel

Emissions from diesel engines are those with the lowest co-emissions of aerosols or aerosols precursors. Only in the case of diesel fuels with high sulfur content co-emission of sulfur dioxide may be of relevance. Due to sulfur content regulations and as the fuel market is a global market this is not expected to be of high importance (maybe except ships). But higher sulfur contents are given in coal and become relevant in small combustion units like small boilers, brick and lime kilns or in coke production for steel that are not equipped with a flue gas cleaning system. Here, a high SO_2/BC ratio occurs. This also accounts for emissions from residential solid fuels in the case of coal firing for cooking and for heating. If wood or dung is used for cooking and heating then SO_2 emissions are low but a relatively high POA/BC-ratio occurs due to poor combustion.

Although accounting for forcing by co-emitted species is fraught with uncertainty, ignoring these effects may convey a mistaken impression about the magnitude or even the sign of net climate forcing by BC emission sources (Bond et al. 2013).

In Bond et al. (2013, Figure 37) an estimation is shown on total climate forcing for relevant BC emission source categories. From this it can be assumed that taking into account all relevant emissions, emissions from diesel engines will result in a net positive radiative forcing. The combined effects from industrial coal result in a net negative radiative forcing. This also accounts for emissions from open burning of forests, grasses and woodlands. The combined effects from emissions from residential solid fuel and from open burning of agricultural fields barely cross the zero line, with a slight tendency of net positive radiative forcing. The impact of all emissions from all BC emission sources is slightly negative (-0.06 W/m^2) with a large uncertainty range (-1.45 to +1.29 W/m^2). Therefore, uniform elimination of all emissions from BC emission sources could lead to no change in climate warming, and sources and mitigation measures chosen to reduce positive climate forcing should be carefully identified (Bond et al. 2013, p.5388).

This is also very important according to open burning of municipal solid waste and/or landfill fires as they co-emit organic carbon in relevant quantities. This does on no account mean that this practice should be kept due to the possibility of negative climate forcing because of OC emissions but it should be considered that there might be no contribution to GHG mitigation through reduction of BC emissions by preventing open burning. Nevertheless, open burning of waste and landfill fires should be banned in any case as they cause severe hazards to human health and the environment.

3.3 Global Warming Potential

Impacts on climate change (greenhouse effect, global warming) through different climate agents are mainly assessed using the aggregation method developed by the Intergovernmental Panel on Climate Change (IPCC). The IPCC provides indicators – the Global Warming Potentials (GWPs) – for climate gases for a 20-, 100- and 500-year time horizon. The 100-year time horizon is nearest to the approximate lifetime of CO_2 in the atmosphere[5], and thus represents best the overall impact of CO_2.

The GWPs of different climate agents are calculated as the relation between the time-integrated global mean radiative forcing (RF) of a pulse of 1 kg of this climate agent and that of CO_2 (IPCC 2007, Chapter 2). The GWP for CO_2 thus is "1" independently of the chosen time horizon. This means that CO_2-emissions are best represented with the 100-year time horizon, and are underrepresented within a 20-year time horizon compared to climate agents with a shorter lifetime as only a fraction of the radiative forcing of CO_2 is considered (see Figure 3). On the other hand short-lived pollutants have the same radiative forcing over 20, 100 and 500 years as their lifetime is shorter than 20 years. Therefore, their GWP is the highest for the 20-year time horizon, and their relative importance decreases with a longer time horizon. Conversely, the GWP for substances with a longer atmospheric lifetime than CO_2 increases with a longer time horizon.

The selection of the time horizon should depend on the policy goal. The parties to the Kyoto Protocol chose to use primarily the 100-year time frame in calculating their emission inventories, which shows a preference for long term impacts and therefore, long-lived greenhouse gases (ICCT 2009). It also shows a preference to recognize CO_2-emissions which are responsible for 55-60% of anthropogenic radiative forcing according to IGSD (2013).

GWPs are the recommended metric to compare future climate impacts of long-lived climate gas emissions. In general, a multi-gas strategy such as GWPs allows the comparison of the impact of different climate agents and thus allows the implementation of comprehensive and cost-effective policies for mitigation. But as explained above it is impossible to likewise value both short-lived and long-lived climate pollutants with the GWP metric. The Global Temperature Potential (GTP) metric provides an alternative approach by comparing global mean temperature change at the end of a given time horizon. Nevertheless, compared to the

[5] CO_2 has a variable atmospheric lifetime, and cannot be specified precisely. In principle, CO_2 molecules are removed from the atmosphere by mixing into the ocean, photosynthesis, and other processes. This takes place within the order of 30-95 years. However, this excludes the balancing fluxes of CO_2 into the atmosphere from the geological reservoirs. Altogether, more than half of the CO_2 emitted is removed from the atmosphere within a century, while some fraction (about 20%) of emitted CO_2 remains in the atmosphere for many thousands of years.

GWP, the GTP gives equivalent climate response at a chosen time, while putting much less emphasis on near-term climate fluctuations caused by emissions of short-lived species (IPCC 2007, chapter 2, p.211). Another alternative, the RF index (RFI) introduced by IPCC (1999), should not be used as an emission metric according to IPCC (2007) since it does not account for the different residence times of different forcing agents.

Figure 3: Integrated Radiative Forcing for Year 2000 Global Emissions (IPCC 2007, chapter 2)

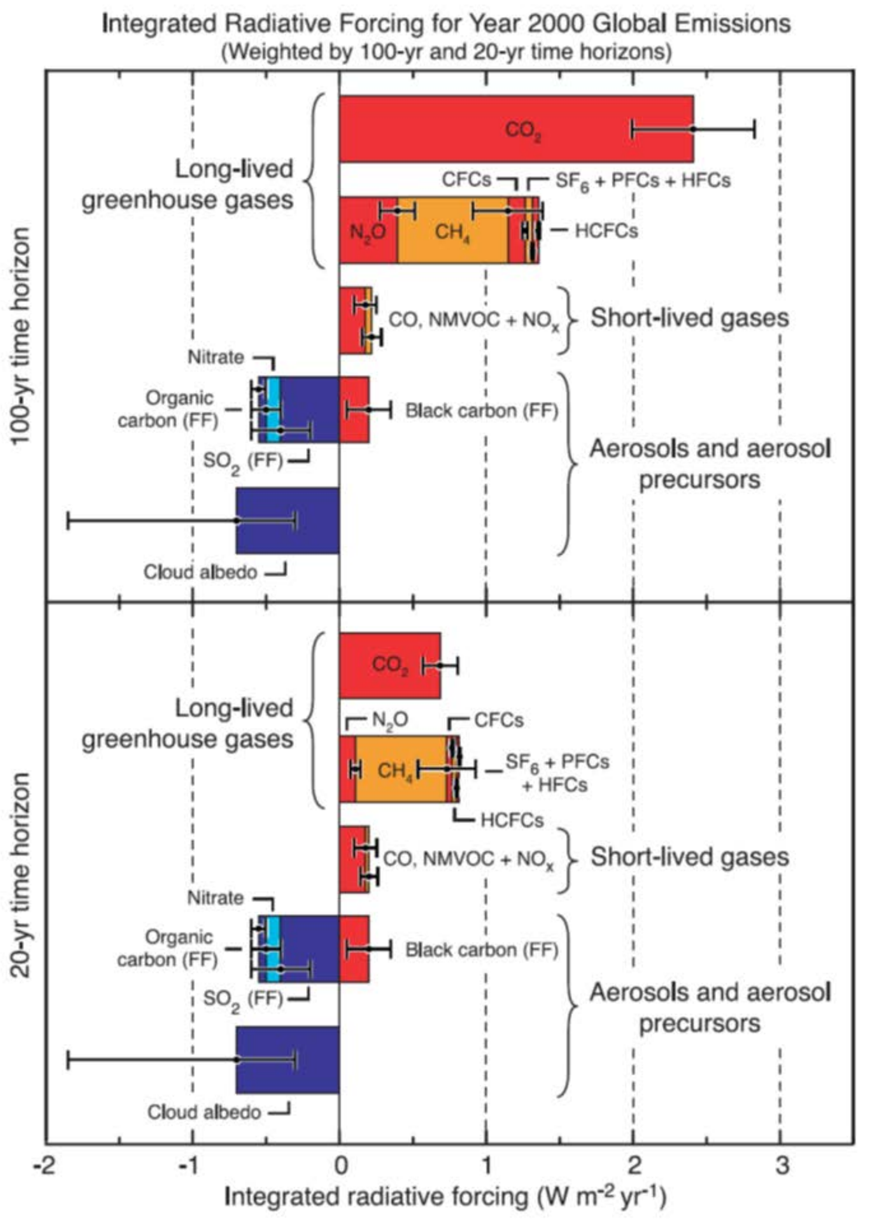


Figure 2.22. *Integrated RF of year 2000 emissions over two time horizons (20 and 100 years). The figure gives an indication of the future climate impact of current emissions. The values for aerosols and aerosol precursors are essentially equal for the two time horizons. It should be noted that the RFs of short-lived gases and aerosol depend critically on both when and where they are emitted; the values given in the figure apply only to total global annual emissions. For organic carbon and BC, both fossil fuel (FF) and biomass burning emissions are included. The uncertainty estimates are based on the uncertainties in emission sources, lifetime and radiative efficiency estimates.*

Due to the above mentioned discrepancies and also due to the high uncertainties in estimating the climate forcing effects for black carbon (see chapter 3.2), IPCC did not provide any GWPs for BC so far. Because of its short lifetime BC is not well mixed in the atmosphere, and the same mass emission from different locations can have markedly different climate effects, especially considering the indirect effects and the albedo effect, effects that also make BC different from most GHGs. Nevertheless, metrics that attempt to place BC and GHGs on a common scale are useful in the context for decision making, but because of the differences in lifetime and climate forcing mechanisms any such metric and corresponding results should be used with caution.

Globally averaged GWPs have been calculated by different authors as shown in Table 3. The dependency on region and time of emission and the high uncertainty of the values can be seen in the high range of uncertainties given in brackets. The GWPs according to Bond et al. (2013) are calculated based on the values for radiative forcing as described in chapter 3.2. The GWPs for total climate forcing include direct, indirect, semi-direct and snow albedo effects, whereof the cloud effects were considered to have positive climate forcing, while IPCC (2007) estimates the cloud albedo effect to be zero or negative (see chapter 3.2).

Table 3: GWPs for black carbon from different sources (uncertainty ranges in brackets)

Source	GWP 20	GWP 100	GWP 500	Climate forcing effect
ICCT (2009)[1]	1600	460	140	direct effect
Bond et al. (2013)	3200 (270-6200)	900 (100-1700)	280 (24-550)	total climate forcing
	2100 (420-3700)	590 (140-1100)	180 (36-320)	direct effect
Bond et al.(2005)	2200 (690-4700)	680 (210-1500)		direct effect
Reddy & Boucher (2007)		480 (374-677)[2]		direct effect
		281 (1200)[3]		snow albedo effect

1) calculated from values for radiative forcing in IPCC 2007 (+0.34 W/m², see chapter 3.2); ICCT (2009) also provides GWPs for organic carbon which are: -240 for the GWP 20, -69 for GWP 100, -21 for GWP 500
2) global mean, range in brackets for different regions; regional differences arise largely from different BC atmospheric residence times and amount of insolation
3) global mean, value in brackets for Europe, is largest due to a very large contribution to BC deposition (63%); calculations based on RF = 0.1 W/m²; RF for different regions apportioned according to BC deposition in high degree of latitudes

According to ICCT (2009) the application of the GWP assumes that the emissions being compared produce radiative forcing that is evenly spread across the globe, so any two emissions produce equivalent radiative forcing regardless of their location. But since black carbon is short-lived and its radiative forcing is regionally concentrated, this assumption does not hold. Short-lived aerosols travel short distances, producing strong regional radiative forcing sometimes referred to as "hot spots". The location and duration of this forcing will vary with local conditions that influence their lifetime and transport. Therefore, no two emissions of black carbon weighted by GWP can be expected to produce an equivalent radiative forcing. This suggests that black carbon emissions weighted by the GWP do not necessarily represent a CO_2-equivalent value.

The CCAC MSW Initiative has its focus on mitigation strategies for SLCPs, including black carbon. The problems combined with the attempt to place short- and long-lived climate pollutants on one metric are well understood. Therefore, the Initiative aims at a parallel approach understanding SLCP measures as a complementary strategy. The reduction of SLCPs can slow down the global warming in a short time frame. Combined with CO_2 mitigation measures that take effect in the long term the overall long-term global warming can be minimized more effectively.

Nevertheless, the climate forcing effects of black carbon are of very high uncertainty. This aspect also accounts for other metrics which only take into account SLCPs like the toolkit being developed for the CCAC SNAP Initiative (see chapter 2) which estimates the impact of SLCP emissions (black carbon, methane, tropospheric ozone, some hydrofluorocarbons) calculating the endpoint indicators "premature mortality avoided" and "crop yields".

In addition, BC emissions in the waste management sector mainly occur from open waste burning and/or landfill fires. Other sources are expected to be of low relevance. Municipal solid waste is composed of a high share of organic matter especially in developing countries where open burning and landfill fires are of relevance. Therefore, climate forcing effects of BC emissions should not be considered alone but always in combination with the climate forcing effects of OC emissions.

As for an assessment tool for the cities in the CCAC MSW Initiative it is strongly recommended to not only consider BC emissions but also OC emissions. Furthermore, despite of all uncertainties and weaknesses from putting short-lived and long-lived climate pollutants on one scale, the GWPs should be used to at least get an impression of what these emissions may mean to the global warming, and also to get some kind of understanding what the impacts mean in comparison to methane and CO_2-emissions. For this purpose – to assess the relevance of BC emissions in the context of waste management – scenarios are calculated in the following chapter.

3.4 Assessment of relevance of black carbon in GHG accounting in SWM

BC emissions only occur from incomplete combustion. In the context of waste management this is relevant only in case of uncontrolled landfill fires or open waste burning. Controlled incineration processes with high combustion efficiency or filter technologies are low BC emitters (see chapter 3.1). In addition, BC emissions from diesel engines are of relevance on the global scale. With the aim to assess the possible relevance of BC emissions in GHG accounting in the waste sector, the following scenarios are defined for municipal solid waste (MSW) treatment.

Collection and transport

Distance: 50 km
Emission factors[6]: 2 g BC/kg fuel (= 0.17 g BC/tkm) and 230 g CO_2/tkm

Landfill without gas collection

DOC: 11% wet waste
DOCf, CH_4-content landfill gas: default values IPCC (2006)
Methane correction factor (MCF) varied:
a) 0.4 (unmanaged landfill) and b) 1 (managed landfill)

Open waste burning

Fossil carbon: 5% wet waste

[6] Values correspond to pre-regulation trucks, for BC see Table 1.

BC emission factors varied:
a) minimum value 0.65 g BC/kg waste and b) maximum value 5.5 g BC/kg waste
OC emission factors varied:
a) minimum value 5.27 g OC/kg waste and b) maximum value 44.6 g BC/kg waste

The BC and OC emission factors for open waste burning correspond to the values given in Table 1 according to Akagi et al. (2011) and UNEP (2013). The minimum values for BC and OC represent the mean values of the measurements undertaken in Christian et al. (2010). For the maximum value of BC emissions according to UNEP (2013) no corresponding OC emission factor is available. The factor has been calculated under the assumption of a similar OC/BC ratio as for the minimum values.

Due to the high uncertainties and differing values from different studies for the radiative forcing effect of BC (see Table 3) several variations for the GWP are examined:

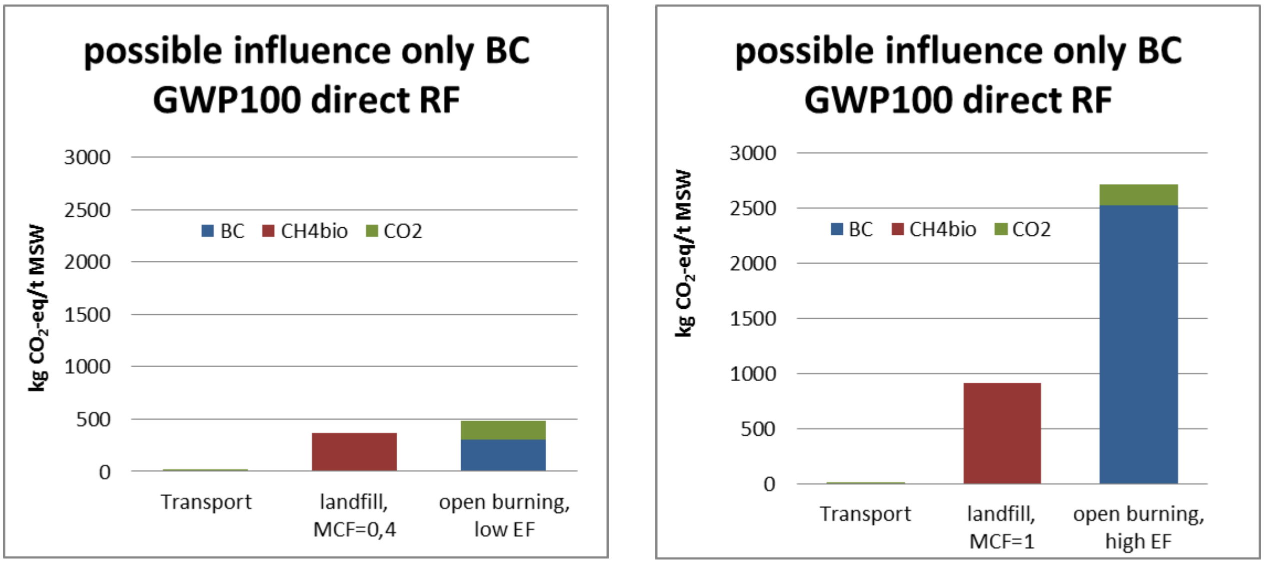
GWPs – variations:

a) **only BC**, GWP100 direct RF (ICCT 2009)
b) BC **and OC**, GWP100 direct RF (ICCT 2009)
c) BC and OC, **GWP20** direct RF (ICCT 2009)
d) BC GWP20 **total climate forcing** (Bond et al. 2013), OC GWP20 direct RF (ICCT 2009)

In general, it seems more adequate and conservative to use the GWPs for the direct effect as the total climate forcing that includes the indirect effects (cloud effects) add considerable positive forcing and substantial uncertainty (see chapter 3.2). In this assessment as a basis the GWPs from ICCT (2009) are selected because this source also provides GWPs for OC. To respect the higher influence of BC emissions with a short time horizon the GWP20 is used as variation to calculate the overall GHG emissions. Finally, also the effect is examined if the total climate forcing is considered as given by Bond et al. (2013). Here again the value for the GWP20 is used. This last assessment is of the most significant uncertainty, not only due to the substantial uncertainty for the indirect effect but also because no corresponding GWPs for OC are available, which are expected to be also higher as the GWP for the direct effect in Bond et al. (2013) is higher than in ICCT (2009).

The first assessment shown in Figure 4 considers BC only according to the above listed variation a). The results are given in kg CO_2-eq/t MSW.

Figure 4: Results GWP 100, direct RF, OC emissions not taken into account

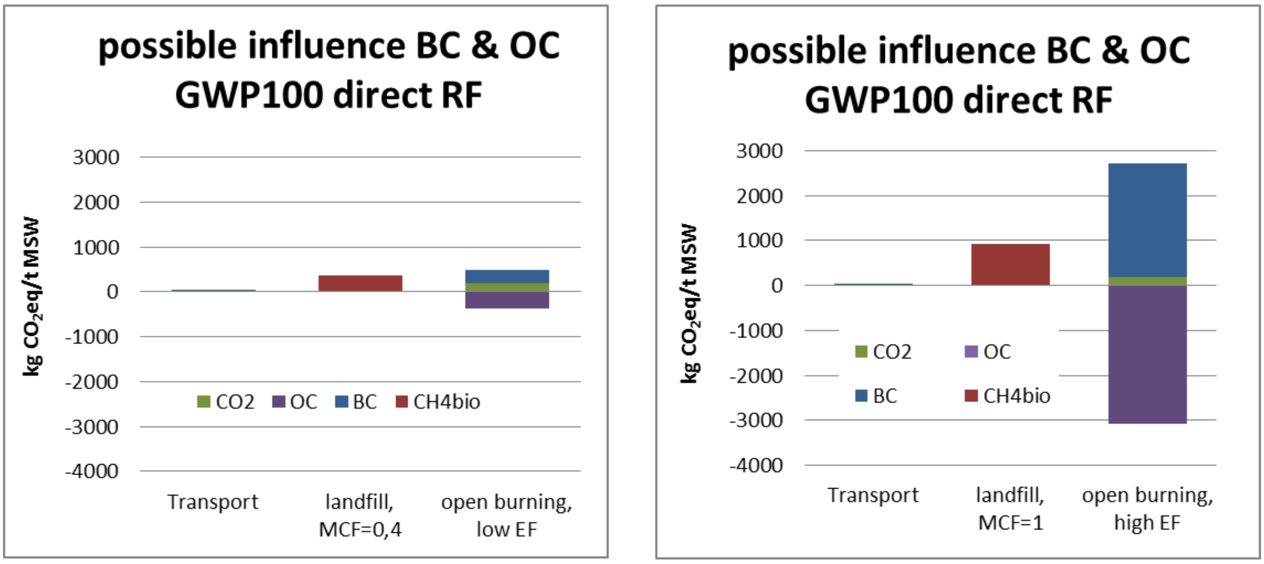


It is obvious that the GHG emissions from collection and transport are of minor importance. This is known for CO_2 emissions in the context of waste management, and it is shown here that this also accounts for BC emissions. The relevance of GHG emissions from transport compared to the GHG emissions from landfilling (MCF=0.4) is below 4%. CO_2 emissions contribute to 75% to the GHG emissions from collection and transport.

BC emissions from open waste burning in kg CO_2-eq are higher than the corresponding CO_2 emissions, irrespective if the minimum or the maximum emission factor for BC is used. In total open waste burning results in higher GHG emissions as landfilling of waste in case of unmanaged landfills with a MCF of 0.4. In the case of a managed landfill with a MCF of 1, open waste burning would result in higher GHG emissions when the maximum EF for BC emissions is given.

The results shown in Figure 5 refer to variation b) listed above. Here, with OC emissions taken into account the picture completely changes. Although, the GWP100 for OC is much lower than that for BC (-69 in contrast to +460, see Table 3), the resulting GHG emissions are even a little higher than those of BC due to the higher emission factor of OC. In the case of the maximum emission factors for BC and OC, this even results in net negative GHG emissions for open burning of waste.

Figure 5: Results GWP 100, direct RF, OC emissions taken into account



The results shown in Figure 6 refer to variation c) listed above. In contrast, the results from variation b) do not change. This is because the relation between the GWP100 and the GWP20 of BC and OC is the same (GWP 20 is about 3.5 times higher than GWP 100). The only effect from calculating with the GWP20 is that the overall GHG emissions from BC and OC are higher and the relevance of CO_2 emissions is decreasing. Although to a minor extent, this also accounts for the methane emissions (“CH_4bio”) from landfill as the GWP20 for methane is only about 2.8 times higher than the corresponding GWP100.

The results shown in Figure 7 refer to variation d) listed above. Here now the total climate forcing according to Bond et al. (2013) is considered for BC while for OC still the values from ICCT (2009) are used as no other values are available. The used GWP20 for BC is 3200 kg CO_2-eq/kg (see Table 3) and thus 13 times higher than the used GWP20 for direct RF for OC. With this the picture changes again and shows the higher relevance of BC emissions.

Figure 6: Results GWP 20, direct RF, OC emissions taken into account

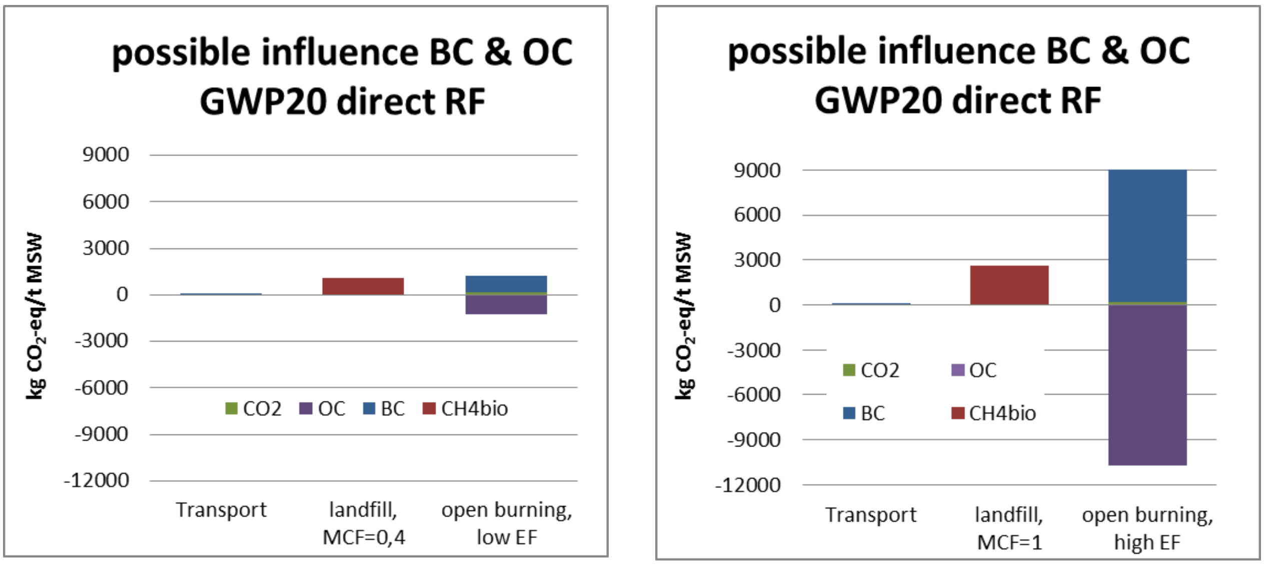
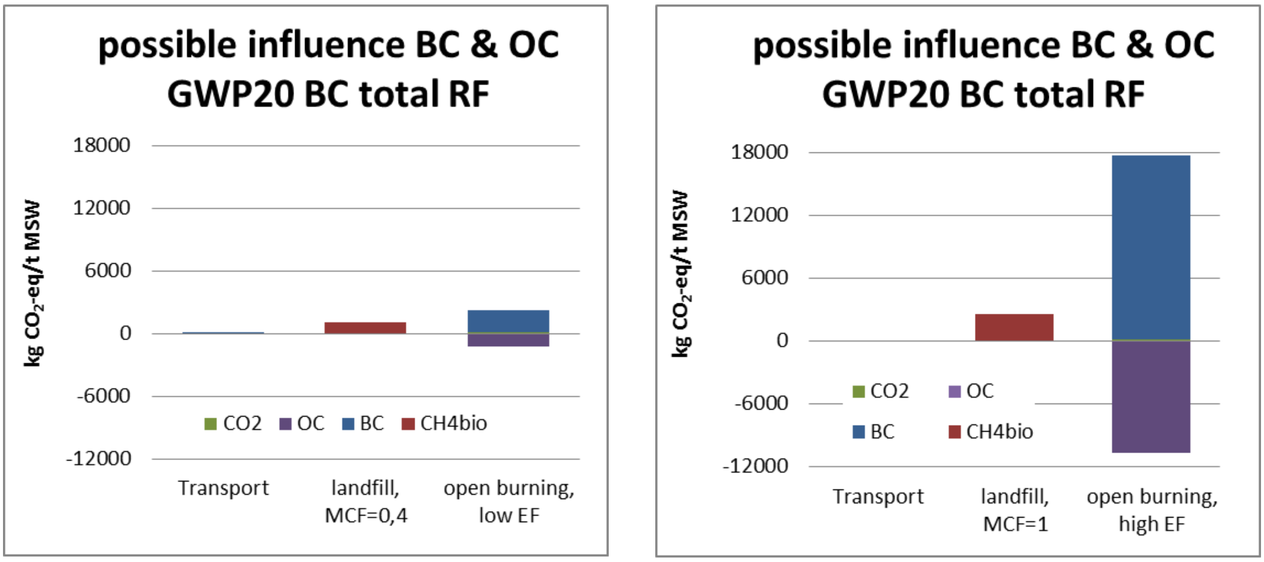


Figure 7: Results GWP 20, BC total climate forcing (RF), OC as before direct RF



It has to be emphasized that the calculation results shown should be considered as orientation values only. Due to the high uncertainties of the climate forcing effect of BC, and assumingly also OC, and due to the differences in lifetime and climate forcing mechanisms of short-lived and long-lived climate pollutants the corresponding results are not to be seen as representative.

Nevertheless, the results stress the importance that it is not sufficient to only take into account BC emissions, irrespective what metric is used to assess global warming. OC emissions also have to be considered in the case of waste management due to the relevant organic carbon content in MSW.

4 Evaluation of existing tools for GHG quantification in waste management

In principle, tools for GHG quantification in the waste sector should be transparent regarding calculations and data sources. They should be publicly available, user-friendly and easy to access. Furthermore, they should use harmonized inventory data, and should offer the possibility to change important parameters. Finally, calculations should be based on scientifically accepted approaches.

4.1 Screening of existing tools

Existing tools have been screened to test their principle qualification to be used as a SLCP and GHG quantification tool in the context of the CCAC MSW Initiative. From the principle criteria mentioned above it is of most importance that tools are transparent and/or can be adopted if necessary and that they follow the LCA approach for assessing system comparison (status-quo compared with possible optimization scenarios).

LCA in waste management is the basic approach for system comparison that ensures assessment of waste management activities in their completeness. This approach was also used in projects on climate protection and waste management undertaken on behalf of the German Federal Environment Agency. Essential characteristics are that the system boundary starts with waste generation and that all generated benefits from waste treatment like saved or avoided effects through production of energy or secondary products are included. Another decisive characteristic is that all current and future emissions associated with the treatment of a certain amount of waste are considered in the accounting. This is especially important in the context of landfilling of organic waste as relevant methane emissions from degradation are not released spontaneously but over decades. Decisions for different treatment options like landfilling, incineration or recycling need to take these overall emissions into account.

Transparency is necessary to understand the results and their crucial influencing variables. Such variables, for example, are waste composition and characteristics (especially fossil and regenerative carbon content and lower heating value), the efficiency of landfill gas collection, and treatment of collected landfill gas, the net efficiency of energy utilization through waste incineration, and emission factors for avoided primary production through recycling (including electricity grid). Especially these variables should be set as parameters in the calculation tool.

In general, tools should be publicly available and the ownership should be transferrable to the CCAC MSW Initiative. In addition, modifications should be possible and/or allowed, e.g. changing or amending emissions factors in case they are only referring to a certain region in an existing tool.

From these basic criteria – LCA approach, availability, transparency and adaptability – tools from the screening phase are selected for further in depth analysis in chapter 4.2.

4.1.1 Tools considered in the Stratus Report

The Stratus Report (Stratus 2013) assessed six selected tools for GHG accounting in waste management for their appropriateness to integrate black carbon emissions. These are:

1. WARM – Waste Reduction Model der US EPA, 1993, update Juni 2013, http://epa.gov/epawaste/conserve/tools/warm/index.html
2. Environment Canada GHG Model, Government of Canada, Environment Canada, based on WARM, http://www.ec.gc.ca/gdd-mw/default.asp?lang
3. EASEWASTE - Environmental Assessment of Solid Waste Systems and Technologies, TU Denmark, 2004, update 2012, http://www.easewaste.dk/
4. EpE Waste Sector Protocol, EpE Entreprises pour l'Environnement, Version 5, May 2013, http://www.epe-asso.org/index_en.php?part=publi&id_rap=20[7]
5. GHG Calculator for Solid Waste, IGES - Institute for Global Environmental Studies, GHG Simulation Version II, 1.10.2013, http://pub.iges.or.jp/modules/envirolib/view.php?docid=4273
6. GHG-SWM Calculator, IFEU Heidelberg on behalf of KfW, 2009, http://www.ifeu.org/english/index.php?bereich=abf&seite=klimarechner

All these tools are Excel-based and easy to access with the exception of EASEWASTE which requires passing through a trainee program that is subject to charges. EASEWASTE is comprehensive and complex and meant for use on a scientific level. Corresponding to this also the manual is very complex and not easy to understand for non LCA experts. Due to the limited access EASEWASTE is not further analyzed.

[7] Version 5 made available via dropbox to the participants of the Workshop in Paris.

The other tools are publicly available for download via the above mentioned links with the exception of the Canadian GHG model which is only available on inquiry. In addition, the Canadian model is a version of WARM adapted for the Canadian conditions. Therefore, also the Canadian GHG model is not further analyzed.

Other than the **EpE Waste Sector Protocol** all tools follow the LCA approach in waste management. Nevertheless, the name „Waste Sector Protocol" is appropriate as this protocol is for waste companies to report GHG emissions from their activities. The EpE Protocol is in compliance with the GHG protocol[8], a standard for companies and municipalities for their annual reporting of GHG emissions (inventory).

GHG Protocol

The GHG Protocol – jointly developed by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) – is recognized as an internationally accepted standard for calculations and reporting of GHG emissions, and is compatible with ISO 14064. The protocol distinguishes three scopes to help delineate direct and indirect emission sources. Scope 1 addresses direct GHG emissions that occur from sources that are owned or controlled by the company. Scope 2 accounts for GHG emissions from the generation of purchased electricity consumed by the company. Physically these emissions occur at the facility where the electricity is generated[9]. Scope 3 is an optional reporting category that allows the inclusion of all other indirect emissions that occur from sources not owned or controlled by the company. Examples are GHG emissions from extraction and production of purchased materials, transportation of purchased fuels, and use of sold products and services. The GHG Protocol does not consider GHG emissions from avoided processes (no offsets) to avoid the risk of double accounting. The reporting covers the GHG emissions of the Kyoto Protocol, biogenic CO_2 emissions have to be reported separately.

Other than the GHG Protocol the EpE Protocol reports avoided GHG emissions but separately from Scope 1 and Scope 2 emissions (also no offset). Carbon sequestration is reported for information only. Scope 3 emissions will have to be reported in the future under the EpE Protocol (not optional anymore).

The decisive difference between the EpE Protocol (reporting) and the LCA approach is the time horizon considered. Reporting systems refer to a certain time interval, typically one year. The LCA approach relates all current and future emissions caused by the treatment of a certain amount of waste to the waste treated (results in impact per metric ton waste). As mentioned this is especially of relevance for landfilling of waste[10], and is absolutely necessary for decision making. In principle, the EpE Protocol tool could be adapted by implementing the necessary overall calculation. Besides different landfilling options this would also affect accounting for

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[8] Full review of the protocol was undertaken in 2012 by the World Resource Institute to ensure that it conforms with the requirements of the GHG Protocol and to obtain the label "built on the GHG Protocol" (labeling was expected for end of 2013).

[9] Only direct emissions from energy generation; emissions from the pre-chain (supply of energy carriers) are not included in Scope 2 but in Scope 3.

[10] Emissions from landfills are not accounted in the EpE Tool but reference is given to four different external methane calculation models which account annual emissions (considering waste disposal since 1950).

generated waste (open burning, scattering, dumping) and providing a set of harmonized emission factors instead of the currently given set of (partially very) different factors from literature studies that the user can (conservatively) choose from. Additionally, the possibility for system comparison is not available in the existing tool.

But it is not recommended to conduct these modifications. The EpE Protocol tool already is rather detailed to meet the requirements of the GHG Protocol like the differentiation between Scope 1, Scope 2 and Scope 3 emissions (must be all considered in system comparison). With the focus on the company level and on emissions they are directly responsible for (like fuels used for processes) the tool already includes very much data entries which would have to be checked by users for relevancy. A modification would downgrade the easy accessibility of the tool and the labeling process might be in conflict to adding the different calculation approach. Therefore, the EpE Protocol tool is not further analyzed.

WARM, a tool from the US EPA, is very simple and follows the calculation principle "activity rate x emission factor". Next to the GHG emissions also results for an energy analysis and carbon equivalents are given. Two scenarios can be compared – one baseline and one alternative scenario. Waste treatment options included are waste prevention (source reduction), recycling, landfilling, incineration and composting. The calculation is done by waste fraction, altogether there are 46 waste fractions distinguished. Examples are aluminium and steel cans, several types of plastic, several paper products (telephone books, textbooks, newspapers, etc.), several organic wastes (grass, leaves, branches, mixed organic waste), personal computers, several demolition wastes (asphalt, Vinyl flooring, etc.). In addition, the tool asks for several conditions with the following answering options:

- individual federal states or national average
- benefit for waste prevention (source reduction) at current market mix of virgin and recycled inputs or 100% virgin
- landfill gas collection yes/no or national average
- landfill gas collected for energy use or flaring or unknown
- degradation rate at landfills (k-value) depending on moisture content: dry, average, wet or bioreactor
- landfill gas collection rate: typical, worst-case or aggressive (see below)
- transport distances to waste treatment facilities

The simplicity of the WARM tool is a disadvantage here. The emission factors used are hard-coded and are not explained in the tool. All other calculations occur on hidden excel sheets and cannot be followed directly. The emission factors, data used and calculations are only explained in a variety of accompanying documents which have to be read. From this it becomes clear that emission factors for recycling and incineration are only valid for the USA. Carbon sequestration is automatically integrated in relevant emission factors (affects landfilling, compost use on fields forest with paper recycling). Energy utilization efficiencies are fixed, only electricity generation is included.

Especially disadvantageous is the given choice for gas collection rates. Three options are available (see above) which refer to fixed calculation schemes with unchangeable values and are explained in the tool as follows:

- typical collection = Years 0-2 0%; Year 3 50%; Years 5-7 75%; Years 8-100 95%
- worst-case collection = Years 0-5 0%; Years 6-7 75%; Years 8-100 95%

- aggressive collection = Year 1 25%; Years 2-3 50%; Years 4-7 75%; Years 8-100 95%

These gas collection rates are much higher than scientifically acknowledged. For Germany the average national gas collection efficiency over the 100 year time horizon is reported to be 60% (national inventory report to the UNFCCC). This accounts for landfills with installed gas collection systems which is the case in Germany for all relevant landfills but not in the USA where a gas collection system is only mandatory for large landfills according to the Clean Air Act (CAA).

Fixed emission factors and the rather fixed calculation of the gas collection efficiency are two aspects of high influence on the results. Especially the high gas collection rates would be misleading and useless for assessments in developing and emerging countries. In addition, the possibility to calculate the impacts from unmanaged landfilling is missing (no methane correction factor included) as well as calculation for open burning of waste or uncontrolled landfill fires. Furthermore, the breakdown into 46 waste fractions is much too high. It is not to be expected that municipalities can provide such detailed information on waste fractions. To apply the WARM tool in the CCAC MSW Initiative context comprehensive modifications would be necessary to ensure transparency, flexibility and the concentration on relevant waste fractions. WARM is widely used in the USA and changes might not be welcome (Stratus 2013). Due to the mentioned aspects WARM is not analyzed further.

The remaining tools, the GHG Calculator for Solid Waste of IGES and the SWM-GHG Calculator from IFEU/KfW both fulfill the requirements mentioned at the beginning. Both tools follow the LCA approach, are publicly available and easy to access. Both are transparent as the calculations are (nearly[11]) completely visible and data sources and calculations are explained in the tool and also in a manual. In addition, both tools provide variables set as parameters, although different ones in each tool.

The Stratus Report (Stratus 2013) did not select or dismiss any of the six compared tools. However, the Stratus Report aimed at answering the question if black carbon could be implemented into the tools, as none of the tools considers black carbon for the time being. Such an implantation is principally possible for all the tools. Nevertheless, the Stratus Report provided recommendations which tool is more or less suitable with respect to several criteria. Thus EASEWASTE should be avoided if having an easy-to-use, transparent and readily accessible tool available to the public is a priority. The EpE Protocol should be avoided if having the LCA approach is preferred over producing an annual inventory. On the other hand the IGES and the EpE tool are recommended if having a modified tool that can be ready for use in the near future is a priority as both are currently undergoing review and revision. If accounting for emissions from open burning is an immediate priority then the IFEU-KfW tool is recommended as it is the only one currently considering open burning, however, it was mentioned that transports are not accounted separately in the tool.

From the screening of the six tools the following recommendations are given here:

Tools not to be further analyzed:

EASEWASTE, due to missing accessibility

GHG Model Canada, as based on WARM and only valid for Canada

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[11] In the IGES tool some side calculations for emissions are done on a hidden Excel sheet.

EpE Protocol, due to missing LCA approach, too detailed and focused on company level with fulfilling requirements according to the GHG Protocol

WARM, because of too many waste fractions, not transparent, no possibility to adjust important variables (e.g. gas collection efficiency)

Tools to be further analyzed:

- GHG Calculator for Solid Waste of IGES, "IGES Tool" in the following
- GHG-SWM Calculator from IFEU, „IFEU-KfW Tool" in the following

4.1.2 Further tools listed in the Stratus Report

In addition to the above described tools the Stratus Report mentions another seven tools not further analyzed. Three of these tools are not publicly available and it is therefore not possible to assess or to analyze them. These tools are:

- Life Cycle Assessment Integrated Waste Management of the European Commission
- Waste Analysis Software Tool for Environmental Decisions of the National Sciences and Research Council of Canada and the Ryerson University
- Waste-Integrated Systems for Assessment of Recovery and Disposal from Ecobilan or Ecobalance, a French private consulting agency belonging to PricewaterhouseCoopers

The further four tools principally publicly available are:

1. Integrated Solid Waste Management Tool of Environment Plastic Industry Council and Corporations Supporting Recycling, http://www.iwm-model.uwaterloo.ca/english.html
2. Organic Waste Research (ORWARE) of the Swedish Waste Research Council, http://www.ima.kth.se/im/orware/
3. Waste and Resources Assessment Tool for the Environment (WRATE) of the United Kingdom Environment Agency, http://www.environment-agency.gov.uk/research/commercial/102922.aspx
4. Municipal Solid Waste – Decision Support Tool (MSW-DST) of the USEPA, developed by RTI International, https://mswdst.rti.org/, https://mswdst.rti.org/resources.htm

The **Integrated Solid Waste Management Tool** was designed for cities. A manual is available from 2004. The tool is based on Visual Basic in Excel and follows the LCA approach. It considers all relevant waste treatment options for collected waste, open burning or uncontrolled dumping is not included. The accessibility is limited because only possible via an application whereat the applicant has to accept the following requirements:

1. Acknowledge that copyright of the model belongs to EPIC/CSR[12]

2. Provide a copy of your final report so that it may be posted on the website

3. Become a part of the network of users (i.e. have your contact information posted on the site)

[12] CSR: Corporations Supporting Recycling and EPIC, the Environment and Plastics Industry Council

Thus obstacles for the use of the tool are that modifications have to be agreed on by EPIC/CSR and it is expected that results from using the tool have to be reported and published. Therefore, the tool is not further analyzed.

The **ORWARE** Tool was originally (1993) designed for organic waste only which is the reason for the name. Until the end of the 90ies the tool was expanded to all types of MSW and sub-models for the calculation of economic aspects were added. The tool includes several treatment options like digestion, composting, landfilling, incineration, gasification, waste water treatment and transports. OWARE is a LCA model which considers a variety of emissions also those addressing other impact categories than global warming. The calculation is based on material flow analysis. The tool is not available for download and is not suitable for public use. In addition, the last internet entry is older than 10 years. Nevertheless, mainly due to the fact that is similarly complex as EASEWASTE it is not further analyzed.

The **WRATE** Tool of the UK Environment Agency is subject to license conditions and uses the Ecoinvent data base. The tool is owned by the Environment Agency and is only allowed to be used in accordance with the license requirements. If third parties should use the tool the approval of the Environment Agency is needed. Training on the tool can be ordered by the Environment Agency and a software support for users is available. Already due to the terms of use WRATE is not suitable to be used in the context of the CCAC MSW Initiative.

The **MSW-DST** has been developed by the US EPA Office of Research and Development (ORD) and the Research Triangle Institute (RTI) International as well as by the North Carolina State University. A revised version has recently been opened to public. The development of the tool already started 20 years ago. In contrast to WARM (other department in the US EPA[13]) the MSW-DST is much more complex. Next to GHG emissions the tool also considers further air emissions, energy, water emissions and costs. It allows the investigation on several waste management strategies depending on population density, infrastructure, electricity grid, waste composition and transport distances. The tool considers all waste management activities and different characteristics of materials (like food waste, glass, metal, paper, plastics and yard waste) which have an influence on the potential to substitute primary processes and conventional energy generation. To use the MSW-DST registry is required[14]. Next to a user manual a variety of accompanying background documents are available. The tool is not self-evident. With public release in the mid of 2013 a webinar was offered for introduction of the tool. The data used in the tool are not set as parameters and are only valid for the USA. Therefore, also the MSW-DST is not further analyzed.

Summarizing none of the additional seven tools mentioned in (Stratus 2013) is suitable for further analysis as they are either not publicly available or not easy to access or too complex.

4.1.3 Further research on tools

Within the further research on GHG accounting tools for the waste management sector two tools were identified which are interesting and are briefly described here although they are not suitable for the CCAC MSW Initiative context:

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[13] WARM was developed by the US EPA Office of Solid Waste and Emergency Response (OSWER) while the MSW-DST was developed by the US EPA Office of Research and Development (ORD).

[14] https://mswdst.rti.org/Login.htm

1. Fenix Project, GiGa - Escola Superior de Comerç Internacional (Universitat Pompeu Fabra), http://www.life-fenix.eu/en/project/results
2. HEAT+, Local Governments for Sustainability (ICLEI), http://heat.iclei.org/heatplusv4n/requestguestaccess.aspx

The **Fenix** Tool is a product from an EU sponsored project. The objective of the project was to develop a user-friendly tool that should enable municipal administrative facilities in Spain and Portugal to obtain or generate LCA results for recycling of light weight packaging (LWP). The tool also takes into account economic and social aspects and can be adopted for other European regions. Project partners were Ecoembes, Sociedade PontoVerde und PE International. The Fenix Tool is based on the software program GaBi[15] from PE International. The tool is only accessible via internet. Results can be downloaded and saved in the Excel format. A manual is available explaining how to use the tool and the processes included in the tool (briefly waste collection and sorting, more extensive waste treatment processes). The calculation itself and the data used are not explained in the manual.

Fenix is interesting because here also municipalities were in the main focus as users which should be supported for decision making through network building and training courses. The tool itself is not suitable within the context of the CCAC MSW Initiative as it is not transparent and only addresses LWP waste.

HEAT+ stands for „Harmonized Emissions Analysis Tool *plus*". HEAT+ is ICLEI's multilingual online emission inventory for the calculation of GHG emissions, other air pollutants and volatile organic compounds (VOC). ICLEI (International Council for Local Environmental Initiatives), a global network of cities, was founded in 1990 and meanwhile is the World's leading association of cities and local governments dedicated to sustainable development. 12 mega-cities, 100 super-cities and urban regions, 450 large cities as well as 450 medium-sized cities and towns in 86 countries are members of the network.

HEAT+ was developed to support municipalities to calculate and generate emission inventories and emission projections. In addition, the tool enables to visualize the success of measurements which can be compared to goals. Calculation and reporting follow the requirements of the GHG Protocol (see chapter 4.1.1). HEAT+ has been used in various cities in South and Southeast Asia and in South Africa. The original version was used in 53 cities for emission inventories.

As the EpE protocol, also HEAT+ is not suitable in the context of the CCAC MSW Initiative as both are reporting tools. In addition, HEAT+ addresses all economic activities, not only the waste sector. Therefore, it is to be expected that the reporting follows the national inventory reporting scheme of the Kyoto Protocol which only considers methane emissions from landfills in the waste sector.

To use the tool cities have to become members. Beyond that it is possible to apply for a guest access. During the research phase this was not possible as the website was under construction. HEAT+ or better ICLEI are interesting due to the global cities network.

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[15] GaBi stands for "ganzheitliche Bilanzierung" (holistic accounting)

4.2 Detailed analysis of suitable tools

In the following the two tools identified for further analysis, the IGES Tool and the IFEU-KfW tool, are described in more detail using the following structure of criteria:

- general conditions (target group, intended use, etc.)
- structure and emissions calculated
- waste treatment options considered
- input data required

Waste treatment options that should be calculable are landfilling, incineration and recycling. Due to the relevance in developing and emerging countries also open waste burning and uncontrolled disposal should be included which means the waste generated has to be considered.

The different waste treatment options are characterized by certain variables which have a high influence on the results. These are:

Landfilling:
- degradable carbon content (DOC)
- degradation rate (DOCf)
- gas collection rate
- methane correction factor (MCF) according to IPCC (2006)
- treatment and use of gas collected

Incineration:
- fossile carbon content
- lower heating value
- efficiency of energy generation
- benefit for energy generated (e.g. emission factor electricity grid)

Recycling:
- waste fractions considered
- calculation and data used
- benefit for secondary products (emission factor primary production)

These variables are crucial to the results and should be transparent in the tool. It would be best to set them as parameters so the user can insert values in accordance to the cities conditions. To ensure transparency, the chosen parameters should be shown and explained by the user (data source, reason for a certain choice) in a results report sheet.

Through the screening some principle differences between the two tools became obvious concerning the calculation and the data used. Therefore, it is best to describe the two tools by comparing them. Required input data and calculations are listed in the following and advantages and/or disadvantages of different approaches are also explained in the following.

4.2.1 Comparison of general conditions

Relevant general conditions are shown in Table 4. Important aspects are the geographic parameter and the possibility for modification. In the IGES tool the user has to choose from a list of 13 countries. Nevertheless, the choice seems to be irrelevant as no calculations in the tool were found linked to it. In addition, the climate zone has to be chosen. This is relevant and linked to the calculation of methane emissions from landfill. All relevant climate zones are included.

Table 4: General conditions

	GHG Calculator for Solid Waste IGES Tool	SWM-GHG Calculator IFEU-KfW Tool
Prepared by/for	IGES	KfW development bank
Year of release	test version 2013	2009
Target group	municipalities, associations	decision makers
Intended use	"facilitate decision-making of local governments, designing MSWM for GHG mitigation and evaluate achievement/progress"	„aid in understanding effects of proper waste management on GHG emissions"
Geographic parameter	emission factors valid for Thailand, representative for 13 countries in the Asian-Pacific-Region	data for recycling, MBT for Germany/EU, else set as parameter with given default data to choose from if needed
Functional unit	Tons per month according to waste management option	waste amount generated
Manual	yes, 30 pages	yes, 55 pages incl. background information
Possibility for modifications	yes, general willingness announced	yes, general willingness announced, approval of KfW given

Both tools use fixed emission factors. In the IGES tool these are mainly default values from the IPCC guidelines (for composting, digestion, MBT, landfill), the emission factors for recycling are based on country-specific information for Thailand. In the IFEU-KfW Tool the emission factors for recycling mainly refer to German and/or European conditions. Emissions from incineration and landfilling are calculated based on waste characteristics derived from the waste composition inserted by the user. Due to the findings from the Workshop in Paris, the tools should be modified, and emission factors for recycling should be set as parameters (with defaults and guidance for defaults given e.g. for five world regions).

The possibility for modifications is given for both tools. The IGES tool is currently undergoing revision and according to (Stratus 2013) the developers are open for recommendations for optimization. Modifications on the IFEU-KfW tool need the approval of the KfW as owner of the tool which is confirmed. It is of great interest to the KfW to further optimize and spread the tool to give aid to developing and emerging countries to help implement an integrated waste management system.

The manuals accompanying the tools both give information on the calculations and data sources. The manual for the IGES tool contains many mathematical formula while the manual of the IFEU-KfW tool mainly is laid out to communicate understanding for the method and how and wherefore the tool can be used.

4.2.2 Structure and emissions calculated

The general appearance of both tools is laid out for easy accessibility. Figure 8 shows a screenshot of the „home" sheet in the IGES tool where, as mentioned above, the country is to be selected as well as the climate zone. In addition, the sheet shows the calculation results in a table. Results are given as "direct GHG emissions", "indirect GHG savings", and "net GHG emissions" in kg CO_2-eq/t waste for each waste treatment option and as total GHG emissions per month managed waste. The term “indirect GHG savings” is capable of being misunderstood and should be renamed to “avoided GHG emissions”.

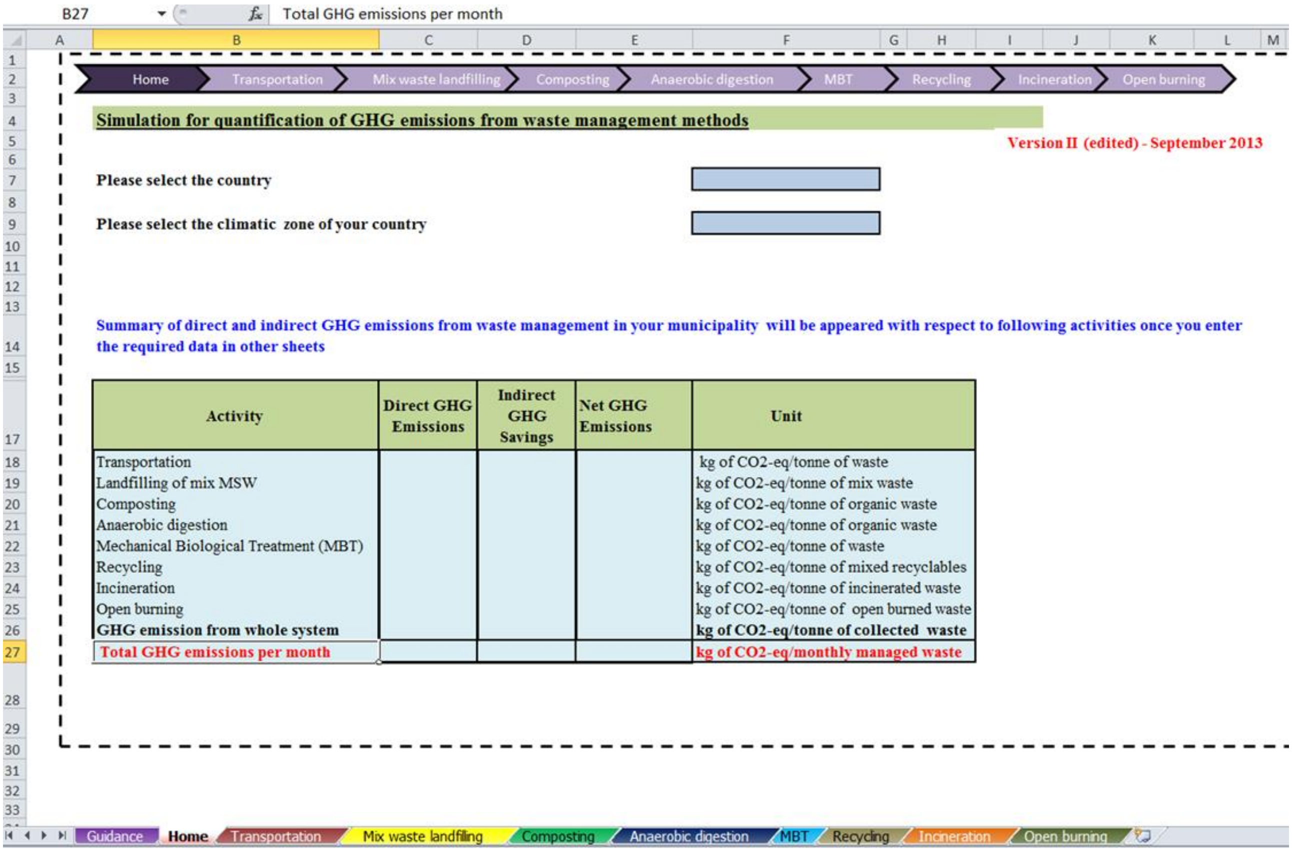
In contrast, the IFEU-KfW tool shows the results in a much more detailed manner. The results are shown in tables and graphs on a separate sheet for each of the four comparable scenarios and combined for all four scenarios on a separate sheet (“Results all”). If the IGES tool is chosen as basis for a CCAC MSW Initiative tool the presentation of the results should be expanded and show at least one figure for the results. In addition, the results should be presented for each waste treatment option together with the respective treated waste amount in totals (not only specific results).

Figure 8 also shows the design of the tool. Each treatment option is addressed on a separate calculation sheet that also shows the respective calculations (except some side calculations on hidden sheet). In contrast the design of the IFEU-KfW tool follows the thought of the system approach. The starting point (“start” sheet) is the waste generated and the definition of the composition of the waste generated which is to be inserted by the user. On a “recycling” sheet the user has to insert the recycling rates for waste fractions. With these rates the remaining waste amount after recycling is calculated automatically as well as the resulting composition (from this waste characteristics are calculated automatically). All calculations in the IFEU-KfW tool can be seen on the “calculation” sheet.

The approach in the IFEU-KfW tool has the advantage that system comparison is in any case scientifically correct as always the same waste generated is considered (with respect to amount and composition). The approach in the IGES tool has the advantage that the user can insert data on waste composition for landfill, incineration and open fire which is to be favored in case the user has measured data available. With literature data or assessments it bears the risk that non fitting data is inserted. Therefore, harmonized default values should be offered to the user and there should be some kind of plausibility control.

A plausibility control is definitely necessary when the possibility of scenario comparison would be added in the IGES tool. There must be a plausibility control to prevent the insertion of different total waste amounts (total waste amounts from the treatment options must be equal in system comparison) which might easily happen going from one sheet to the next not directly seeing the overall amounts. An idea might be to finalize the data input phase by showing an overview with error explanations in case of differing total waste amounts.

Figure 8: Screenshot Excel-sheet „Home" in IGES tool



Apart from that, the sheet by sheet design of the IGES tool is preferable as easier to understand where to find what and because the calculation formula are on the same sheet where data is inserted and thus can be followed at one glance. A respective modification in the IFEU-KfW tool is possible but means comprehensive change in the design. Nevertheless, this should be reflected.

Table 5 gives an overview for these aspects as well as for further structural elements and the emissions considered. The tools are similarly transparent and accurate and/or modifications are easily possible. The possibilities and suggestions for modifications especially concerning variables set as parameters are addressed in the next chapter in more detail.

The most important variables in this context are shown on the lower part of Figure 9 which shows a screenshot of the IFEU-KfW tool. These variables (gas collection rate, gas utilization, energy efficiency of incineration) are of high influence on the results and therefore should be set as parameters. In case the user has no measured data available the presented default data can be used. This ensures an accuracy of calculation for different regions and/or conditions that is not possible, for example, in the WARM tool where gas collection rates cannot be changed.

Table 5: Structure and emissions

	GHG Calculator for Solid Waste IGES tool	SWM-GHG Calculator IFEU-KfW tool
Design	sheet by sheet design for each treatment option, calculations on the respective sheet	follows system thinking, starting with waste generated, splitting this in waste recycled and waste to disposal; all calculations combined on one sheet
Scenario comparison	no (internal offset baseline)	yes, up to four scenarios
Transparency	calculations visible, exception side calculations for landfilling on hidden sheet	calculations all visible on one sheet, due to password protection a bit difficult to follow links
Accuracy of calculation	orienting for recycling due to fixed emission factors for Thailand; medium with default values from IPCC for waste fractions (incineration, landfill) and emissions (MBT, composting, digestion)	orienting for recycling and MBT due to fixed emission factors; good for landfill, incineration if measured data are available, medium with default values
Results	- kg CO_2-eq/t waste for each waste treatment - total CO_2-eq for per month managed waste	-t/a for waste treated and t CO_2-eq/a separately for recycling and disposal, overview and sectoral - GHG mitigation costs
Presentation of results	one table: direct GHG emissions, indirect GHG savings, net GHG emissions	tables (amounts, GHG results), material flow chart, graphs (GHG results) for each scenario and an overview for all four scenarios
GHG considered	CO_2 fossil, CH_4, N_2O	CO_2 fossil, CH_4 fossil and biogenic, N_2O
Characterisation factors (GWPs in CO_2-eq)	IPCC (1995) (as Kyoto Protocol) N_2O = 310, CH_4 = 21	IPCC (2007) (state of knowledge) N_2O = 298, CH_{4reg} = 25, CH_{4foss} = 27.75
Carbon sequestration	no	no

Figure 9 also shows the possibility to compare different scenarios in the IFEU-KfW tool. Up to four scenarios can be assessed, one baseline (status-quo scenario) and three alternatives. For the CCAC MSW Initiative context a tool should at least allow to compare two scenarios. This would have to be added in the IGES tool where no system comparison is possible so far.

Furthermore, Figure 9 shows how total waste generated is considered in the IFEU-KfW tool. The first segment of waste disposal options addresses the treatment of uncollected waste which can be scattered, burned openly or dumped. Although it is usually hardly possible to assess the amounts of waste being treated that way, these options have to be included as they are relevant in developing and emerging countries. It is of outmost importance for stakeholders to understand the impacts of these treatment options and how changes will affect these impacts (see also chapter 4.2.3).

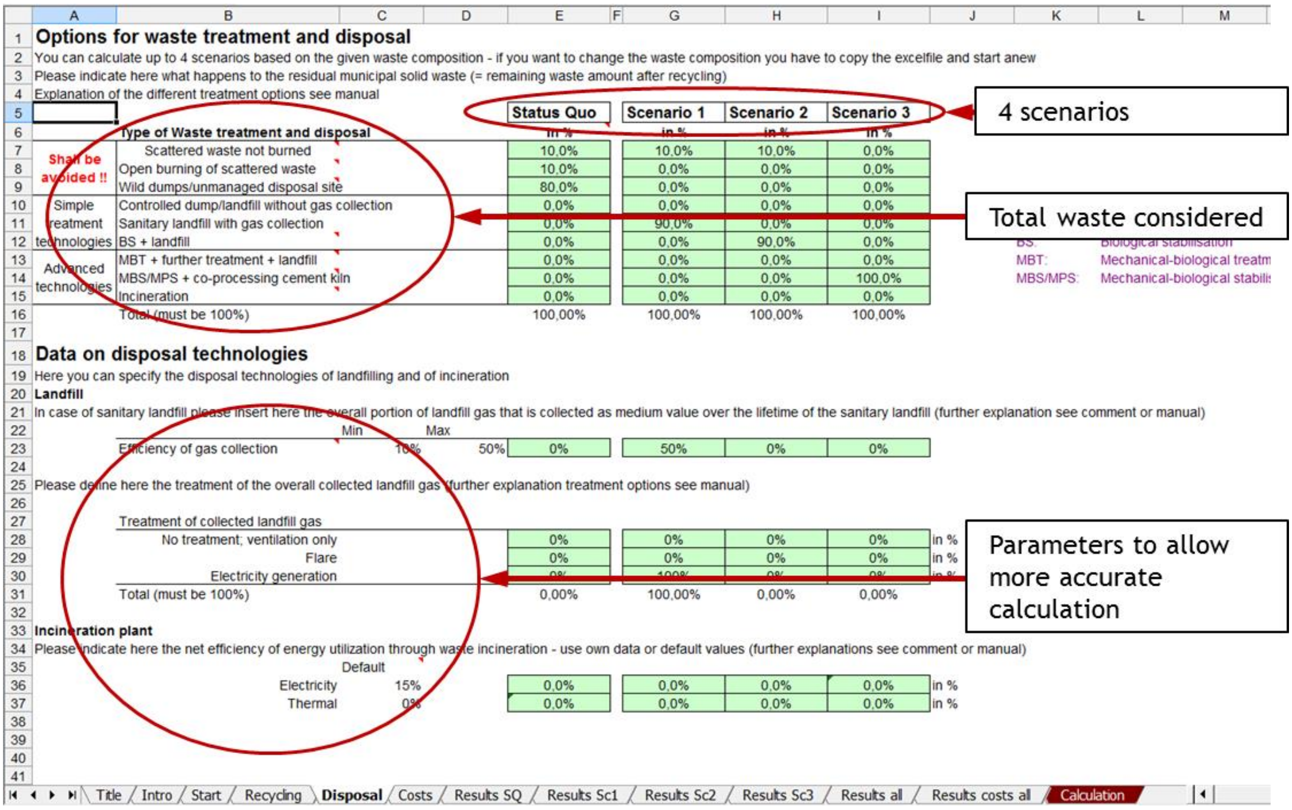
To be observed according to emissions:

The IGES Tool uses the Global Warming Potentials (GPWs) from IPCC (1995). These should be used for national inventory reporting (convention in the Kyoto Protocol). For system or scenario comparison and all other applications the most recent state of knowledge data should be used which is given with the GWPs in IPCC (2007).

None of the tools considers black carbon. This should be added, but not only BC but also organic carbon (OC) emissions as explained in chapter 3.4. Furthermore, despite of all uncertainties and weaknesses from putting short-lived and long-lived climate pollutants on one scale, the GWPs of BC and OC should be used to at least get an impression of what these emissions may mean to the global warming, and also to get some kind of understanding what the impacts mean in comparison to methane and CO_2-emissions. As a conservative approach it is recommended to use the GWP100 for direct radiative forcing, and as sensitivity the GWP20 with the total climate forcing value for BC (see chapter 3.4).

In general, all results should be shown in kg emission for each pollutant, in kg CO_2-eq for each pollutant and as total GHG emissions but the latter without BC and OC due to the high uncertainties of these emissions and their GWPs. This would have to be modified in both tools.

Figure 9: Screenshot Excel-sheet „Disposal“ in IFEU-KfW tool



4.2.3 Waste treatment options considered and input data required

Waste treatment options shall consider both collected waste and uncollected waste. Especially in developing and emerging countries uncollected waste has to be taken into account for the implementation of an integrated waste management system as it should be the general interest to collect all waste generated. In case of existing recycling structures in the informal sector, e.g. door-to-door collection, these amounts should be attributed to recycling. The informal sector should be respected and involved to any changes due to social criteria.

Uncollected waste

Uncollected waste is either scattered, burned openly or dumped. Scattering of waste means that waste is thrown anywhere, on curbsides, fields or into forests. Wild dumping means that waste is thrown on one and the same uncontrolled place. The difference of these two options is decisive for GHG accounting. Scattering does not cause any methane emissions as no anaerobic conditions occur. This is different with wild dumping where waste is piled. According to the

IPCC guidelines unmanaged landfills cause 40% of the total methane generation potential when they are lower than 5 meters, and 80% when they are higher than 5 meters and/or are positioned in water bodies. Therefore, in comparison scattering does not show any relevant impacts in the GHG accounting results.

Nevertheless, all of the above mentioned practices, scattering, dumping and open burning, should be avoided at all costs as they pose massive health hazards to the population and damage the environment. This should be made very clear to users and is the reason why the IFEU-KfW tool attributed "shall be avoided!!" in bold red characters to these options (see Figure 9).

The system comparison in the tool allows the assessment under which circumstances also the GHG accounting will result in an improvement when scattered waste is collected and treated.

To the IGES tool open burning has been added in 2013. Scattering is still not included and there is only one sheet for landfilling. A further sheet should be added to distinguish between unmanaged and managed landfills. Maybe the practices for uncollected waste can be combined on one sheet called "uncollected waste" and where the user has to insert the waste composition and the amounts of waste treated that way. This would be more comfortable for users and would prevent too many sheets in the tool.

The IFEU-KfW tool already comprises calculations for uncollected waste treatment. But the differences in the methane generation potential due to the height of waste dumping are not yet considered. This should be added by introducing methane correction factors from IPCC (2006).

Collected waste

Collected waste should not only consider formally collected waste but also waste collected by the informal sector via door-to-door collection. This collection practice provides high quality recyclables for reuse or recycling with a low degree of impurities as the households usually are paid for the recyclables. But it would be of interest to investigate and maybe coordinate the recycling practices with formally collected recyclables. Waste treatment options included in the tool should at least be recycling of dry valuables, the treatment of organic waste, and the disposal options incineration, landfilling and mechanical-biological treatment (MBT). These treatment routes are already included in both tools.

The IGES tool also considers transportation on a separate calculation sheet. There, the overall fuel consumption (diesel and natural-gas) is asked for and respective GHG emissions are calculated. This gives an impression to the user about the relevance of transportation processes compared to waste treatment and should be sufficient as GHG emissions from transportation typically are of minor importance in the overall life cycle of waste treatment. Nevertheless, if cities are interested to learn more about the collection efficiency, it could be more interesting to analyze transport emissions per waste fraction separately collected, and combine the emissions with the collection distances.

In the IFEU-KfW tool transportation processes are only considered between sorting plants or transfer stations to final recovery for recycling which are integrated in the emission factors. GHG emissions from waste collection are not considered in the tool because these emissions are the same for all scenarios in case of formal collection and they are of minor importance as mentioned above. The minor importance of GHG emissions from transportation processes is also given with BC emissions (see chapter 3.4). Nevertheless, GHG emissions from collection should be added in the IFEU-KfW tool to allow the user to see the influence in the life cycle.

The waste treatment options included in the tools are described in the following. The analysis concentrates on the calculation method, the data base used and the variables set as parameter.

Landfilling

Relevant parameters for landfilling are degradable organic carbon (DOC), decomposition rate (DOCf), gas collection efficiency (see chapter 4.1.1, discussion on WARM) and gas treatment. If methane emissions are calculated as overall emissions resulting from a certain amount of waste (not annually disaggregated) the kg DOCf are converted into m³ landfill gas on a molar basis (22.4/12 = 1.867 [m³/kg DOCf]). The potential methane emissions depend on the fraction of methane by volume in the landfill gas. If the FOD method (IPCC 2006, see footnote 1) is used the calculation in principle is the same but here annual emissions are calculated using a half-life value (k-rate) which expresses the annual methane generation rate in dependency of the climate zone. Four zones are distinguished:

- dry temperate, with temperature 0-20°C, rainfall < evapotranspiration
- wet temperate, with temperature 0-20°C, rainfall > evapotranspiration
- dry tropical, with temperature > 20°C, rainfall < 1000 mm
- wet tropical, with temperature > 20°C, rainfall > 1000 mm

In addition the k-values are differentiated for different waste fractions:

- slowly degrading waste (paper, wood, straw, rubber)
- moderately degrading waste (garden and park waste)
- rapidly degrading waste (food waste, sewage sludge)
- bulk MSW or industrial waste (mixed composition)

The k-values according to the above mentioned criteria given by IPCC range between 0.02 and 0.185 and have been obtained from experimental measurements, calculation models, or GHG inventories and other studies. The different k-values express the different velocity of degradation over the 100 year time horizon.

Table 6 shows the calculation method used in each tool based on these and further input values.

Table 6: Landfilling

	GHG Calculator for Solid Waste IGES Tool	SWM-GHG Calculator IFEU-KfW Tool
Type	landfill without gas collection – methane correction factor (MCF) recognized	controlled landfill with and without gas collection; MCF not recognized
Input data	- waste landfilled in t/month - diesel fuel used in l/month - selection of type of landfill (to determine MCF) - waste composition	- % of residual waste without gas collection - % of residual waste with gas collection - efficiency of gas collection - treatment of collected landfill gas (ventilation, flare, electricity generation)
Calculation	calculation of DOC from waste composition, DOC data from IPCC (2006)[1] DOCf default IPCC = 50%	
	methane emissions according to IPCC (2006) FOD method over 100 years CH_4 content = 50 Vol%, default IPCC (2006) oxidization factor (OX) = 15%[2]	Overall methane emissions over 100 years (not annually disaggregated) CH_4 content = 55 Vol%, typical for Germany OX = 10%, default IPCC (2006) for managed covered landfills

1) IGES uses DOC values related to wet waste, IFEU calculates DOC related to dry waste as difference from total C and fossil C related to dry waste.
2) On request IGES explained that this is typical for Asia-pacific conditions

The methane correction factor is only relevant for unmanaged landfills. For collected waste it is assumed that the waste is landfilled on managed landfills. According to IPCC (2006) managed means that these landfills 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.

The IGES tool only considers landfilling without gas collection. The possibility to calculate landfilling with gas collection would have to be added. The variable should be set as parameter as in the IFEU-KfW tool.

The oxidation factor (OX) is set to 15% in the IGES tool. The IFEU-KfW tool uses the default value from IPCC which is 10% for managed landfills covered with methane oxidizing material[16] (e.g. soil, compost). In both tools the oxidation factor is not set as parameter. This seems appropriate as this value is difficult to determine in a representative way: According to IPCC (2006) field and laboratory measurements shall not be used directly to determine the oxidation factor, since in reality, only a fraction of the methane generated will diffuse through such a homogenous layer. Another fraction will escape through cracks/fissures or via lateral diffusion without being oxidized. In addition, IPCC (2006) recommends that the use of an oxidation value higher than 10%, should be clearly documented, referenced, and supported by data relevant to national circumstances. If this is not possible for the 15%[17] used in the IGES tool the value should be reset to the IPCC default value of 10%.

[16] The IPCC default value for oxidation factor is zero. The use of the oxidation factor of 10% is justified for covered, well-managed landfills (IPCC 2006).

[17] The manual for the IGES tool does not mention the 15% but only refers to the IPCC default values.

In addition, it is recommended that the tools should differentiate between the landfill types "managed" and "well-managed, covered". Only in the latter case the oxidation factor of 10% should be applied. This would have to be modified in both tools. As an alternative the oxidation factor can be set as parameter but then has to be documented as required by IPCC (see above) by the user in the results report sheet.

The DOC data are in both cases taken from IPCC (see Table 7). The IGES tool uses the DOC values related to wet waste (as does the IPCC in the provided "IPPC_waste_model[18]) while the IFEU-KfW tool calculates the DOC as difference of the also given total carbon content, dry matter content and fossil carbon fraction to be consistent with the values used for incineration in the tool. Unfortunately, the values given in IPCC are not consistent and small differences occur. In the case of textiles the difference is relevant: The DOC given in IPCC is 24% while the difference calculation results in 32%[19] (see Table 7). As the IGES tool also calculates incineration using the IPCC values directly given, this should be recognized and changed to be consistent either starting by subtracting the DOC from the given total carbon content or the other way round as in the IFEU-KfW tool.

Table 7: Degradable organic carbon (DOC) according to IPCC (2006, Table 2.4)

	IGES Tool	IFEU-KfW Tool			
	DOC content in % of wet waste, Default	Dry matter content in % of wet weight	Total carbon content in % of dry weight	Fossil carbon fraction in % of total carbon	DOC content in % of wet waste, calculated
Paper/cardboard	40	90	46	1	41,0
Textiles	24	80	50	20	32,0
Food waste	15	40	38	-	15,2
Wood	43	85	50	-	42,5
Garden and Park waste	20	40	49	0	19,6
Nappies	24	40	70	10	25,2
Rubber and Leather	(39)	84	67	20	45,0
Plastics	-	100	75	100	0
Metals	-	100	NA	NA	0
Glass	-	100	NA	NA	0
Other, inert waste	-	90	3	100	0,0

In addition to the calculation of methane from landfilling the IGES tool has „diesel fuel use for operation of the machinery" set as parameter. This as well as other energy demand is calculated in the IFEU-KfW tool with fixed values. In principle, the GHG emissions from energy

[18] The model (Excel-file) implements the FOD Tier 1 method for estimating emissions of methane from solid waste disposal sites according to 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 5 Chapter 3.

[19] With 80% dry matter content, total carbon 50% dry waste, fossil carbon fraction 20% of total carbon: 80%*50%*(100%-20%) = 32%

use are of minor importance compared to the methane emissions from landfilling. Nevertheless, it seems a good idea to offer the user the possibility to be more precise with local conditions. But this should then also be possible at least for the electricity demand which would have to be added and set as parameter.

Landfill as baseline in the IGES tool:

The IGES tool includes a baseline which can be described as “avoided landfill without gas collection”. The application of this baseline is not explained in the tool. It appears on the calculation sheets for incineration, MBT, composting, anaerobic digestion as “avoided methane emissions from organic waste landfilling”. The calculation of the avoided GHG emissions is not transparent as done on a hidden sheet. For recycling the baseline appears as emission factor for avoided landfilling of paper (only organic waste type). The offset is included in the overall avoided emissions from recycling which appear as final result in the results table (“home” sheet).

In general, it is inadvisable to offset a baseline in a nontransparent manner. This makes it very difficult to understand the results. Especially in the case of paper recycling where a net benefit is only given due to offsetting the baseline. Without that baseline the emission factors used in the IGES tool lead to the result that paper recycling is worse than primary production of paper. This is unexpected for Thailand and maybe the emission factors should be revised[20]. Nevertheless, in general it is to be strongly recommended to report offsets from a baseline separately from the waste treatment results. Otherwise it is not possible to understand weak points and be enabled to identify optimization potentials.

In any case the baseline shall be deleted if the IGES tool is chosen to be modified for the CCAC MSW Initiative context. In this case system comparison will be introduced into the tool and offsetting a baseline is obsolete (would have to be the same for every compared system).

Incineration

Relevant criteria for incineration are fossil carbon content, energy efficiency and the emission factor for avoided emissions from conventional energy generation. Table 8 shows the calculation method used in each tool based on these and further input values.

Both tools calculate the fossil carbon content from the waste composition using the default values from IPCC (2006) for total carbon content and fraction of fossil carbon (see Table 7). Likewise both tools calculate fossil CO_2 emissions under the assumption of a 100% oxidation of the contained fossil carbon. In the IFEU-KfW tool it is explained (comment in calculation sheet and in the manual) that this is an assumed simplification for a technically advanced incineration plant with a high burnout. Mathematically, this simplification is valid because carbon emissions from incomplete incineration (mainly carbon monoxide and volatile organic compounds) are likely to be converted to CO_2 in the atmosphere sooner or later.

[20] Emission factors are used based on country-specific information for Thailand. In the manual it is explained that paper production in Thailand uses 96.2% from coal and the rest from fuel oil and diesel. With this fossil energy basis it seems not plausible that recycling would cause higher impacts than primary production as harvesting etc. is substituted.

Table 8: Incineration

	GHG Calculator for Solid Waste IGES Tool	SWM-GHG Calculator IFEU-KfW Tool
Method	four different types of furnaces to select from, CO2 fossil from 100% oxidation	100% oxidation assumed as simplification for technically advanced incineration plants
Input data	- selection of furnace - incinerated amount in t/month - diesel fuel use in l/month - grid electricity use in kWh/month - waste composition - selection of type of energy recovery (none, electricity, heat, or both); input of energy produced in kWh/month and percentage of auxiliary power in %	- % of residual waste - net efficiency for electricity and heat
Calculation	C fossil content calculated from waste composition; type of furnace determines CH_4 and N_2O-Emissionen (default values IPCC (2006)); offset "avoided CO_2 emissions from conventional electricity production and from conventional fuel uses for heat production" (calculation of benefits on hidden sheet, not transparent)	C fossil content from calculated waste composition for residual waste (generated waste minus recycled waste); further emissions neglected; offset emission factors for grid electricity (input parameter) and for conventional heat production (visible on "calculation" sheet)

The IGES tool also considers CH_4- and N_2O-emissions using IPPC (2006) default values for four types of furnaces (continuous stocker, continuous fluidized bed, semi-continuous stocker, semi-continuous fluidized bed). Strictly speaking the CH_4 emissions would have to be subtracted from the CO_2 emissions from 100% oxidation as the GWP used in the IGES tool according to IPCC (1995) includes the global warming potential from the conversion of CH_4 to CO_2 in the atmosphere. Nevertheless, the double counting from this is of minor importance. In addition, with the GWPs from IPCC (2007) which should be used in a tool for system comparison (see chapter 4.2.2) this is not relevant anymore because the GWP for CH_4 in IPCC (2007) does not include the conversion into CO_2[21].

Energy generated is calculated in the IFEU-KfW tool based on the lower heating value (LHV) of the waste incinerated (calculated from waste composition of residual waste and LHVs for waste fractions according to (AEA Technology 2001)) and the net efficiencies for electricity and heat inserted by the user. The benefit for net electricity is calculated with the emission factor for grid electricity also inserted by the user. For heat a fixed emission factor for conventional generation of heat is used (visible in the "calculation" sheet).

In the IGES tool the energy generated has to be inserted by the user as well as the auxiliary energy. The offset for energy generated is not comprehensible as referring to a hidden sheet ("variables"). Depending on the data situation of users it might be easier to ask for lower heating value and net efficiencies as in the IFEU-KfW tool instead of asking for energy generated. Especially with optimization scenarios, this information is not readily at hand. In any case with respect to transparency the hidden calculations should be made visible.

[21] This is the reason the IFEU-KfW tool distinguishes between fossil and biogenic methane; the impact of CO_2 as secondary product in the atmosphere has to be considered and added for methane from fossil origin (+2.75 kg CO_2-eq/kg, see Table 5).

Mechanical-biological treatment

Relevant criteria for MBT are the mass flows and the further treatment of the output fractions.

The IFEU-KfW tool distinguishes three types of mechanical-biological treatment:

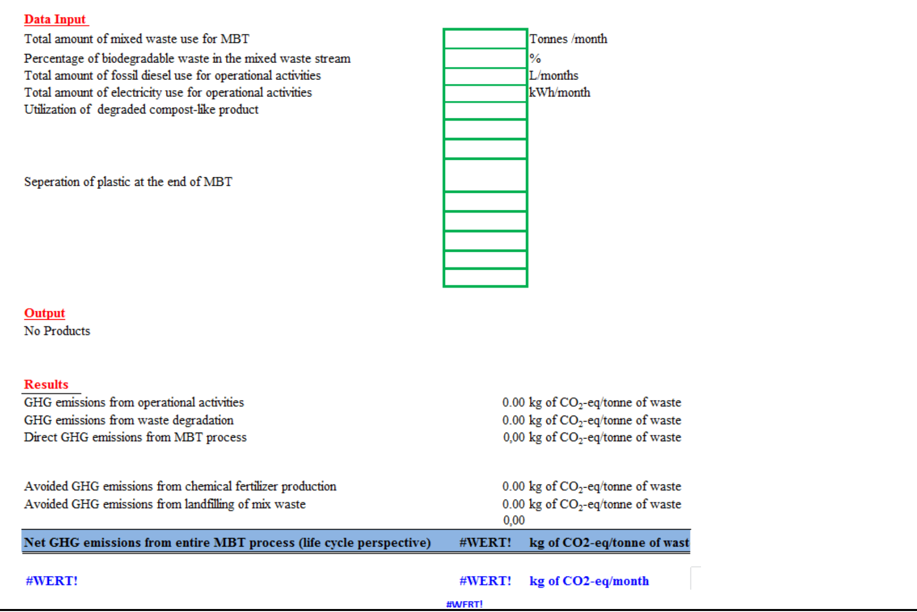
- simple biological treatment ("mixed-waste composting") and landfilling of the stabilized output; GHG emissions result from energy demand and residual methane emissions from the stabilized output landfilled; this option has no benefit
- MBT, typical for Germany, with separation of Fe- and NF-metals (to recycling), impurities (to MSW Initiative), and a refuse derived fuel (RDF) fraction (to co-incineration in a cement kiln) and subsequent biological treatment (composting) and landfilling of the stabilized output; GHG emissions result from energy demand, residual methane emissions from the stabilized output landfilled, from incineration of the impurities and co-incineration of RDF; benefits result from energy generation (RDF, impurities) and from metal recycling
- mechanical-biological stabilization (MBS), typical for Germany, with separation of Fe- and NF-metals (to recycling) and impurities (to MSW Initiative), and subsequent biological treatment (stabilization) to produce RDF (to co-incineration in a cement kiln); GHG emissions result from energy demand, from incineration of the impurities and incineration of RDF; benefits result from energy generation (RDF, impurities) and from metal recycling

All three variants are calculated with fixed values according to energy demand, mass flows and emissions and are explained in the manual. If the IFEU-KfW tool should be used as a basis for a tool in the CCAC MSW Initiative context it would be preferable to modify this fixed calculation and allow user defined calculations as done in the IGES tool.

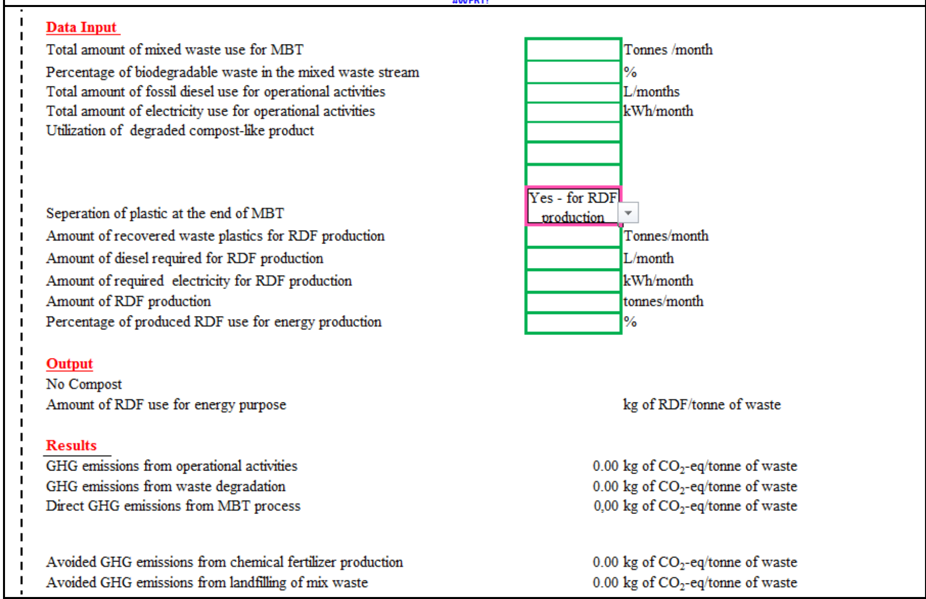
Input parameters in the IGES Tool are:

- waste amount for treatment in t/month
- percentage of organic waste
- fossil diesel and electricity use in l and kWh/month
- application of the compost-like product: yes/no
- separation of plastic at the end of MBT: no, yes – for RDF, yes – for crude oil production

Figure 10: Screenshot Excel-sheet „MBT“ in IGES tool



screenshot before answering questions



screenshot after answering a question with „yes“ (here yes – for RDF production from separated plastic at the end of MBT)

GHG emissions are calculated from the energy use and also direct CH_4- and N_2O emissions from the biological treatment are considered using IPCC (2006) default values for composting. If “yes” is answered to the question “utilization of compost-like product” then further questions become visible according to the amount of compost-like product and the percentage used for soil-amendment. Based on this avoided emissions (CO_2, CH_4, N_2O emissions per t compost) are calculated for substituted mineral fertilizer. According to the manual (Ch5, composting) these emission factors are derived from nutrient contents in good-quality compost given in “Patyk 1996”. The manual also points out that the GHG avoided emissions should be excluded if compost users do not reduce chemical fertilizer use even after application of compost.

First of all, this hint is important as only in case of substitution the GHG mitigation happens. Therefore, this hint should be also integrated in the tool itself (e.g. in red letters when entering the percentage of compost use). But in general, it is questionable if mixed waste compost should get a credit for mineral fertilizer at all. The nutrient contents mentioned above account for good-quality compost and usually mixed waste compost is of low nutrient content but of rather high heavy metal content and therefore is not advisable to be used on fields.

For the separation of plastic at the end of MBT further questions appear when “yes” is answered. In case of “yes - for RDF production” the questions refer to the amount of separated plastic, diesel fuel and electricity use for RDF production, amount of RDF produced and percentage used for energy production. In case of “yes - for crude oil production” the questions are analog.

Figure 10 shows a screenshot of the calculation sheet before and after answering “yes” to the questions. This kind of programming is very charming as the user is not overburdened with many questions from the beginning but only if the aspects are relevant to the user.

If plastics are separated and further treated, GHG emissions from the energy demand for treatment are calculated and avoided emissions are calculated for the amount of crude oil and/or energy substituted. The calculation is based on a series of fixed values not further explained.

In comparison of the two tools the programming in the IGES tool is more user-friendly. Nevertheless, the use of the compost-like product should not be credited.

Composting and anaerobic digestion

Relevant aspects for composting and anaerobic digestion are direct CH_4 and N_2O emissions, energy demand and biogas generation and use from anaerobic digestion.

In the IFEU-KfW tool the amount of organic waste (food waste and garden and park waste) collected separately is asked for on the “recycling” sheet as percentage of total waste generated. Furthermore, the percentage of organic waste to composting and to digestion has to be inserted. The GHG accounting is mainly done using fixed emission factors which include the above mentioned aspects. Data base for direct emissions are measurements in Germany which are also valid for other regions in similar climate zones. However, the electricity generated from biogas use is calculated in the tool with a biogas yield of 100 m^3/t wet waste, methane content 60% by volume and 30% net efficiency for electricity generation in a CHP. The avoided emissions through electricity generated are credited with grid electricity using the emission factor which has been inserted by the user (“start”). The combined heat production is neglected because usually it is hard to find an external costumer.

In the IGES tool the following input variables have to be inserted:

- amount of food waste use for treatment in t/month
- amount of garden waste use for treatment in t/month
- diesel fuel and electricity use for operation in l and kWh/month

In addition, for composting the amount of compost production is requested in t/month and the percentage of compost use for agricultural or gardening purposes. The GHG emissions are calculated from the energy demand and from direct CH_4 und N_2O emissions using IPCC (2006) default values (same as for MBT). Avoided emissions are calculated in the same way as described for the compost-like product from MBT (CO_2, CH_4, N_2O emissions per t compost according to “Patyk 1996”).

For anaerobic digestion the following input data are requested additionally: approximate water content of the influent (needed to calculate CH_4 emissions because IPCC default value used refers to dry weight) and the kind of biogas use (either electricity or heat production). The calculation of the biogas generated is visible on the Excel-sheet with biogas yield of 592 m^3/t dry waste, methane content 60% by volume and net efficiency for electricity generation 35%. If electricity is produced the avoided emissions correspond to substituted conventional electricity production but the calculation is not visible but refers to hidden sheet ("Variables"). If heat is produced the avoided emissions correspond to substituted liquefied petroleum gas (LPG). The calculation is visible on the sheet but the fixed values used are not explained or documented. The produced digestate is not considered at all in the IGES tool. This should be added.

In principle, also here it seems favorable to use internationally valid emission factors like the IPCC default values for the direct emissions. Nevertheless, these emission factors are in contradiction to findings from measurements in Germany. The IPCC default values indicate that GHG emissions from digestion are lower than from composting. Measurement on different digestion and composting plants in Germany show that it is the other way round:

IGES tool IPCC default composting: 4 kg CH_4/t waste, 0.3 kg N_2O/t waste

IGES tool IPCC default digestion: 0.4 to 1 kg CH_4/kg wet weight
(calculated from 2 g CH_4/kg dry weight and water content between 80% and 50%)

Measurements Germany composting: 0.3 to 3 kg CH_4/t waste, 0.05 to 0.2 kg N_2O/t waste

Measurements Germany digestion: 3.2 to 4.6 kg CH_4/t waste, 0.04 to 0.2 kg N_2O/t waste

Therefore, the corresponding GHG emission results should be used with caution.

In addition, it is recommended to use more recent data for the avoided emissions from compost use. The nutrient content taken from "Patyk 1996" (per t compost: 7.1 kg N, 4.1 kg P_2O_5, 5.4 kg K_2O) may not be adequate on a global level. Furthermore, the corresponding avoided emissions for chemical fertilizer substituted should be checked and replaced by more recent data if these are also taken from "Patyk 1996".

Recycling of dry valuables

Relevant criteria for recycling are the considered waste fractions, the method of calculation and/or the emission factors used for direct emissions and for avoided emissions. Table 9 shows these values for both tools. Both tools consider the relevant waste fractions. The inclusion of textiles as in the IFEU-KfW tool is not implicitly necessary and should on the contrary only be considered when textiles are collected from door-to-door collection as only in this manner the textiles are likely to have the quality for reuse.

The emission factors in the IGES tool are based on country specific information in Thailand. The emission factors used in the IFEU-KfW tool are related to the average situation in the EU27. In comparison the values are similar according to ferrous metals and/or steel, aluminium and glass. High differences are given with the emission factors for paper and plastics. For these factors a harmonization is necessary. It is recommended to set the emission factors as parameters and provide default values with guidance for users. As proposed from the Topic 1 breakout session at the ISWA/UNEP workshop in Paris harmonized and peer reviewed emission factors, for example, for five world regions should be strived for (see chapter 2).

Table 9: Recycling

	GHG Calculator for Solid Waste IGES Tool	SWM-GHG Calculator IFEU-KfW Tool
Method	simple calculation „activity rate x emission factor “	
Input data	- total amount of separated recyclables - composition of separated recyclables in %	%of generated waste per waste fraction
waste fractions and emission factors in kg CO_2-eq/t waste: debit / credit / net	paper, 1266 / -971 / net +295 plastics, 2148 / -1899 / net +249 aluminium, 393 / -12486 / net -12093 steel, 1102 / -2949 / net -1847 glass, 569 / -1024 / net -454	paper/cardboard, 180 / -1000 / net -820 plastics, 1023 / -1437 / net -414 aluminium, 700 / -11800 / net -11100 ferrous metals, 22 / -2047 / net -2025 glass, 20 / -500 / net -480 textiles, 32 / -2850 / net -2818

4.3 Summary of recommended modifications (tool modifications)

In the following all aspects mentioned in the detailed tool comparison in chapter 4.2.3 that are relevant for modification for a tool intended to be used in the CCAC MSW Initiative context are summarized.

General modifications relevant for both tools:

- integrate black carbon: relevant in waste management are emissions from incomplete combustion especially open burning of waste and landfill fires; if available also emission factors from incineration plants and co-incineration could be added but are expected to be low BC emitters (see chapter 3.1); although of minor importance, emission factors from transport should be added to allow users to understand the relevance
- due to the findings in chapter 3.4 also corresponding emissions of organic carbon should be added for thermal processes especially open burning and landfill fires; for both BC and OC also the GWPs should be calculated despite of all uncertainties and weaknesses from putting short-lived and long-lived climate pollutants on one scale as only this allows to get some kind of understanding what the impacts mean to each other and in comparison to methane and CO_2-emissions; as a conservative approach it is recommended to use the GWP100 for the direct effect, but the GWP20 with the total climate forcing value for BC should also be considered as sensitivity
- results should be presented in kg emission for each pollutant, in kg CO_2-eq for each pollutant and as total GHG emissions but the latter without BC and OC due to the high uncertainties of these emissions and their GWPs
- possibility to calculate impacts from landfill fires should be added
- managed landfilling should be distinguished between “managed” and “well-managed, covered” landfill; only the latter is justified to use the 10% oxidization factor; values higher than 10% should not be allowed (-> 0% and 10% as fixed values), or would have to be clearly documented
- add input request for energy use for the different waste treatment options, at least diesel fuel for machinery and electricity use (diesel use already considered in IGES tool; in IFEU-KfW tool both integrated in calculations)

- recycling: set emission factors as parameters and provide default values with guidance for use; as proposed from the workshop in Paris (chapter 2), harmonized emission factors, for example, for five world regions should be offered
- add result sheet for reporting; should at least present: amounts and fate of waste, input data and results; input data (parameters) have to be documented, referenced, and, if not default data, supported by data relevant to national circumstances; all sensitive data (data uncertainties) should be highlighted

Modifications recommended for the IGES Tool:

- add possibility to compare scenarios, at least two (baseline, alternative), considering:
  - total waste amount has to be the same for each scenario and also overall waste composition; insert plausibility control for total waste amount
  - delete actual calculated baseline (landfill without gas collection)
- use GWP characterization factors according to IPCC (2007)
- the choice from the list of 13 countries seems to be irrelevant as no links to any calculations are evident: can be deleted, or substituted by (e.g. five) world regions which are linked to a set of harmonized emission factors (see below)
- show results also in totals with reference to the corresponding total waste amount treated; show results also in more detail (emissions from energy demand, emissions from treatment, avoided emissions separately for the substitution of electricity, heat, fossil fuel, products) and in graph
- the term “indirect GHG savings” on the results table (“Home”) is capable of being misunderstood and should be renamed to “avoided GHG emissions”
- transportation is maybe better calculated per waste fraction separately collected with the emissions combined with the collection distances if cities are interested to learn more about the collection efficiency
- fate of non-collected waste is to be added: scattering, wild dump (similar to existing landfill sheet); if feasible could be added on the sheet for open burning by renaming this to “uncollected waste”; for all these practices but especially for scattering it must be made very clear that although the GHG accounting may be better than with a managed landfill these practices should be avoided at all costs as they pose massive health hazards to the population and damage the environment
- landfill gas collection and use needs to be added; should be set as input parameter as in the IFEU-KfW tool
- the DOC and C fossil values used from IPCC (2006) should be harmonized (see Table 7); either use DOC as basis or total carbon and fossil carbon fraction
- the oxidation factor (OX) of 15% needs to be documented, referenced, and supported by data relevant to national circumstances to be in compliance with IPCC (2006), or reset to 10% (IPCC (2006) value for well-managed, covered landfills, default value is zero)
- calculations on hidden sheet (“variables”) should be made visible for transparency

- incineration: depending on the data situation of users it might be easier for them to ask for lower heating value and net efficiencies as in the IFEU-KfW tool instead of asking for energy generated; default values should be provided
- better no credit for "compost-like product" from mixed waste composting (MBT); usually has low nutrient content but high content of heavy metals and other pollutants; but at least point out also in the tool that "GHG avoided emissions should be excluded if compost users do not reduce chemical fertilizer use even after application of compost" as done in the manual
- although IPCC (2006) default values are used for direct GHG emissions for composting and anaerobic digestion these should be used with caution as they indicate that digestion has less direct GHG emissions than composting which is not the case due to measurements undertaken at German treatment plants (maybe IPCC value only accounts for sewage sludge)
- better use more recent data for the avoided emissions from compost use: data from "Patyk 1996" (per t compost: 7.1 kg N, 4.1 kg P_2O_5, 5.4 kg K_2O) may not be adequate on a global level; and corresponding avoided emissions for chemical fertilizer substituted should be checked and replaced by more recent data if also taken from "Patyk 1996"
- compost from anaerobic digestion also has to be considered; can be used on fields directly as fertilizer or after further aerobic treatment in the same way as aerobic compost
- recycling: emission factors for paper recycling should be revised

Modifications recommended for the IFEU-KfW tool:

- sheet by sheet calculations as in the IGES tool seems more user-friendly but would mean complete change of design and reprogramming of the IFEU-KfW tool
- calculation for different unmanaged landfill types should be added by introducing the methane correction factor; the user should be enabled to choose between the different types
- transportation (collection) should be added per waste fraction collected separately to allow the user to understand the relevance in the GHG accounting
- incineration: maybe add CH_4 and N_2O emissions (IPCC default values as in IGES tool, but are of minor relevance)
- change calculation of MBT and MBS: allow input data by user and use questionings for programming as done in IGES tool (would also mean a major change in IFEU-KfW tool)
- textile recycling should only be calculated in case of door-to-door collection to ensure quality of textiles for reuse

In general, both tools are suitable for modification and for both comprehensive modifications would be necessary to use them in the CCAC MSW Initiative context. In addition, the possibility for reporting and monitoring would have to be added. This could be done by including extra calculation sheets in the tool but should preferably be realized in a separate tool which may be linked to the tool for system comparison.

At any rate it is recommended that the development of a tool should be accompanied by an advisory council. This council could meet at the beginning to verify the identified modifications, on an interim phase to discuss a draft version, and at the end of the project to verify the final version.

5 Standardized emission factors for avoided processes (material recycling)

In a current project on behalf of the German Federal Environment Agency on waste management and climate protection in OECD countries, India and Egypt it became clear that it is of advantage to use a set of harmonized emission factors to calculate avoided processes from material recycling irrespective of the region.

This is due to the fact that often national data for primary processes that are avoided through recycling are not available or are of minor representativeness (rough assessments). Another difficulty is that available emission factors are sometimes not described transparently and therefore hard to interpret. This is, for example, the case with emission factors for paper recycling in the USA. The factors suggest very high GHG mitigation through paper recycling due to the fact that carbon sequestration is included. But the background data and calculations to derive the emission factors are not transparently described. From the current state of knowledge data for carbon sequestration in general involve considerable uncertainties.

As benefits for avoided processes have a high influence on calculation results the mentioned aspects led to the agreement in the above mentioned project to mainly use one and the same data set of emission factors for avoided processes through recycling in the examined countries and regions. With this the communicated net results (balance of debits and credits) do not bare the risk to point out regional advantages which may not be reliable.

Nevertheless, a GHG accounting tool that should enable cities from different regions to assess their performance of waste management and their options for GHG mitigation should describe the regional conditions as good as possible. This was also an outcome of the Topic 1 break-out session on the Workshop in Paris (see chapter 2). According to the experts suggestions it is better to use location specific default values and/or emission factors whenever possible. This refers especially to emission factors crediting energy utilization through waste incineration (electricity grid) but also to emission factors for avoided primary processes like glass or paper production.

However, it is known that such local emission factors are not readily available. Therefore, default values can be used for a start but users (the city authorities) should be encouraged to collect more detailed or measured data. The Topic 1 expert group also suggested that default data to start with should be peer reviewed inventories, published with guidance for use. This first data set could later on be possibly expanded to harmonized emission factors, for example, for five world regions.

For the time being peer reviewed data sets exist from different data bases like the peer reviewed Ecoinvent database. Nevertheless, to access this data base it is required to purchase a license. Therefore, it might be more feasible to collect a data set for the most relevant processes from publicly available data which should be done by an LCA expert group. It would be best to use data which are available from studies for waste management on a national level on behalf of national authorities. The most crucial aspect for such a data set is as mentioned that the data should be described transparently and in case of choices guidance should be given to the user.

Although regional emission factors have the advantage for local authorities to better understand their conditions and therefore their options, it makes it more difficult to compare the results of different cities. Therefore it is of outmost importance that the results for comparison between cities are not shown as net results but separately as debits (direct emissions) and credits (avoided emissions) which is the case with reporting and monitoring systems (e.g. EpE protocol following the GHG protocol). But it has to be ensured that all direct, indirect and other indirect emissions are included[22].

Another approach for better comparability between cities might be to use two parallel data sets, one with the local data and one data set equally used by all participating cities for comparison.

This could also include emission factors for avoided conventional energy generation as this might differ dramatically from region to region. Some countries like India produce their electricity mainly from coal while others use renewable energy. With this any waste incineration activity in India will always be combined with high benefits from avoided conventional electricity generation while this will not at all be the case in a country using mainly renewable energy. It may also be a good idea to generally provide two basic default emission factors, one for a carbon intensive electricity grid and one for a low carbon electricity grid. The choice of one of these two can lead to completely different results for the question if material recycling is better than energy utilization, and would support awareness building for such major influences for users.

6 Conclusions and perspective

The screening and in depth analysis of existing tools for GHG accounting in waste management showed that from a series of tools two – the IGES tool and the IFEU-KfW tool - are suitable to be modified and used in the context of the CCAC MSW Initiative. All aspects that are subject to modification for the two tools are summarized in chapter 4.3.

Both tools are also suitable to implement black carbon emissions. Nevertheless, the integration of black carbon emissions should recognize several aspects:

- black carbon emissions are relevant in waste management for thermal processes especially open waste burning and landfill fires; for the time being there only exist a handful of emission factors which are not very reliable but also not completely out of range and can be used for the purpose of integration
- the global warming impact of black carbon is of high uncertainty; the regional variability is ±30–40% for direct effects, the snow albedo effect ranges from practically zero to 30 to 60% of the direct effect depending on the region; indirect effects are subject to scientific discussion with the positions that they have a high positive climate forcing although with substantial uncertainty (Bond et al. 2013) on the one hand and that they should not strictly be considered an RF because of modifications to the hydrological cycle (IPCC 2007)
- incomplete combustion is associated with many other emissions along with black carbon (BC); especially organic carbon (OC) and sulfur dioxide have a negative climate forcing; organic carbon is relevant for open burning and landfill fires and the global

[22] Emissions according to scope 1 and 2 of the GHG protocol do not include GHG emissions from the pre-chain like supply of energy carriers, this is only the case with the inclusion of scope 3 (see chapter 4.1.1).

warming impact may outmatch the climate forcing of black carbon; this does on no account mean that open burning of waste should not be prevented[23] but it should be considered that there might be no contribution to GHG mitigation; as a consequence the inclusion of black carbon should be done by inclusion of at least also organic carbon

- despite of all uncertainties and weaknesses from putting short-lived and long-lived climate pollutants on one scale, the GWPs for BC and OC should be used to at least get an impression of what these emissions may mean to the global warming, and also to get some kind of understanding what the impacts mean in comparison to methane and CO_2-emissions

Both tools use fixed values (emission factors) to recognize emission savings from the substitution of primary processes. These avoided emissions have a high influence on the overall results of GHG accounting. Therefore, the following is recommended:

- the fixed values should be replaced by set parameters which can be changed by the user to value local conditions; default values with guidance for use should be provided; it should be strived for harmonized data sets, for example, for five world regions; the data should be transparently described (calculations and data sources) and users should be encouraged to collect more detailed regional or measured data
- it is recommended that such data sets should be collected from publicly available data by an LCA expert group; it would be best to use data which are available from studies for waste management on a national level on behalf of national authorities; the financing or organization for this effort could be provided by the CCAC MSW Initiative partner countries
- in any case results should always be shown separately for direct emissions (debits) and avoided emissions (credits) to allow transparency; for comparability between cities it is proposed that the tool should permanently provide one harmonized data set of emission factors in parallel to local emission factors for avoided processes

In general, it is recommended that the development of a tool should be accompanied by an advisory council. This council could meet at the beginning to verify the identified modifications, on an interim phase to discuss a draft version, and at the end of the project to verify the final version.

[23] Open burning of waste and landfill fires should be banned in any case as they cause severe hazards to human health and the environment.

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